Use of the Valveless Trocar System Reduces Carbon Dioxide Absorption During Laparoscopy When Compared With Standard Trocars

Amin S. Herati, Sero Andonian, Soroush Rais-Bahrami, Mohamed A. Atalla, Arun K. Srinivasan, Lee Richstone, and Louis R. Kavoussi

OBJECTIVES To prospectively compare a novel type of valveless trocar that creates a curtain of pressurized carbon dioxide [CO_2] gas (which maintains pneumoperitoneum at a lower gas flow rate) with standard trocars; to quantify the volume of CO_2 used; and to characterize CO_2 elimination during laparoscopic renal surgery.

METHODS A total of 51 patients undergoing laparoscopic renal surgery by a single surgeon were prospectively evaluated using either the valveless trocar (n = 26) or standard trocars (n = 25). Patient demographics, operative time, volume of CO_2 gas consumed, CO_2 elimination, perioperative parameters, and postoperative complications were recorded and analyzed.

RESULTS Both patient cohorts were comparable in their preoperative demographics, including body mass index, the number of patients with chronic obstructive pulmonary disease, and smoking history. Mean operative time was lower in the valveless trocar cohort (124.1 minutes) compared with the conventional trocar group (145.6 minutes), $P = .047$. Use of the valveless trocar was associated with a lower volume of intraoperative CO_2 consumed (120.0 ± 82.8 vs 300.6 ± 191.5; $P < .001$) and reduced CO_2 elimination compared with standard trocar use after the first 16 minutes of insufflation ($P < .05$). Minimal complications occurred, including 2 cases of subcutaneous emphysema in the valveless trocar group, and 1 case of respiratory acidosis in the conventional trocar group.

CONCLUSIONS Use of a valveless trocar significantly reduced CO_2 consumption during transperitoneal laparoscopy. The valveless trocar also demonstrated significantly reduced CO_2 elimination and absorption when compared with the standard trocar. UROLOGY 77: 1126–1132, 2011. © 2011 Elsevier Inc.

The standard approach for laparoscopic surgery involves insufflation of the peritoneal cavity with gas to allow for an adequate working space. Carbon dioxide (CO_2) is the most commonly used gas because it is relatively inexpensive, colorless, odorless, nonflammable, and rapidly eliminated from systemic circulation.[1-3] Exposure is maintained throughout the case by the continuous infusion of CO_2 gas to sustain an intraperitoneal pressure setting of 15-20 mm Hg. By applying Henry's Law, the combination of a CO_2 gas medium and increased pressure setting equates to an increase in the concentration of diffused gas into a liquid. The increased systemic absorption of CO_2 gas during transperitoneal and retroperitoneal laparoscopy has been demonstrated by measuring end-tidal CO_2 ($ETCO_2$) and CO_2 elimination rates in multiple studies.[4,5] Although elevations in $ETCO_2$ are well tolerated by most patients, they can have deleterious effects in patients who are either obese or have preexisting respiratory compromise.[6,7] Laparoscopic surgery in this patient population can potentially result in serious hypercarbia, acidemia, reduced cardiac output with the potential for end-organ ischemic damage, peripheral venous stasis leading to deep venous thrombosis, and even death.[8]

Various alternatives to CO_2 gas insufflation have been investigated for high-risk patients, including low-pressure and gasless pneumoperitoneum, or the use of alternative insufflant gases such as helium, argon, and nitrous oxide.[3,9,10] However, these alternatives have their own limitations, including complex assembly and irregular elevation of the abdominal wall with the lifting devices in the

From the Arthur Smith Institute for Urology, North Shore–Long Island Jewish Health System, Hofstra University School of Medicine, New Hyde Park, New York

Reprint requests: Louis R. Kavoussi, M.D., Arthur Smith Institute for Urology, North Shore–Long Island Jewish Health System, Hofstra University School of Medicine, 450 Lakeville Road, Suite M-41, New Hyde Park, NY 11040. E-mail: Kavoussi@nshs.edu

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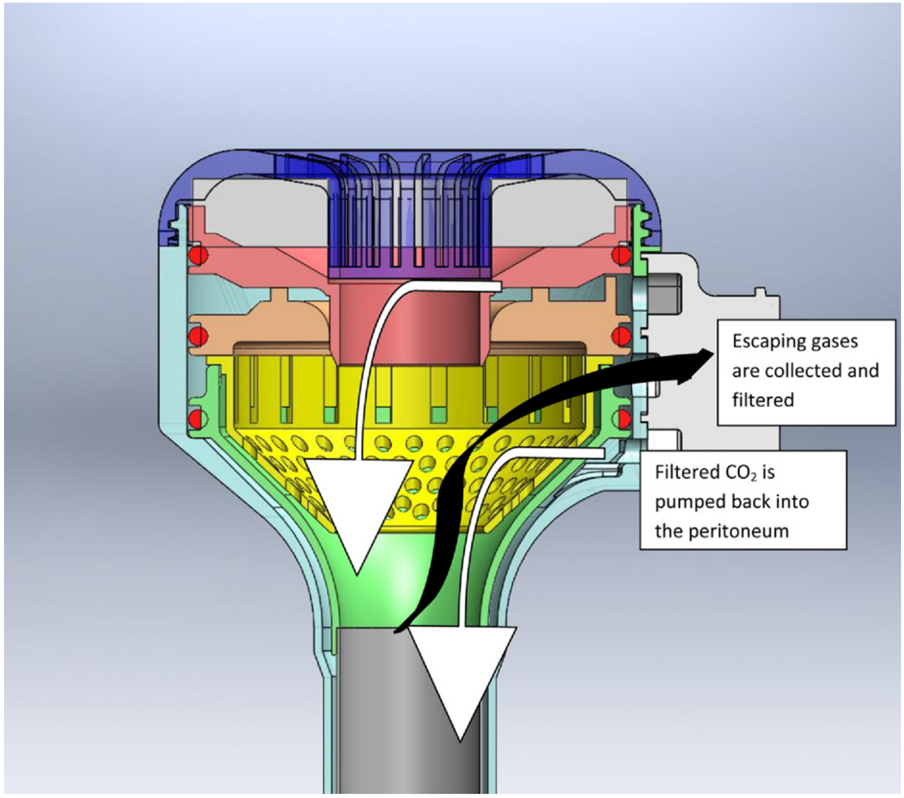

Figure 1. Schematic diagram of the Airseal trocar.

case of gasless pneumoperitoneum; gas embolisms and protracted subcutaneous emphysema with helium; and combustibility of nitrous oxide in the context of extensive electrocautery with nitrous oxide pneumoperitoneum.[3,9,11]

A novel class of valveless trocars has been designed that replace the standard "trap door" valve and silicone valve trocars with a curtain of forced CO_2 gas (Fig. 1).[12] Escaping gas is collected at the proximal end of the trocar, filtered, and redirected into the peritoneal cavity to maintain the pressure differential. In a retrospective study evaluating the safety of this novel trocar, we found that the dynamic gaseous environment not only eliminated stagnant surgical smoke but also blunted $ETCO_2$ elevations and resulted in lower volumes of CO_2 elimination when compared with other studies that have assessed the volume of CO_2 elimination during transperitoneal laparoscopic surgery using standard trocars.[5,13] Therefore, the aim of the present study was to prospectively compare the amount of CO_2 gas used and the $ETCO_2$ as a surrogate for CO_2 absorption between valveless trocars and standard trocars in patient undergoing laparoscopic renal surgery.

MATERIAL AND METHODS

Patient Demographics

After obtaining institutional review board approval, a prospective, nonrandomized comparison was performed on 51 consecutive patients (26 patients with valveless trocars and 25 patients with standard trocars) undergoing transperitoneal laparoscopic renal surgery by a single surgeon between October 2008 and April 2009. Laparoscopic partial nephrectomy was performed in 18 patients in the valveless trocar group and 16 patients in the standard trocar group. Laparoscopic nephrectomy was performed in 6 patients in each group. Two laparoscopic donor nephrectomy procedures were selected for inclusion in the valveless group, whereas 2 laparoscopic nephroureterctomy procedures were selected for inclusion in the standard trocar group. These procedures were included as they require comparable tissue dissection and cauterization, whereas laparoscopic pyeloplasties and renal cyst decortications were excluded. Data collected included patient age, height, weight, American Society of Anesthesiologists (ASA) score, and past medical history, including chronic obstructive pulmonary disease (COPD), past abdominal surgical history, social history focusing on smoking history, and medications. Both patient cohorts were comparable in terms of preoperative demographic characteristics, including categories of body mass index (BMI) and COPD (Table 1).

Technique

Pneumoperitoneum was established using a Veress needle placed at the umbilicus. An 11-mm reusable "trap-door" valve trocar (Ternamian EndoTIP trocar, Storz, Tuttlingen, Germany) was placed at the umbilicus for insertion of a 10-mm, 30° laparoscope. At this point, either the AirSeal valveless trocar (SurgiQuest; Orange, CT) or a 12-mm Endopath Xcel trocar (Ethicon Endo-Surgery, Cincinnati, OH) was placed at the midclavicular line under direct vision. Only 1 AirSeal trocar was used for each case in the valveless trocar group. All other standard trocars were placed under

Table 1. Demographics and perioperative outcomes for patients undergoing laparoscopic surgery with either the valveless or standard trocar

	Valve-Less Trocar Group	Standard Trocar Group	p Value
Demographics			
Patients (n)	26	25	
Men/women	14/12	15/10	1*
Mean age ± SD (range), y	61.6 ± 14.2 (24–83)	59.7 ± 14.3 (30–82)	.65†
Mean body mass index ± SD	30.8 ± 6.3	29.34 ± 7.3	.5†
Mean American Society of Anesthesiologists classification ± SD	2.5 ± 0.7	2.2 ± 0.6	.13†
Chronic obstructive pulmonary disease	1	2	1*
Smoking history	14	11	.58*
Mean pack-years ± SD	50.3 ± 65.7	18.9 ± 11.26	.02†
Mean mg/dL preop serum creatinine ± SD (range)	1.0 ± 0.2 (0.68–1.44)	0.92 ± 0.2 (0.75–1.18)	.21†
Mean L/g preop. serum hemoglobin ± SD (range)	14.1 ± 1.7 (10.4–16.4)	14.1 ± 1.8 (8.4–17.4)	.71†
Mean % preop. serumhematocrit ± SD (range)	43.0 ± 3.7 (34.5–48.2)	42.7 ± 4.9 (28.8–52.8)	.21†
Type of procedure performed			
Partial nephrectomy	18	17	
Radical nephrectomy	6	6	
Donor nephrectomy	2	0	
Nephroureterectomy	0	2	
Perioperative outcomes			
Mean min operative time ± SD (range)	123.1 ± 42.7 (51–196)	145.6 ± 54.5 (86–325)	.05†
Mean cc estimated blood loss ± SD (range)	304.2 ± 248.9 (100–800)	318.8 ± 353.5 (50–1700)	.86†
Mean volume (L) carbon dioxide gas used ± SD (range)	111.7 ± 77.3 (18–386)	306.4 ± 218.5 (41–927)	<.001†
No. blood transfusions	0	1	1*
Mean mg/dL serum hemoglobin ± SD (range)			
Preop to postop difference	25 ± 1.3 (−0.2–0.8)	2.3 ± 1.5 (−1.3–5.7)	.76†
Mean % serum hematocrit ± SD (range)			
Preop to postop difference	7.1 ± 3.0 (1.4–11.9)	6.9 ± 4.0 (3–10.4)	.85†
Mean mg/dL serum creatinine ± SD (range)			
Preop to first day postop	0.2 ± 0.3 (−0.2–0.8)	0.4 ± 0.4 (−0.1–1.4)	.09†
Mean serum bicarbonate			
Preop to postop difference	2.0 ± 3.3 (−4–9)	0 ± 4.1 (−11–9)	.08†
Mean days hospital stay ± SD (range)	2.6 ± 1.1 (1–5)	22 ± 1.0 (1–6)	.22†
No. complications	3	2	1*
Suboutaneous emphysema	2	0	
Pheumomediastinum	1	0	
Respiratory acidosis	0	1	
Bowel injury	0	1	

Preop, preoperative; postop, postoperative.
* Chi-squared.
† *t* test.

direct vision. During the initial establishment of pneumoperitoneum and trocar placement, CO_2 gas flow rates were set at 40 L/min with a pressure of 20 mm Hg. Once pneumoperitoneum was established and all remaining trocars required for the case were placed, pneumoperitoneum pressure was reduced to 15 mm Hg for the remainder of the case. When standard trocars were used, the CO_2 flow rates were maintained at 40 L/min. However, when the AirSeal valveless trocar was used, the CO_2 flow rates were reduced to 3 L/min as prescribed by the manufacturer.

Carbon Dioxide Elimination

All cases were performed with routine general endotracheal anesthesia with the patients in a modified lateral flank position. Anesthesiologists adjusted the tidal volume and respiratory rate to adjust for changes in the $ETCO_2$. Positive end-expiratory pressure (PEEP) was also adjusted during the procedure at the discretion of the anesthesiologists.

Intraoperative measurements of $ETCO_2$, tidal volume, and respiratory rate were obtained at 8-minute intervals starting immediately before insufflation through to the time of extubation. Data collection at 8-minute intervals was chosen arbitrarily. Electronic anesthesia records were also reviewed for each case to corroborate intraoperatively measured values. Prior studies have demonstrated that CO_2 elimination rates are directly related to CO_2 absorption rates, as the patient is kept metabolically constant. Thus any increase in CO_2 elimination can be attributed to increased absorption.[5,14,15] The CO_2 elimination rate for each time point was estimated using the equation previously described by Wolf et al.[14] and Ng et al.[15]

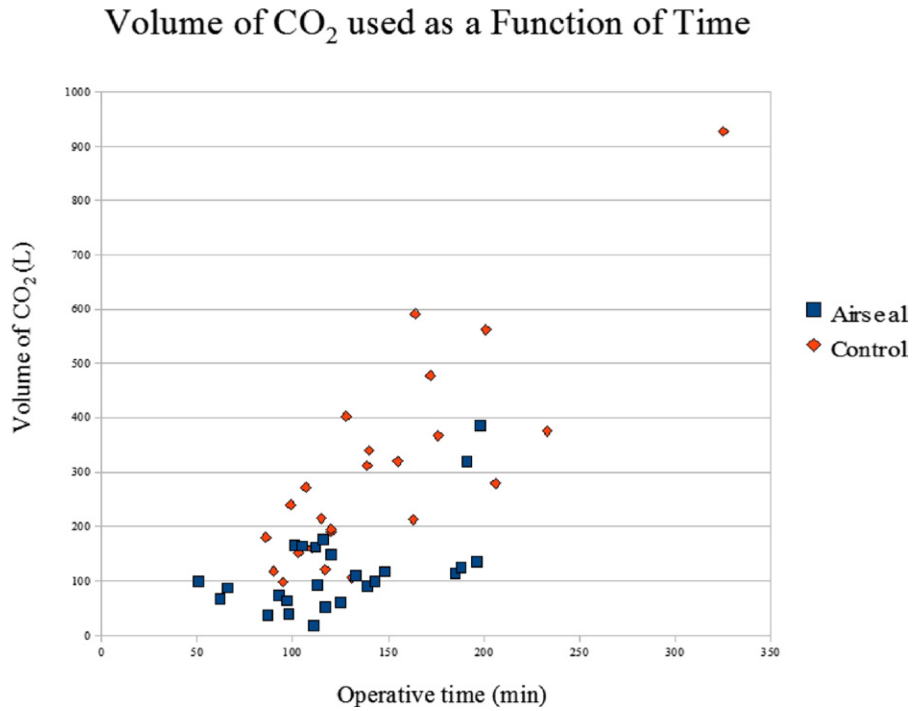

Figure 2. Differences in carbon dioxide consumption between the Airseal and standard trocar cohorts.

$$\text{Carbon dioxide elimination rate} = \frac{\mathbf{ETCO_2 \times TV \times RR}}{\mathbf{(P_B - P_{H20}) \times Wt}}$$

where $ETCO_2$ is the end-tidal carbon dioxide pressure, TV is the expired tidal volume, RR is the respiratory rate, P_B is the barometric pressure (760 mm Hg), P_{H20} is the partial pressure of water vapor (13 mm Hg), and Wt is the patient's weight in kilograms. Operative time and volume of CO_2 gas used were collected for each case. The presence of subcutaneous emphysema was assessed postoperatively for each case using palpation of the chest and abdomen for crepitus. Chest radiographs were obtained when subcutaneous emphysema was clinically detected.

Using a porcine model, Geibler et al.[4] demonstrated a marked inferior vena cava pressure gradient and decreased renal blood flow secondary to renal vein compression during pneumoperitoneum. For comparison of possible impact on renal function between the valveless trocar cohort and the standard trocar cohort, on the first postoperative day serum creatinine levels were also recorded and compared with preoperative baseline levels. Changes in serum bicarbonate between preoperative baseline levels and first postoperative day levels were also compared between the 2 groups as an indirect marker of acid–base balance.

Statistical Analysis

Fisher's exact *t* test was used to compare categorical variables, and the Mann–Whitney *U* test was used to compare the means of continuous variables. Continuous variables are reported as the mean ± SD with a two-tailed $P < .05$ considered statistically significant. SPSS for Windows, version 16.0 (SPSS Inc., Chicago, IL) was used for data analysis.

RESULTS

A total of 51 patients were included in the present study, with 26 patients having the valveless trocar and 25 patients having the standard trocar. There was no significant difference between the 2 groups in terms of age, ASA score, BMI, past medical history, and past surgical history. Table 1 lists demographic characteristics and perioperative outcomes of patients enrolled in this study.

There was 1 patient with COPD in the valveless trocar group, and there were 2 patients with COPD in the standard trocar group. The number of patients reporting a history of smoking was similar in the 2 groups (14 vs 11, $P = .57$), with a mean pack-year value of 50.27.

There were no significant differences in EBL, amount of intravenous fluids administered, rate of blood transfusion, or length of hospital stay between the 2 study groups. Similarly, no significant difference was found in the change in serum creatinine and HCO_3 levels between the groups. However, the mean operative time was significantly lower in the valveless trocar cohort (124.13 vs 145.63 minutes, $P = .047$). This difference is likely attributable to the reduced need for surgical smoke evacuation with the valveless trocar.

The volume of CO_2 consumed was significantly lower in the valveless trocar cohort when compared with the standard trocar cohort (Fig. 2) ($P < .001$). When comparing CO_2 elimination using the equation above, no difference was detected between the 2 cohorts during the first 16 minutes of insufflation. However, the standard trocar cohort was found to have significantly higher CO_2 elimination after 24 minutes ($P < .05$). This statistically significant difference lasted until 152 minutes after the start of insufflation (Fig. 3).

Two patients in the valveless trocar group and 1 patient in the standard trocar group developed complica-

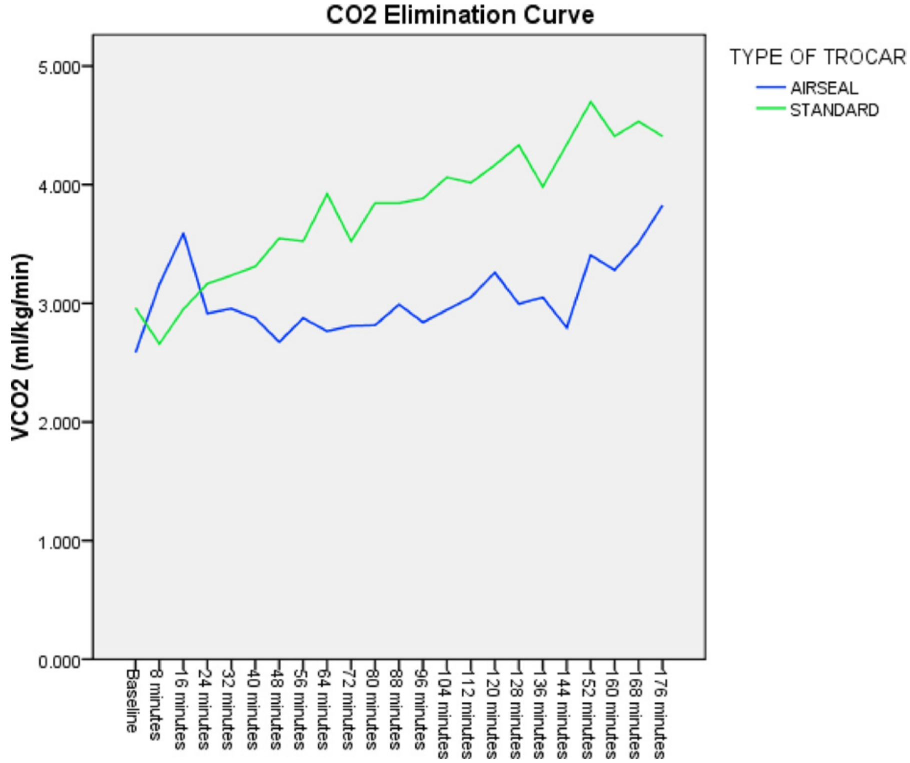

Figure 3. Carbon dioxide elimination curves for Airseal and standard trocars.

tions related to pneumoperitoneum. Both patients in the valveless trocar cohort developed subcutaneous emphysema. One of these patients was noted to have pneumomediastinum on the postoperative chest X-ray. The pneumomediastinum was clinically insignificant and resolved spontaneously. One patient in the standard trocar cohort developed intraoperative respiratory acidosis, with an $ETCO_2$ of 80 and a serum pH of 7.1. The acidemia resolved after intraperitoneal pressures were decreased and minute ventilation was increased to remove the excess CO_2. Another patient in the standard trocar cohort had a bowel injury during Veress needle insertion. This complication was unrelated to the pneumoperitoneum and required no intraoperative repair or alteration in the routine hospital course.

COMMENT

With the growth of laparoscopy over the last 2 decades, laparoscopic instruments have evolved in efficiency and safety. One area of laparoscopy that has seen very little technological advancement has been the technique of obtaining and maintaining pneumoperitoneum. Standard trocars have a trap door valve or a silicone seal, which allow for the egress of CO_2 gas with the passage of instruments through the trocar. A new class of valveless trocars has been designed, replacing trap door valves with a pressurized gas barrier at the proximal end of the trocar cannula. In the present study, we found that patients undergoing laparoscopic renal surgery using these valveless trocars had significantly lower CO_2 elimination and thus significantly lower CO_2 absorption intraoperatively when compared with patients undergoing surgery with standard trocars.

Factors associated with greater CO_2 absorption include higher insufflation pressures,[16,17] prolonged insufflation time,[18,19] operative site,[14,15] and presence of subcutaneous emphysema.[14,20] Standard trocars compensate for the inadvertent gas leakage during exchange of laparoscopic instruments by insufflating the peritoneal cavity with a constant flow of CO_2 gas to maintain a constant intraperitoneal pressure of 15-20 mm Hg and thus to maintain adequate visualization. The curtain of forced gas created by the valveless trocar system not only minimizes the amount of CO_2 gas lost during each case but also stabilizes the fluctuations in intra-abdominal pressure. Since the valveless trocar is open, it acts like a pop-off valve to release excess gas when the intraperitoneal pressure unexpectedly rises, such as with the movements of the diaphragm during breathing, use of argon electrocautery, and wearing-off of neuromuscular blockage. This may explain the lower CO_2 gas consumption and absorption.

In the present study, there was an initial peak of absorbed CO_2 followed by a plateau in absorption with the valveless trocar, whereas the standard trocar demonstrated a gradual rise in CO_2 throughout the entire case. This stepwise increase in CO_2 absorption can have several important clinical implications, including a higher risk of respiratory acidosis and gas embolism formation.[21,22] Indeed, a problem was seen in 1 of the patients in the standard trocar group, who developed hypercarbia, respiratory acidosis, and acidemia intraoperatively. Intraperitoneal pressures were decreased, and the per minute volume of ventilation was increased to remove the excess CO_2. In addition, the higher intraperitoneal pressure settings predispose patients to developing tension pneumoperitoneum. Although there was no statistically significant difference in perioperative complications between the 2 cohorts, differences may arise with larger sample sizes. There were 2 cases in the valveless trocar cohort early in our experience with this technology who developed subcutaneous emphysema. This occurred by displacement of the valveless trocar out of the peritoneal cavity. Thereafter an anchoring suture was used to secure the trocar to the skin to prevent inadvertent displacement of the trocar from the peritoneal cavity. The suture was secured around the trocar's tubing, as there are no anchoring holes on the trocar. This prevented any further similar events, suggesting a structural design error of the valveless trocar. No anchoring sutures were needed in the standard trocar cohort, as we did not encounter any problems with displacement with these trocars. Future valveless trocars should be equipped with such anchoring holes for this purpose.

Several experimental and clinical studies have demonstrated that prolonged, increased intraabdominal pressures during insufflation are associated with reduced renal function. The mechanism by which this occurs is unclear, but is thought to be multifactorial and caused by decreased renal blood flow from vascular compression, systemic hormonal effects, and direct renal parenchymal compression. In the rat model, Kirsch et al[23] demonstrated the effects of elevated pneumoperitoneal pressures on urine production and on central venous and aortic blood flow. They found that an increase in intraperitoneal pressures from 5 to 10 mm Hg resulted in a reduction in central venous and aortic blood flow from 53% and 62.7% to 7.1% and 53.6%, respectively.

In our study, there was no significant difference between the 2 groups in terms of postoperative serum creatinine and bicarbonate levels ($P = .09$). Therefore patients with the standard trocars were compensated by increased minute ventilation and were able to eliminate the excess CO_2 accumulated. The impact of various pneumoperitoneal pressures was demonstrated in a study performed by Hawasli et al., which assessed the impact of 2 different pressure settings (10 and 15 mm Hg) on renal function in a cohort of donor nephrectomy patients.[24] In that study, the authors found no statistically significant difference between the 2 pressures used. Similarly, Nishio et al[25] found no significant difference in serum creatinine between patients who underwent laparoscopic adrenalectomy and gasless laparoscopic adrenalectomy. These 2 studies suggest that serum creatinine on the first postoperative day may not be sensitive enough to detect the effects of intraoperative hemodynamic alterations.

Our study was limited by its nonrandomized nature, predisposing it to a potential selection bias. We partly controlled for this bias by alternating patient enrollment into each cohort on the day of surgery. In the future, valveless trocars should be compared with standard trocars in a randomized fashion. This study was also limited by the fact that direct measurement of CO_2 absorption was not performed. Although the CO_2 elimination rate is a reasonable estimate of the CO_2 absorption, it does not account for the effects of circulatory shunting and venous admixture. Shunted blood will increase the arterial CO_2; however, as the same equation was applied for all patients, the impact of this difference was standardized across all patients in this study.

Given the ability of the valveless trocar system to function with a low flow setting and demonstrable reductions in CO_2 absorption, use of this system has the potential to reduce cardiopulmonary compromise secondary to insufflation with CO_2 gas. The valveless trocar may therefore be beneficial in lengthy laparoscopic procedures in COPD patients. Although the present study was not a cost analysis, valveless trocars cost as much as standard trocars while potentially offering a cost-benefit advantage by using significantly lower volumes of CO_2 insufflant. In addition, using less CO_2 will likely reduce the number of occasions in which the CO_2 tank empties and needs to be switched during a procedure. Such "tank-switches" can be distracting and potentially dangerous if they occur at an inopportune moment, such as during hemorrhage.

CONCLUSIONS

Valveless trocars are associated with reduced CO_2 use, absorption, and elimination. This may prove to be advantageous in patients with compromised cardiopulmonary function, such as those with COPD. Although the reduction in CO_2 absorption makes the valveless trocar an attractive alternative to standard trocars, especially for patients at high risk for cardiopulmonary compromise, randomized comparisons are necessary to better characterize the potential benefits and advantages and to demonstrate the clinical significance of our findings.

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