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Original Article

Diagnostic and Therapeutic Strategies for Hypercarbia in Elderly Patients Undergoing Prolonged Retroperitoneoscopic Surgery ——The Role of $TcPCO_2$ and PEEP

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ABSTRACT

Background: Retroperitoneal laparoscopy provides less operation injury and faster postoperative recovery. However, long-term pneumoperitoneum increases the risk of hypercapnia that may induce severe postoperative complications, especially in elderly patients. Our study aims at investigating the sensitivity and reliability of continuous transcutaneous carbon dioxide ($TcPCO_2$) monitoring in diagnosing hypercapnia during retroperitoneoscopic surgery in elderly patients and evaluating the effect of positive end-expiratory pressure (PEEP) against retroperitoneum induced hypercapnia.

Methods: Fifty-five patients aged over 65 years who were scheduled for selective retroperitoneoscopic surgery under general anesthesia were enrolled. The correlations between $TcPCO_2$, end-tidal partial pressure of CO_2 ($P_{ET}CO_2$) and arterial CO_2 ($PaCO_2$) were evaluated before pneumoperitoneum as well as 30 and 60 minutes after establishment of pneumoperitoneum (time 0, 1 and 2), respectively. Patients were randomly assigned to 5 groups accepting different levels of PEEP: 0, 4, 6, 8 and 10 cm H_2O (group I, II, III, IV and V). $PaCO_2$ and $P_{ET}CO_2$ were measured at 80 minutes following pneumoperitoneum (time 3). Heart rate (HR), arterial pressure, airway pressure were evaluated throughout surgery.

Results: There was a significant correlation between $TcPCO_2$ and $PaCO_2$ ($r=0.87$, $P<0.01$), but the correlation between $P_{ET}CO_2$ and $PaCO_2$ was lessened with prolonged pneumoperitoneum. The consistency limit (mean ± 2SD) between $PaCO_2$ vs. $TcPCO_2$ and $PaCO_2$ vs. $P_{ET}CO_2$ was (-2.86, 5.46) and (-1.61, 20.11) mm Hg, respectively. A difference of ⩽5 mm Hg happened in 96% results of $PaCO_2$ vs. $TcPCO_2$ and 32% of $PaCO_2$ vs. $P_{ET}CO_2$ ($P<0.01$). After the use of PEEP, the $PaCO_2$ was increased in group I and II, sustained in group III, but decreased in group IV and V ($P<0.05$). In addition, PEEP restored the correlation between $P_{ET}CO_2$ and $PaCO_2$($r=0.6$, $P<0.01$, $N=55$). The hypercapnia induced enhancement of mean arterial pressure (MAP) and HR was normalized by 10 cm H_2O PEEP although the airway plateau pressure (P_{PLAT}) and airway pressure peak (P_{PEAK}) values were elevated.

Conclusions: $TcPCO_2$ may be used as an alternative non-invasive monitoring to predict the $PaCO_2$ levels in elderly patients undergoing long-term retroperitoneoscopic surgery. PEEP (10 cm H_2O) combined with low tidal volume (VT=7 ml/kg) ventilation provides a therapeutic approach to ameliorate pneumoperitoneum-induced hypercapnia in these patients.

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Retroperitoneal laparoscopy plays a special role in urinary surgery for elderly patients due to the advantages of less injury, faster postoperative recovery (1), and low risks in tumor cells proliferation (2). However, carbon dioxide insufflation during laparoscopic surgery may cause respiratory acidosis and refractory hypercapnia that may lead to lethal complications, such as perioperative decompensation, especially in elderly patients. Thus it is necessary to establish an accurate monitoring approach and treatment strategy to effectively prevent hypercapnia.

Transcutaneous partial pressure of carbon dioxide ($TcPCO_2$) is a noninvasive method to monitor CO_2 in microcirculation in a real-time manner. It has been used to reflect the arterial CO_2 ($PaCO_2$) in multiple clinical scenarios. When the end-tidal partial pressure of CO_2 ($P_{ET}CO_2$) is disturbed by increased intrathoracic pressure, severe cardiac or pulmonary diseases, etc., $TcPCO_2$ becomes a valuable supplement to $P_{ET}CO_2$ (3). However, the efficacy of $TcPCO_2$ in predicting $PaCO_2$ in elderly patients with complex ventilation parameters and declined pulmonary function during retroperitoneal laparoscopy has not yet been well understood.

Hypercapnia can be corrected by moderately excessive ventilation. However, in retroperitoneal laparoscopy, moderately excessive ventilation is not sufficient to improve the lung function and reduce $PaCO_2$, in addition, it may increase the incidence of airway barotrauma and impede blood reflux and hemodynamic stability (4). Positive end expiratory pressure (PEEP) can be applied to prevent alveolar atrophy or collapse, reduce pulmonary arteriovenous shunting, thus improving ventilation/blood flow ratio and diffusion function.

The main goal of this study was to evaluate the correlation between $PaCO_2$ and $TcPCO_2$, compare that to the correlation between $PaCO_2$ and $P_{ET}CO_2$ during prolonged retroperitoneoscopic surgery, and investigate the role of PEEP in treating hypercapnia.

MATERIALS AND METHODS

Patients and Ethical Approval

The study was conducted at the Department of Anaesthesiology, Xuanwu Hospital, Beijing, China, between 1 October 2011 and 31 August 2012. Fifty-five patients aged 65-85 years who were graded as American Society of Anaesthesiologists physical status (ASA) I-II and were scheduled for elective urologic surgery with retroperitoneal laparoscope under general anesthesia were enrolled. Patients with special skin conditions unsuitable for $TcPCO_2$ monitoring were excluded. Cases were removed from the study if the surgical time was less than 80 minutes or they switched from a surgical approach to another one.

The study was approved by the Ethic Committee of Xuanwu Hospital, and informed consents were signed by all the recruited patients.

Anesthesia and Monitoring

All patients accepted general anesthesia. Vein access in the upper limb was obtained prior to anesthesia, and electrocardiogram (ECG), heart rate (HR), pulse oxygen saturation (SpO_2), noninvasive blood pressure (NIBP), $P_{ET}CO_2$ and nasopharyngeal temperature (NT) were continuously detected via a multifunctional monitor (AS/5, Datex-Ohmeda, Finland). Sedation was monitored by Bispectral index (BIS, Covidien, MA, USA) and maintained between 40-60 during surgery. Nasopharyngeal temperature was controlled between 36-37 ℃ by an automatic heating blanket and heated air device. Blood gas analysis was performed with i-STAT system (Radiometer, Denmark) after induction of general anesthesia. $TcPCO_2$ was monitored with a TCM4 system (Radiometer, Denmark). All the monitor parameters were calibrated regarding to the manual instructions prior to anesthesia. Anesthesia induction was performed with midazolam 0.02 mg/kg, fentanyl 2 μg/kg, etomidate 0.15 mg/kg and cisatracuriumbesylate 0.15 mg/kg in proper order, then endotracheal intubation was performed and mechanical ventilation was established. During operation, anesthesia was maintained with propofol (3-6 mg/kg/h), remifentanyl (0.025-0.1 μg/kg/min), and cisatracuriumbesylate (0.05-0.1 mg/kg/h). Intraoperative fluid therapy followed the "4-2-1 Principle" with a ratio of 1:1 for crystalloid versus colloids to accomplish physical requirements. Intraoperative blood loss was supplemented with an equal amount of colloid fluid. Before pneumoperitoneum, ventilation parameters were set as f 12-22 times/minute, VT 6-8 ml/kg, I:E ratio 1:2, in-

haled fraction of oxygen concentration 40% (FiO_2), $P_{ET}CO_2$ 35-45 mm Hg (4). Pneumoperitoneum was established at 30 minutes after the stabilization of $TcPCO_2$ to reach a stable $TcPCO_2$ equilibrium (3, 5). CO_2 pressure in pneumoperitoneum was maintained at 15 cm H_2O through the surgery. When $PaCO_2$ was over 55 mm Hg after pneumoperitoneum, the ventilation parameters were changed as follows: VT 7 ml/kg, and f 17 times/minute. $TcPCO_2$, $P_{ET}CO_2$, $PaCO_2$ values were collected before pneumoperitoneum as well as 30 and 60 minutes after establishment of pneumoperitoneum (T 0, 1 and 2).

After T2, patients were randomly assigned to 5 groups receiving different levels of PEEP: 0, 4, 6, 8 and 10 cm H_2O, respectively (group I, II, III, IV and V, N=11 in each group). $PaCO_2$, $P_{ET}CO_2$, NIBP, HR, airway plateau pressure (P_{PLAT}), airway pressure peak (P_{PEAK}), and PaO_2 were recorded. The indication of administration of vasoactive drugs was as follows: NIBP beyond the range of 90-160/40-95 mm Hg or HR beyond the range of 50-120 beats/minute. The data of aforementioned monitoring parameters were collected at 20 minutes following the PEEP (80 minutes after pneumoperitoneum, T3).

Statistical Analysis

According to the preliminary experiment, a sample size of 11 patients per group was needed such that 30% or more difference in $PaCO_2$ could be detected between two groups with Type I error of 0.10 and Type II error of 0.20. Data were expressed as means ± standard deviation (SD) and were analyzed by SPSS 13.0. The correlation of $TcPCO_2$ with $P_{ET}CO_2$ and $PaCO_2$ was evaluated with Pearson analysis, respectively. The consistency of $TcPCO_2$ with $P_{ET}CO_2$ and $PaCO_2$ was evaluated by Bland-Altman method, respectively. One-way ANOVA and q-test were applied for the comparison among groups at a given level of PEEP. Repeated measure t-test was used for the comparison in the same group at different time points. $P<0.05$ was considered as statistical significance.

RESULTS

In 55 patients undergoing retroperitoneal laparoscopy, 7 patients were subject to radical nephrectomy, 10 patients were assigned to partial nephrectomy, 18 patients received resection of adrenal gland tumor, and 20 patients accepted fenestration for renal cysts. Demographic data were displayed in table 1.

Table 1. Demographic Data.

Group	Gender (M/F)	Age (Year)	Height (cm)	Weight (kg)	ASA (I/II)
Overall	31/24	72±5	164±9	65±9	10/45
I	7/4	72±7	164±7	65±8	2/9
II	5/6	72±4	164±9	69±9	2/9
III	6/5	72±4	166±8	63±9	1/10
IV	6/5	73±5	163±12	64±9	3/8
V	7/4	73±4	164±8	63±8	2/9

Measurement data were expressed as means ± SD (n=55). χ^2 test was used for analysis on gender ratio and ASA grade composition among groups with different levels of PEEP. With respect to age, height, and weight, there is no statistical difference shown by one-way ANOVA.

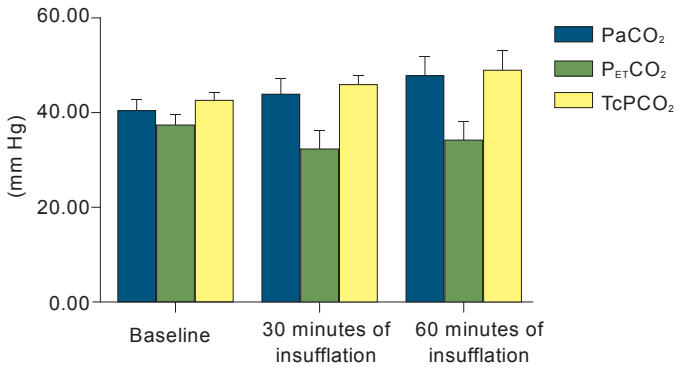

Figure 1. Comparison of $P_{ET}CO_2$, $TcPCO_2$ and $PaCO_2$ Values at Different Time Points (Baseline, 30 and 60 Minutes of Insufflation). With prolonged time of pneumoperitoneum, $PaCO_2$ gradually rose ($P<0.05$), and the difference between $PETCO_2$ and $PaCO_2$ increased gradually ($P<0.05$), and correlation became weaker (significant correlation between $P_{ET}CO_2$ and $PaCO_2$ was only found at time 0 and 1, $r=0.75$ [$P=0.000$] and 0.54 [$P=0.000$] respectively); the difference between $TcPCO_2$ and $PaCO_2$ was small and stable, and was not affected by pneumoperitoneum (r of correlation of $TcPCO_2$ and $PaCO_2$ at time 0, 1 and 2 were 0.74 [$P=0.000$], 0.78 [$P=0.000$] and 0.80 [$P=0.000$] respectively).

The Correlation Between $TcPCO_2$, $P_{ET}CO_2$ and $PaCO_2$

With prolonged time of pneumoperitoneum, the difference between $P_{ET}CO_2$ and $PaCO_2$ increased gradually with rise in $PaCO_2$, and no overall correlation was shown between $PaCO_2$ and $P_{ET}CO_2$ (Figure 1, Figure 2). The difference between $TcPCO_2$ and $PaCO_2$ was not affected by duration of

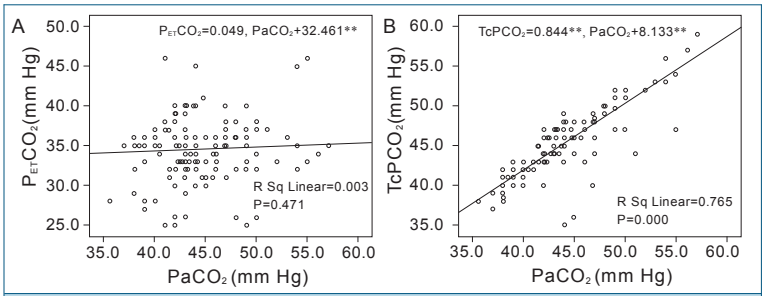

Figure 2. Scatter Plot and Straight Regression Line of $P_{ET}CO_2$ and $TcPCO_2$ Relative to $PaCO_2$.
During pneumoperitoneum (baseline, 30 minutes and 60 minutes). Highly significant correlation was found between $TcPCO_2$ and $PaCO_2$ values, as shown in B (r=0.874, linear equation: $TcPCO_2$=0.844 $PaCO_2$ + 8.133, P< 0.01); but no correlation was observed between $P_{ET}CO_2$ and $PaCO_2$ values (P>0.05), as shown in A.

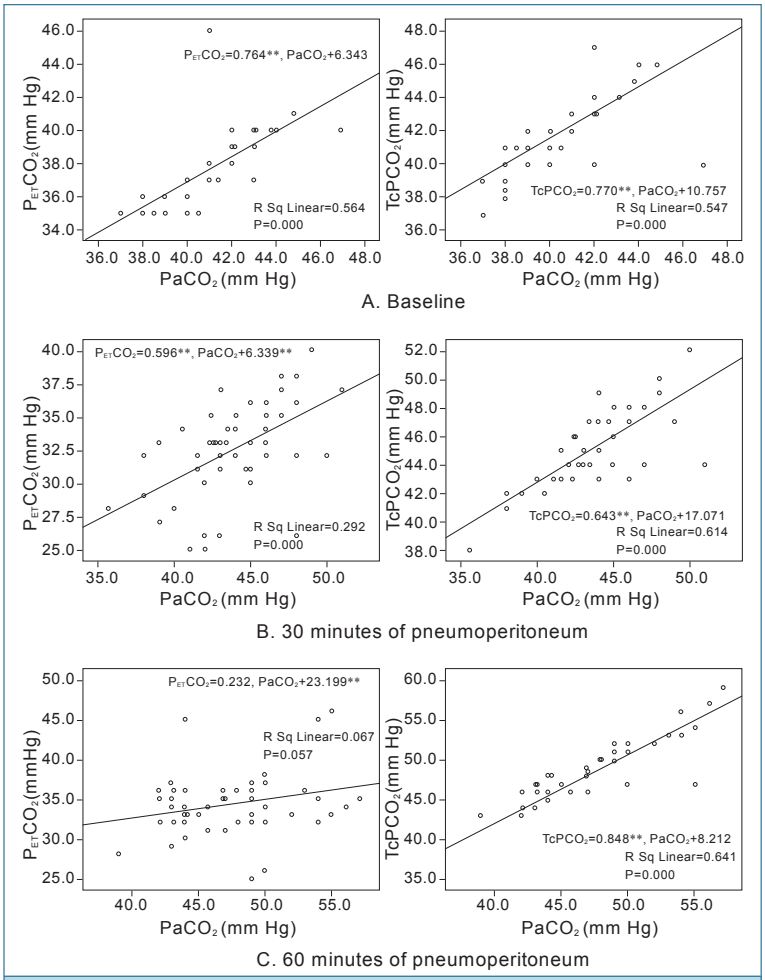

Figure 3. Scatter Plot and Regression Line in $P_{ET}CO_2$ and $TcPCO_2$ Relative to $PaCO_2$ (Baseline, 30 and 60 Minutes of Pneumoperitoneum).
Only significant correlation was found between $P_{ET}CO_2$ and $PaCO_2$ values at baseline and moderate correlation at 30 minutes of pneumoperitoneum; correlation coefficient r=0.751 (N=55, P<0.01), and r=0.540 (N=55, P<0.01), respectively. No correction existed between $P_{ET}CO_2$ and $PaCO_2$ at 60 minutes of pneumoperitoneum (P>0.05). Stable and excellent correction was found between $TcPCO_2$ and $PaCO_2$ at three time points.

pneumoperitoneum (Figure 1), and there was a significant correlation between $TcPCO_2$ and $PaCO_2$ regarding to all the three time points, with the correlation coefficient (r) of 0.87 (P= 0.000). The correlation coefficient of correlation of $TcPCO_2$ and $PaCO_2$ at time 0, 1 and 2 were 0.74 (P=0.000), 0.78(P=0.000) and 0.80 (P=0.000), respectively. However, significant correlation between $P_{ET}CO_2$ and $PaCO_2$ was only found at time 0 and 1, r = 0.75 (P= 0.000) and 0.54 (P = 0.000), respectively (Figure 3).

The Consistency Among $TcPCO_2$, $P_{ET}CO_2$ and $PaCO_2$

Among all the data that were collected at 3 time points, 96% of results of $TcPCO_2$ and $PaCO_2$ showed a difference ⩽5 mm Hg, which was only seen in 32% results of $P_{ET}CO_2$ and $PaCO_2$ (P= 0.023) (Figure 4).

PEEP Affects $PaCO_2$ Level During Pneumoperitoneum

The $PaCO_2$ level was significantly related to the level of PEEP. At twenty minutes following PEEP, $PaCO_2$ level was increased in group I and II (P=0.012), with a less increase in group II (P= 0.031). However, $PaCO_2$ level was decreased in group IV (P=0.013) and further decreased in group V (P=0.017) (Figure 5).

PEEP Affects Blood Pressure and Heart Rate During Pneumoperitoneum

The hemodynamic data showed both MAP and HR levels were increased in group I but decreased in group IV and V following PEEP as compared to the baseline levels (P=0.018, 0.008, 0.003, respectively, Figure 6). There was also an increase in MAP in group II after PEEP (P=0.034). The strongest decline in MAP and HR values occurred in group V, but it was still in the range of ±20% of baseline values.

Pneumoperitoneum and PEEP Influences the Airway Pressure and PaO_2

The values of P_{PLAT} and P_{PEAK} increased in proportion to the level of PEEP (P=0.008, 0.007 respectively, Figure 7A), while the values of P_{PLAT} and P_{PEAK} in group V were still under 35 cm H_2O. PaO_2 value, which stands for the oxygenation function, changed with the values of P_{PLAT} and

P_{PEAK} (P=0.003, 0.006, respectively, Figure 7B).

PEEP Restores the Correlation Between $P_{ET}CO_2$ and $PaCO_2$

To investigate whether PEEP affects the accuracy of $P_{ET}CO_2$, we evaluated the correlation between $P_{ET}CO_2$ and $PaCO_2$ at 20 minutes following PEEP. According to the evidence from figure 8 and table 2, at 60 minutes of pneumoperitoneum, no correlation between $P_{ET}CO_2$ and $PaCO_2$ was found in group II, III, IV and V (PEEP applied was above 0 cm H_2O, P=0.075), but their correlation were observed at 20 minutes following PEEP, i.e., 80 minutes after pneumoperitoneum (correlation coefficient r=0.62, P=0.001, N=44). At 80 minutes after pneumoperitoneum, as the value of PEEP applied increased, the correlation coefficient between $P_{ET}CO_2$ and $PaCO_2$ elevated in sequence: r IV/V> r III/IV> rII/III.

DISCUSSION

The retroperitoneal laparoscopic surgery significantly improves postoperative outcomes due to less invasiveness compared to traditional open abdominal surgeries. However, due to the large area of CO_2 contact and abundant blood supply in the loose connective tissue (6), CO_2 gas was rapidly absorbed, and more severe hypercapnia was prone to happen (7).

Nowadays, there are both noninvasive and invasive techniques of measuring blood CO_2 content. $PaCO_2$ and $P_{ET}CO_2$ are commonly used methods, while $TcPCO_2$ has been initiated recently. Arterial blood gas analysis is the gold standard for measuring $PaCO_2$, however, it is invasive, cumbersome and time-consuming when multiple measurements are required. In normal circumstances, the difference between $P_{ET}CO_2$ and $PaCO_2$ is a constant, thus $P_{ET}CO_2$ can provide indirect estimates of $PaCO_2$. However, in patients with complicated coexisted diseases, the reliability of $P_{ET}CO_2$ prediction for $PaCO_2$ decreases (8). In particular, during the retroperitoneal laparoscopic surgery, the excessive ventilation may increase intrathoracic pressure, reduce pulmonary blood flow, and increase proportion of dead space ventilation. Thus, CO_2 partial pressure difference ($PaCO_2$- $P_{ET}CO_2$) at the end of expiration will significantly increase (3, 9). $TcPCO_2$ causes the temperature of skin surface

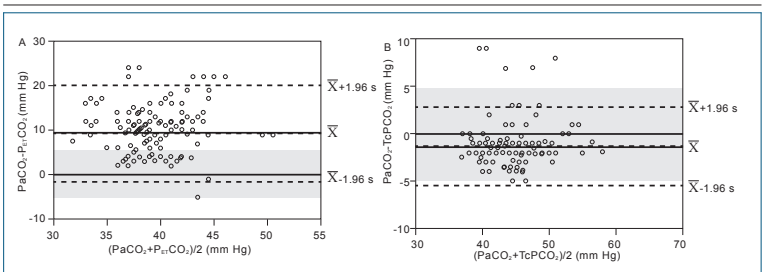

Figure 4. Consistency of $PaCO_2$ with $P_{ET}CO_2$ and $TcPCO_2$ was Evaluded Using Bland-Altman Method.

A. Consistency of $PaCO_2$ with $PETCO_2$ was evaluated using Bland - Altman method. $P_{ET}CO_2$ and $PaCO_2$ consistency boundaries (- 1.61, 20.11) mm Hg were beyond the scope of the maximum error in measurement clinically allowed (gray area in the figure), indicating that d line representing the average difference between $P_{ET}CO_2$ and $PaCO_2$ (y = 9.25 mm Hg) was relatively far away from zero line.

B. Consistency of $PaCO_2$ with $TcPCO_2$ was evaluated using Bland - Altman method. Scatting dots representing the correlation between $TcPCO_2$ and $PaCO_2$ were evenly distributed above and below d line (y = 1.30 mm Hg), and d line was near to zero line. Consistency boundaries (-2.86,5.46) mm Hg were in the scope of normal deviations clinically allowed (96% of samples fell in the normal range of deviations clinically allowed).

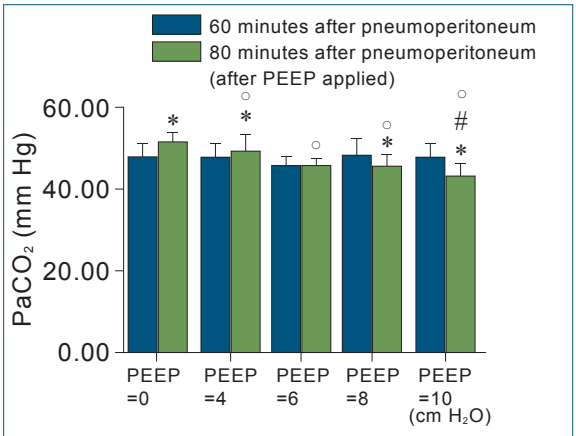

Figure 5. Comparison of $PaCO_2$ in 5 Groups Before and After Application of PEEP.

*P<0.05 vs. 60 minutes, ○P<0.05 vs. PEEP=0, #P< 0.05 vs. PEEP=8 cm H_2O. After application of PEEP, $PaCO_2$ still increased in Group I and II, of which the increase was lower in Group II than Group I. $PaCO_2$ stopped to rise in Group III after application of PEEP. And $PaCO_2$ decreased in Group IV and V after application of PEEP, of which the decrease was larger in Group V than IV.

increase to increase the blood flow velocity in capillary, resulting in arterialization. Higher solubility and diffusivity of CO_2 are used to measure the concentration of CO_2 dispersing from arterialized capillaries in skin, and furthermore to predict $PaCO_2$. In our study, the skin at the flexor

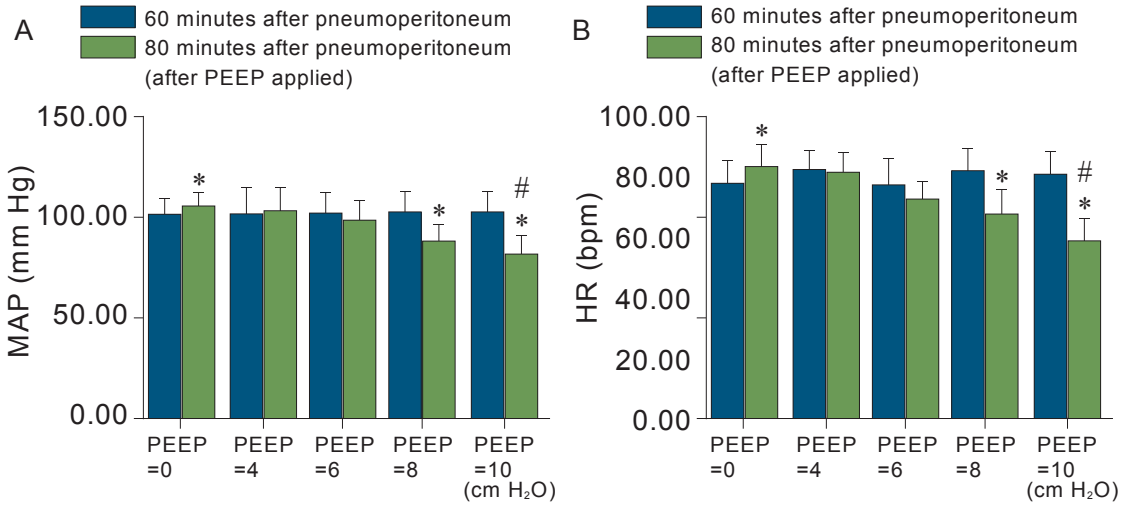

Figure 6. Changes in MAP and HR Among 5 Groups Before and After Application of PEEP.
*P<0.05 vs. 60 minutes, #P<0.05 vs. PEEP=8 cm H_2O. Compared to pre-PEEP condition, MAP and HR increased in group I (as the pneumoperiotonium lasted for another 20 minutes), kept equal in group II and III, and decreased in group IV and V after application of PEEP, of which, the decrease in MAP and HR in group V was larger, but still within the normal range (±20%).

side of brachioradialis was monitored to obtain stable and accurate data. It has been indicated that $TcPCO_2$ can accurately (11-15) predict $PaCO_2$ in a real-time manner (4), and has been widely used (8). The most important thing is that $TcPCO_2$ is a valuable supplement to $P_{ET}CO_2$ monitoring in patients with a large gap between $PaCO_2$ and $P_{ET}CO_2$ and in those concurrently requiring continuous accurate non-invasive control of CO_2 levels (4, 8, 9). But it has also been shown that $TcPCO_2$ - $PaCO_2$ difference will increase (8) in the following settings: $PaCO_2$ above 60 mm Hg (4), hypoperfusion in measurement site, shock, edema, thick skin and vasocontractive drugs.

In this study, 3 time points were chosen to analyze the correlation between $PaCO_2$ and $P_{ET}CO_2$: before pneumoperitoneum (baseline), 30 minutes (when CO_2 absorption was the fastest [7]) and 60 minutes (when $PaCO_2$ was relatively stable [7]) after establishment of pneumoperitoneum. Prior to pneumoperitoneum, there was a significant correlation between $PaCO_2$ and $P_{ET}CO_2$. After establishment of pneumoperitoneum, the hyperventilation setting (small tidal volume and high frequency) was used (10) to increase pulmonary ventilation volume. Due to the increased dead space ventilation and decreased pulmonary blood flow, $P_{ET}CO_2$ increased as well and correlation between $PaCO_2$ and $P_{ET}CO_2$ was lost. According to our results, in elderly patients who underwent retroperitoneal laparoscopic surgery, it is not reliable to use $P_{ET}CO_2$ to predict the $PaCO_2$ level.

Our results indicated that significant correlation between $TcPCO_2$ and $PaCO_2$ still existed until 60 minutes of insufflation. Therefore, $TcPCO_2$ may effectively predict the value and change trend of $PaCO_2$. $TcPCO_2$ value was not significantly affected by intrathoracic pressure, age-related changes in skin and subcutaneous circulation, pneumoperitoneum and hyperventilation modes in laparoscopic surgeries. Further evaluation using Bland - Altman method on consistency of $TcPCO_2$ and $P_{ET}CO_2$ with $PaCO_2$ was performed and the maximum measurement error allowed clinically was assumed as plus or minus 5 mm Hg (16). Our results showed a poor correlation existed between $P_{ET}CO_2$ and $PaCO_2$ in retroperitoneal laparoscopic surgery, while $TcPCO_2$ was highly correlated with blood gas $PaCO_2$, hence it could be a good alternative measurement of blood CO_2 level (16).

Studies by Mohsen et al. (17) showed that mild hypercapnia ($PaCO_2$ 45-53 mm Hg) provided a slight effect on cardiopulmonary function, while moderate to severe hypercapnia ($PaCO_2$ 54-70 mm Hg) may result in a significant change of cardiopulmonary function. In elderly

patients with impaired organ function and compensatory mechanism, the tolerance to refractory hypercapnia drop dramatically. Intractable hypercapnia without effective treatment may further lead to acidosis, cause systemic inflammatory response syndrome and even multiple organ function failure (18-21). On the other hand, refractory hypercapnia may affect the cerebral oxygen saturation and increase the risk of delayed postoperative awakening in elderly patients.

It has been recognized that moderate excessive ventilation can correct CO_2 accumulation and treat intractable hypercapnia. Moderate excessive ventilation, which means an increase of 10-15% in minute ventilation, is usually achieved by increasing tidal volume or breathing rate (7).

In elderly patients, certain lesions in small airways may exist. Insufflation easily induces increase in physiological dead space due to limited lung volume. High volume plus low frequency ventilation was considered capable of treating CO_2 accumulation in elderly patients, but the improvement was not obvious (22); Further comparison of VA/Q ratio before and after insufflation was performed, the results indicated that this VA/Q ratio still significantly fell after insufflations. This suggested that high volume ventilation was not sufficient to improve lung function; on the other hand, blindly increasing the ventilation volume would increase the possibility of airway injury, affect the venous reflux and damage hemodynamic stability (22). Therefore, the small tidal volume plus high frequency ventilation strategy may be a better choice (23).

PEEP means that the ventilator produces a positive pressure higher than the atmospheric pressure at the end of expiration. PEEP could prevent alveolar atrophy or collapse, increase functional residual capacity (FRC) by opening up closed alveolus, decreasing arteriovenous shunt, and restoring ventilation/blood flow ratio and diffusion function. In that case, respiratory function could be improved in elderly patients with lung diseases (24). However, an even higher level of PEEP will induce an obvious elevation in airway pressure or intrathoracic pressure, which leads to ventilation injury and declined cardiac output.

Recently, a series of researches have recommended that small tidal volume (5-7 ml/kg) with a certain level of PEEP could be a safer and effective ventilation strategy for elderly patients (7). Unfortunately, It is still controversial which level (high [4, 25, 26] or low [23, 27]) of PEEP is proper.

In our study, comparison of $PaCO_2$ before and after PEEP was performed. Our data suggested that small tidal volume (7 ml/kg) with PEEP

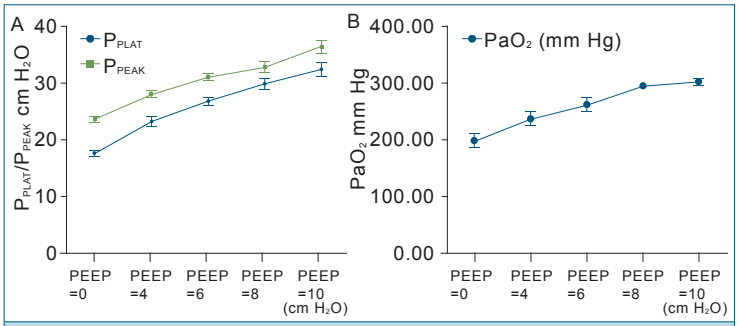

Figure 7. Changes in P_{PLAT}, P_{PEAK} and PaO_2 Among 5 Groups Before and After Application of PEEP.
The values of P_{PLAT} and P_{PEAK} increased in proportion to the level of PEEP ($P<0.05$ respectively, Figure 7A), while the values of P_{PLAT} and P_{PEAK} in group V were still under 35 cm H_2O. PaO_2 value, which stands for the oxygenation function, changed with the values of P_{PLAT} and P_{PEAK} ($P< 0.05$, respectively, Figure 7B).

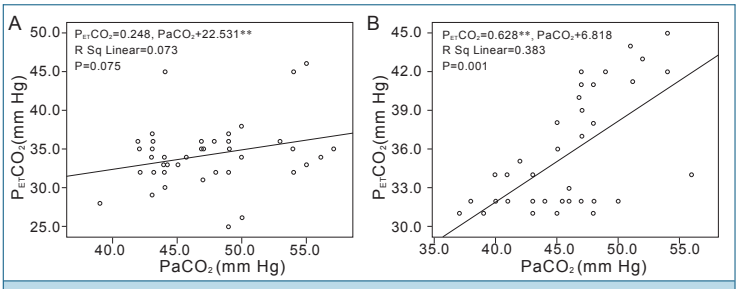

Figure 8. The Correlation Between $P_{ET}CO_2$ and $PaCO_2$ in Group II, III, IV and V at Different Time Points.
At 60 minutes after pneumoperitoneum, no correlation was found between them ($P > 0.05$) (A); However , at 20 minutes after application of PEEP (i.e. 80 minutes after insufflation), their correlation restored with correlation coefficient $r=0.62$ ($P<0.01$, linear equation: PETCO2=0.628 PaCO2+6.818, n=44) (B).

Table 2. Correlative Coefficients Between $PaCO_2$ and $P_{ET}CO_2$ in Each Group.

Group	II~V		II~III		III~IV		IV~V	
	r	P	r	P	r	P	r	P
60 minutes	0.271	0.075						
80 minutes	0.620	0.001	0.499	0.018	0.612	0.002	0.802	0.000

No correlation existed between them in group II-V before application of PEEP(P>0.05); but correlation restored after application of PEEP for 20 minutes. At 80 minutes after pneumoperitoneum, as the PEEP increased, correlative coefficients between $PaCO_2$ and $P_{ET}CO_2$ correction elevated in sequence.

could, to a certain extent, effectively reverse pneumoperitoneum induced hypercapnia, and within 4-10 cm H_2O, the treatment effect was more significant with the rising of PEEP levels (Figure 5).

Until now, the therapeutic role of PEEP in hypercapnia has been confirmed. We continued to investigate the adverse effects of PEEP (4-10 cm H_2O), and its impact on pulmonary and cardiovascular system was used as indicators.

In this study, adequate depth of anesthesia, proper analgesia and muscle relaxtion were maintained during operation to eliminate their effect on pulmonary and cardiovascular system. Our results showed that MAP and HR stopped to elevate in group II and III after application of PEEP, this illustrated that the effect of PEEP (4-6 cm H_2O) was enough to compensate the impact of hypercapnia. Furthermore, MAP and HR decreased more significantly in Group IV and V, indicating that higher levels of PEEP (> 8 mm Hg) had reversed the effect of hypercapnia and relieved the overactivation of sympathetic nerves. Another possible explanation is that high level of PEEP could increase intrathoracic pressure and damage venous reflux, resulting in drop in cardiac output. In spite of this, the decrease in MAP or HR was still within the clinical acceptable range (28) and did not harm the perfusion of vital organs in elderly patients. Our data demonstrated that P_{PLAT} and P_{PEAK} increased gradually with application of PEEP. The average value of P_{PEAK} was over 30 mm Hg in group IV and V, simultaneously, mean P_{PLAT} was above 25 mm Hg in those two groups. It has been recognized that P_{PLAT}>25 mm Hg is the main risk factor for barotrauma, indicating that PEEP>8 cm H_2O may increase risk of ventilator-induced lung injury. By contrast, several meta-analysis focused on reducing postoperative pulmonary complications by different ventilation strategies. Their results recommended that a higher level of PEEP (3 to 12 cm H_2O) is more advantageous to prevent postoperative lung injury, infections and atelectasis (29). Our data also indicated that 4 to 10 cm H_2O of PEEP could effectively improve intraoperative oxygenation without any significant adverse hemodynamic effects in elderly patients. So in general, a PEEP value of 10 cm H_2O could be accepted, which is a preferred strategy for its better effect of reversing hypercapnia.

To conclude, the strategy to ventilate patients using small tidal volume (7 ml/kg) plus 10 cm H_2O PEEP can effectively alleviate the hypercapnia without obvious adverse effects in retroperitoneal laparoscopic surgery. A point worth emphasizing is that only relatively healthy elderly patients (ASA I -II) were enrolled into our study and the ventilation strategy could just induce a certain extent decrease in $PaCO_2$ after pneumoperitoneum. In elderly patients with moderate to severe lung disease or perioperative severe hypercapnia, further studies are still needed to test the efficacy and safety of the forementioned strategy. Several impacting factors, such as preoperative status, operation time and insufflation pressure, should be carefully considered.

After 60 minutes of pneumoperitoneum, $P_{ET}CO_2$ and $PaCO_2$ became unmatched. However, at 20 minutes after the application of PEEP, their consistence restored and $P_{ET}CO_2$ - $PaCO_2$ correlation coefficient increased with the level of PEEP. The increase in $P_{ET}CO_2$ - $PaCO_2$ difference was more marked due to the impact of pneumoperitoneum, lateral clasp-knife position, and shunt in the lung. At this point, the further increase in ventilation frequency would shorten exhalation time and worsen the CO_2 expiration. The use of PEEP was a better choice to solve this problem. This strategy could effectively narrow the gap between $P_{ET}CO_2$ and $PaCO_2$, and restore their consistence. This effect was proportional to the level of PEEP in the range of 4-10 cm H_2O.

In conclusion, in elderly patients subject to retroperitoneal laparoscopic surgery for more than 1 hour, correlation and consistency between $PaCO_2$ and $TcPCO_2$ are higher compared to $P_{ET}CO_2$. Hence, $TcPCO_2$ can effectively predict $PaCO_2$ level. In addition, during this kind of surgery, the ventilation strategy using small tidal volume (7 ml/kg) plus 10 cm H_2O PEEP can be a safe and effective choice to treat pneumoperitoneum-induced hypercapnia, and restore the consistency between $P_{ET}CO_2$ and $PaCO_2$.

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