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Cardiopulmonary changes induced by retroperitoneal insufflation in healthy dogs in sternal recumbency

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Cardiopulmonary Changes Induced By Retroperitoneal Insufflation In Healthy Dogs In Sternal Recumbency

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Abstract

This study assessed the effects of retroperitoneal carbon dioxide (CO_2) insufflation on cardiopulmonary variables and intra-abdominal pressure (IAP) in mechanically ventilated dogs in sternal recumbency with the abdomen unsupported, following placement of a positioning kit and towels under the pectoral and pelvic regions. General anesthesia was induced in eight healthy adult male Beagles. A Swan-Ganz catheter was placed in the pulmonary artery via the jugular vein for cardiac output measurements. A Foley urethral catheter was placed to monitor trans-vesical IAP. A 10-mm balloon blunt-tip trocar was inserted into the retroperitoneal space. With a fixed respiratory rate and tidal volume by mechanical ventilation, insufflation pressure was sequentially increased from 0 to 10 mmHg in 5-mmHg increments, followed by desufflation. All variables were measured before insufflation, 5 min after the establishment of each insufflation pressure, and after desufflation. At 10 mmHg, IAP was nearly equal to insufflation pressure. Cardiopulmonary function was not compromised at any point, although the cardiac index (CI), heart rate, mean arterial pressure (MAP), and mean pulmonary arterial pressure increased within normal ranges. The end-tidal CO_2 concentration, partial pressure of arterial CO_2, and oxygen delivery index (DO_2I) increased, whereas the pH decreased at 10 mmHg. CI, MAP, and DO_2I did not recover to baseline after decompression. Thus, retroperitoneal CO_2 insufflation up to 10 mmHg is

well-tolerated by mechanically ventilated dogs positioned in sternal recumbency with the abdomen unsupported, although sympathetic changes may occur with an insufflation pressure increase.

Keywords: cardiac output, cardiopulmonary changes, dog, retroperitoneal insufflation.

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Table of contents

Ⅰ. INTRODUCTION

In human medicine, retroperitoneal laparoscopy has gained wide acceptance as a standard procedure for several surgeries ranging from excision of retroperitoneal organs to removal of ureteral calculi (Constantinides et al. 2012, Wu et al. 2012, He et al. 2016). Unlike the transperitoneal approach, retroperitoneal laparoscopy facilitates direct visualization of and access to target organs, such as the adrenal glands, kidneys, and ureters, thus preventing physical interference by abdominal organs during procedures. The cardiopulmonary effects of retroperitoneal pressure in humans have been investigated in studies that compared the hemodynamic effects of intraperitoneal and retroperitoneal insufflation. Overall, no deleterious cardiovascular effects have been identified up to an insufflation pressure of 25 mmHg; moreover, the intra-abdominal pressure (IAP) is reported to increase by a considerably smaller margin, presumably because the retroperitoneal space is a confined space (Chiu et al. 1995, Fernandez-Cruz et al. 1996, Giebler et al. 1996, Giebler et al. 2000, Callender et al. 2009). Similarly, other studies have shown that the impact of retroperitoneal insufflation on the ventilatory system is minimal, relative to that of transperitoneal insufflation (Sasagawa et al. 1999, Nadu et al. 2005, Lorenzo et al. 2006).

A previous study in dogs evaluated the retroperitoneal approach and working space by increasing retroperitoneal pressure

from 5 to 15 mmHg in 5-mmHg increments, with carbon dioxide (CO_2) instillation into the retroperitoneum in combination with pressure-dependent space distention (Jeong et al. 2016). To maximize the gravitational retraction of the intraperitoneal organs, the authors of that study adopted the sternal position with the abdomen unsupported. In another study, total retroperitoneoscopic adrenalectomy was experimentally performed at a pressure of 5 mmHg in healthy Beagle dogs (Ko et al. 2018). However, these canine studies involving retroperitoneal insufflation did not document the cardiopulmonary changes induced by different insufflation pressures in the sternal position with the abdomen unsupported (Jeong et al. 2016, Ko et al. 2018). The characteristic retroperitoneal space development pattern at a low insufflation pressure (≤15 mmHg) in dogs has not been observed in humans and pigs. In addition, previous hemodynamic studies in humans and other species involved evaluations at high insufflation pressures (15–30 mmHg) in a variety of positions, including the jackknife position and the lateral position with table flexion (Fernandez-Cruz et al. 1996, Giebler et al. 1996, Giebler et al. 2000, Lorenzo et al. 2006). Therefore, it can be inferred that different consequences might be observed in healthy dogs positioned in sternal recumbency with the abdomen unsupported.

Accordingly, the aim of the present study was to investigate the cardiopulmonary changes induced by different insufflation pressures during retroperitoneal insufflation in dogs positioned in sternal recumbency with the abdomen unsupported. The first

hypothesis was that retroperitoneal insufflation in this position would not have a negative impact on the cardiopulmonary system in healthy dogs. The second hypothesis was that IAP would increase concurrently with retroperitoneal insufflation because of distention of the retroperitoneal space.

Ⅱ. MATERIALS AND METHODS

Animals

Eight sexually intact, adult male Beagle dogs, aged 2.4 ± 0.9 years (mean ± standard deviation [SD]; range, 1.0 to 4.0 years) and weighing 10.2 ± 1.3 kg (mean ± SD; range, 8.8 to 11.7 kg), were included in this study. No preexisting diseases or cardiopulmonary abnormalities were identified in any of the dogs based on medical history, physical examination, hematological and biochemical profiling, and thoracic radiography prior to the study. Food, but not water, was withheld for 12 hr before premedication. The experimental protocol was approved by the Seoul National University Institutional Animal Care and Use Committee (SNU-181219-1).

Anesthesia

For each experiment, a 22-gauge catheter was aseptically placed in the cephalic vein and lactated Ringer's solution was intravenously administered at a rate of 5 m*l*/kg/hr. Following premedication with intravenous (IV) tramadol (5 mg/kg), subcutaneous carprofen (4.4 mg/kg), and IV acepromazine (0.01

mg/kg), anesthesia was induced with alfaxalone (5 mg/kg IV to effect; Alfaxan®, Jurox Inc., Kansas City, MO, U.S.A.). An appropriately sized endotracheal tube was placed, and the dogs were connected to a rebreathing anesthetic circuit. Anesthesia was maintained with isoflurane (Ifrane, Hana Pharm, Hwaseong, Republic of Korea) delivered in 100% oxygen at an end-tidal concentration of 1.8% - 1.9%. The dogs were allowed to breath spontaneously until the end of the instrumentation period.

Instrumentation and positioning

The dogs were positioned in lateral recumbency on a table, after which the hair over the right jugular vein, dorsal pedal artery, and caudal aspect of the hemithorax and lateral abdomen was adequately clipped. The animals were subsequently moved to the operating room and positioned in lateral recumbency for aseptic scrubbing at the trocar and catheter insertion sites. An arterial catheter was placed in the dorsal pedal artery for arterial blood sampling and continuous invasive blood pressure monitoring. In addition, a 6-Fr, 12-cm introducer sheath (FAST-CATH hemostasis introducers, St. Jude Medical, Minnetonka, MN, U.S.A.) was simultaneously placed in the right jugular vein via the Seldinger technique. Three pressure transducers (Transpac IV Monitoring Kit, ICU Medical Inc., San Clemente, CA, U.S.A.), calibrated against mercury manometer prior to each study, were connected to the arterial catheter, as well as the distal and proximal ports of the

Swan - Ganz catheter, through saline-filled, noncompliant tubing. The pressure transducers were zeroed at the level of the sternum. A 5-Fr, 75-cm Swan - Ganz catheter (Edwards Lifesciences Corp., Irvine, CA, U.S.A.) was advanced through the sheath and placed in the pulmonary artery. The final position of the catheter tip was confirmed by characteristic pressure waveforms corresponding to the right ventricle and the pulmonary arterial occlusion pressure (PAOP) on inflation of the balloon located at the catheter tip. A multiparameter monitor (FI/Carescape Monitor B650, GE Healthcare, Helsinki, Finland)—equipped with an agent analyzer, a side-stream capnograph, a pulse oximeter, and a spirometry module—displayed the heart rate (HR), respiratory rate (RR), tidal volume (TV), end-tidal carbon dioxide concentration ($ETCO_2$), end-tidal isoflurane concentration (ET_{ISO}), mean arterial pressure (MAP), and central venous pressure (CVP). Hemoglobin (Hb) saturation and electrocardiograms were also monitored during general anesthesia. The thermistor on the Swan - Ganz catheter measured the core body temperature (BT), whereas the distal port of this catheter measured the mean pulmonary arterial pressure (PAP) and PAOP via another electronic monitor (Datex-Ohmeda S/5, GE Healthcare, Helsinki, Finland) with a cardiac output module (Datex-Ohmeda M-COP, GE Healthcare). During anesthesia, BT was maintained between 36°C and 38°C using warm water blankets (HTP-1500, Adroit Medical Systems, Loudon, TN, U.S.A.) and a warm air unit (Bair Hugger warming unit, model 505, Augustine Medical, Eden Prairie, MN, U.S.A.).

An 8-Fr Foley catheter (Foley catheter, Yushin Medical Corporation, Seoul, Republic of Korea) was placed to maintain an empty bladder during general anesthesia and for trans-vesical measurement of IAP, in accordance with the Malbrain technique used in previous veterinary studies (Way and Monnet 2014, Jang et al. 2018). For each pressure measurement, the urinary bladder was vacated and filled with 1 ml/kg of 0.9% sodium chloride (Way and Monnet 2014).

For repositioning of the dogs in sternal recumbency with the abdomen unsupported (Naan et al. 2013, Jeong et al. 2016), a commercial patient positioning kit (Vacu-positioner kit, Shor-line, Kansas City, KS, U.S.A.) was used and supplemental towels were placed under the pectoral and pelvic regions to ensure that the abdomen freely hung above the table (Fig. 1). For further position security, adhesive tape was minimally applied as necessary around the thorax and pelvic region. The three blood pressure transducers and the intraperitoneal pressure transducer were zeroed at the level of the right atrium and pubic symphysis, respectively.

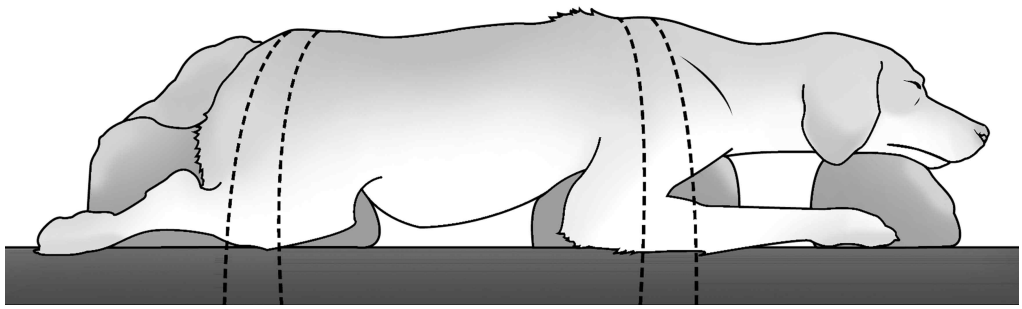

Fig. 1. Schematic presentation of a dog in sternal recumbency on the surgical table with abdomen unsupported by towels and positioning kit under the pectoral and pelvic areas.

For cardiac output measurement using the thermodilution method, 5% dextrose solution at a temperature of 0–4°C was rapidly and manually administered as a 5-m*l* injectate into the proximal port of the Swan–Ganz catheter at the end of expiration (Creedon and Davis 2012). At each time point, three values with <10% variations among five consecutive measurements were chosen, and the average of these values was determined as the cardiac output. Arterial blood from the dorsal pedal artery and mixed venous blood from the distal port of the Swan–Ganz catheter were anaerobically collected in heparinized syringes at each time point. A blood gas analyzer (ABL-80 Flex, Radiometer America, Westlake, OH, U.S.A.) was used to measure the pH value, Hb concentration, partial pressure of carbon dioxide ($PaCO_2$), partial pressure of arterial oxygen (PaO_2), bicarbonate (HCO_3^-) level, and base excess (BE) in these samples. Standard formulae (Steve Haskins 2005) were used to acquire all derivative parameters, including the cardiac index (CI), stroke volume index (SI), systemic vascular resistance index (SVRI), pulmonary vascular resistance index (PVRI), dead space (DS), arterial oxygen content (CaO_2), oxygen delivery index (DO_2I), oxygen consumption index (VO_2I), and oxygen extraction ratio (OER).

Retroperitoneal trocar placement

In accordance with the retroperitoneal access technique for dogs (Jeong et al. 2016, Ko et al. 2018), a 1.5-cm vertical incision site was created at the level of the second lumbar vertebrae on the

right side in four dogs and the level of the third lumbar vertebrae on the left side in the other four dogs. Using Metzenbaum scissors in the dominant hand, with the index finger of the nondominant hand as a guide, blunt dissection was performed to the retroperitoneal space below the level of the epaxial muscle. When the dorsal margin of the kidney could be palpated with the index finger, a 10-mm, inflatable balloon blunt-tip trocar with an adjustable sleeve (OMS-T10BT, Covidien, Dublin, Ireland) was placed into the retroperitoneal space. The balloon was inflated to prevent leakage of the insufflated gas and dislocation of the placed trocar. Subsequently, a 5-mm 0° telescope (Karl Stortz, Tuttlingen, Germany) was advanced into the port to confirm the trocar tip within the retroperitoneal space through visualization of loose connective tissue mesh (Jeong et al. 2016). The telescope was removed after confirmation.

Experimental procedure

Mechanical ventilation was initiated after instrumentation was complete. Respiratory paralysis to facilitate ventilation was induced by atracurium injection (0.2 mg/kg IV as the initial loading dose and 0.1 mg/kg IV as needed). $ETCO_2$ was maintained between 35 and 40 mmHg using a volume-cycled ventilator (Vent-V, Royal Medical Co., Ltd., Seoul, Republic of Korea) with the following settings: RR, 15 - 20 breaths per minute; TV, 15 ml/kg; inspiratory:expiratory ratio, 1:2; and peak airway pressure (P_{aw}), <15 cmH_2O. When the $ETCO_2$ of each experiment was >40 mmHg before commencement of baseline

data acquisition, I controlled the respiratory rate and maintained the tidal volume at 15 ml/kg with a maximum peak air way pressure of <15 cmH_2O until the values were equilibrated. Dogs were then well ventilated and the target $ETCO_2$ of 35 to 40 mmHg was soon achieved. For each dog, the respiratory settings were fixed when $ETCO_2$ was within the target range and the systemic blood pressure was stable. The dogs were stabilized for 15 min. After the equilibration period, baseline values were measured and an electronic CO_2 insufflator (Karl Stortz, Tuttlingen, Germany) was set to deliver CO_2 at a rate of 1.0 *l*/min. The mean retroperitoneal insufflation pressure was sequentially increased from 0 to 10 mmHg in 5-mmHg increments. Cardiopulmonary parameters and IAP were measured, in conjunction with acquisition of blood samples for arterial and mixed venous blood gas analysis, 5 min after the establishment of each predefined pressure. Following measurements at 10 mmHg, the inflatable balloon trocar was maintained open and the abdomen was gently compressed so that the infused gas could be purged out of the retroperitoneal space while maintaining sternal recumbency with unsupported abdomen. Cardiopulmonary parameters were measured again at 5 min after deflation.

Postoperative care and pain management

When the inflatable balloon trocar, pulmonary and peripheral arterial catheters, and introducer had been removed, incisions at the trocar and puncture sites were closed in a routine manner. Firm

pressure was applied over the catheterized sites on the neck and hind limb to ensure hemostasis and prevent hematoma. Following the recovery of spontaneous breathing, IV neostigmine (0.04 mg/kg) and atropine (0.04 mg/kg) were administered to reverse neuromuscular paralysis. The dogs were extubated when a repetitive swallowing reflex was observed and were closely monitored after extubation. For pain control, oral analgesics (tramadol 5 mg/kg, carprofen 2.2 mg/kg twice daily) were administered for 5 days. One investigator (DMS) used the Colorado State University Veterinary Medical Center Canine Acute Pain Scale (Gaynor and Muir 2015) to assess postoperative pain at 1, 2, 4, 6, 12, and 24 hr after tracheal extubation and once daily for the next 5 days. A pain score ≥ 2 was considered an indication for rescue analgesia. Survey thoracic radiography was performed to check for pneumomediastinum.

Statistical analysis

The normality of data distribution in terms of the pressures and approach side (right, left) was assessed using the Shapiro - Wilk test. Repeated-measures one-way analysis of variance (ANOVA) and the Mann - Whitney U test were used to compare differences in normally distributed and non-normally distributed values at each pressure, respectively, between right and left sides. I have found that the side did not affect cardiopulmonary values; therefore, this factor was excluded from further analysis. For parametric variables, repeated measures one-way ANOVA was used for comparisons among

different insufflation pressures. When a significant effect was observed, values were compared using post hoc tests with Bonferroni correction. For nonparametric variables, Friedman repeated measures ANOVA was performed with post hoc pairwise Dunn - Bonferroni adjustment to identify significant differences among insufflation pressures. Based on the results of normality test at each insufflation pressure, all parametric values are displayed as mean ± SD. The values of mPAP, PAOP, $ETCO_2$ and DO_2I were non-parametric; thus, these variables are presented as median [range]. All statistical analyses were performed using a commercial software package (IBM SPSS statistics version 22, IBM, Armonk, NY, U.S.A.). A P-value < .05 was considered statistically significant.

Ⅲ . RESULTS

All surgical procedures were completed without any complications, and no additional doses of atracurium were used during the study. All dogs exhibited uneventful recovery from general anesthesia within <150 min. None of the dogs showed pneumomediastinum in survey thoracic radiography.

All data were acquired for all dogs. As mentioned above, the approach side did not affect the variables; therefore, further analyses excluded this aspect. The results are presented in Tables 1 and 2. Mean BT ranged from 36.8°C to 37.0°C and ET_{ISO} was constant at 1.7% throughout the study. The prescribed TV was maintained at 15 m*l*/kg, while the average RR was fixed at 18 ± 2 breaths per min throughout the measurement period. Consequently, mean minute ventilation remained virtually unchanged from the baseline value, at 2.74 L/min during the study period. IAP remained unchanged at 5 mmHg and exhibited a significant increase at 10 mmHg (9.3 ± 1.0 mmHg at 10 mmHg versus 5.1 ± 0.6 mmHg at baseline; $P < .001$). At 5 mmHg, none of the cardiovascular variables other than MAP ($P = .037$) showed a significant change relative to baseline. At 10 mmHg, CI, HR, MAP, mPAP, and PAOP were significantly higher than their respective baseline values ($P = .008$, $P = .01$, $P = .004$, $P < .001$, $P = .006$, respectively). Among these variables, CI, MAP, and mPAP ($P = .006$, $P = .021$, $P = .012$, respectively) remained elevated

after desufflation, with significant differences from their respective baseline values. SVRI, PVRI, and SI showed no significant changes during and after insufflation.

With regard to the pulmonary variables, no significant changes were observed at a pressure of 5 mmHg. At 10 mmHg, $ETCO_2$, $PaCO_2$, and DO_2I exhibited significant increases (P = .003, P = .016, P < .001, respectively), while the pH exhibited a significant decrease (P = 0.042). DO_2I remained high after desufflation (P = .012). The other parameters—namely PaO_2, Hb, CaO_2, VO_2I, OER, P_{aw}, systemic respiratory compliance, and dead space—showed no significant changes during and after insufflation.

Table 1. Relationship between insufflation pressure and cardiovascular variables during retroperitoneal insufflation in healthy dogs (n = 8) positioned in sternal recumbency with the abdomen unsupported

Parameter	Pre-insufflation	5 mmHg	10 mmHg	Desufflation
ET_{ISO}(%)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
IAP (mmHg)	5.1 ± 0.6	5.0 ± 1.2	9.3 ± 1.0 a)	5.4 ± 0.9
CI (L/min/m^2)	4.1 ± 0.8	4.7 ± 0.7	5.5 ± 0.8 a)	5.3 ± 0.6 a)
SI (mL/kg)	1.7 ± 0.4	1.9 ± 0.3	2.1 ± 0.4	2.0 ± 0.3
HR (beats/min)	115 ± 9	120 ± 10	127 ± 11a)	126 ± 15
MAP (mmHg)	71 ± 9	80 ± 11 a)	94 ± 10 a)	83 ± 12 a)
CVP (mmHg)	2.6 ±1.3	2.6 ± 2.1	3.4 ± 1.5	2.8 ± 0.7
mPAP (mmHg)	14.5 [12.0-15.0]	15.0 [12.0-19.0]	17.0 [14.0-21.0] a)	18.0 [13.0-20.0] a)
PAOP (mmHg)	6.5 [6.0-9.0]	7.5 [6.0-11.0]	9.0 [6.0-12.0] a)	8.0 [5.0-10.0]
SVRI (dynes·sec/cm^5·m^2)	1369 ± 237	1329 ± 241	1325 ± 108	1219 ± 163
PVRI (dynes·sec/cm^5·m^2	144 ± 46	128 ± 45	123 ± 41	135 ± 40
BT (°C)	37.0 ± 0.7	36.9 ± 0.6	37.0 ± 0.6	36.8 ± 0.4

Data are expressed as mean ± standard deviation or median [range]. a) Within a row, values significantly differ ($p < 0.05$) from the respective preinsufflation values. BT, body temperature; CI, cardiac index; CVP, central venous pressure; ETISO, end-tidal isoflurane concentration; HR, heart rate; IAP, intra-abdominal pressure; MAP, mean arterial pressure; mPAP, mean pulmonary arterial pressure; PAOP, pulmonary arterial occlusion pressure; PVRI, pulmonary vascular resistance index; SD, standard deviation; SI, stroke volume index; SVRI, systemic vascular resistance index

Table 2. Relationship between insufflation pressure and pulmonary variables during retroperitoneal insufflation in healthy dogs (n = 8) positioned in sternal recumbency with the abdomen unsupported

Parameter	Pre-insufflation	5 mmHg	10 mmHg	Desufflation
P_{aw}(cmH_2O)	11.8 ± 1.8	11.9 ± 1.7	12.4 ± 1.8	11.6 ± 1.8
CL (mL/cm H_2O)	17.9 ± 3.0	17.6 ± 3.1	16.5 ± 3.6	18.5 ± 3.8
PaO_2(mmHg)	543 ± 54	574 ± 54	578 ± 47	583 ± 33
$ETCO_2$(mmHg)	37.0 [35 - 40]	36.5 [35 - 43.5]	42 [38 - 47] a)	39.5 [36 - 43.8]
$PaCO_2$(mmHg)	43.8 ± 3.9	44.5 ± 7.0	48.7 ± 5.6a)	46.9 ± 6.0
MV (L/min)	2.74 ± 0.31	2.74 ± 0.31	2.72 ± 0.30	2.77 ± 0.32
Dead space	14.0 ± 6.5	12.7 ± 7.0	12.6 ± 5.1	14.1 ± 4.5
Blood pH	7.32 ± 0.03	7.32 ± 0.05	7.29 ± 0.04 a)	7.3 ± 0.04
HCO_3^-(mmol/L)	21.8 ± 1.4	22.2 ± 1.7	22.6 ± 1.1	22.3 ± 1.31
BE (mmol/L)	−3.6 ± 1.1	−3.5 ± 1.4	−3.6 ± 1.0	−3.8 ± 1.0
aHb (g/dL)	10.4 ± 1.5	9.8 ± 1.3	10.3 ± 1.2	10.3 ± 1.4
CaO_2(ml/dL)	16.0 ± 2.0	15.3 ± 1.7	16.0 ± 1.6	16.0 ± 1.9
DO_2I (ml/min/m^2)	644 [528 - 743]	694 [666 - 744]	838 [778 - 986] a)	805 [763 - 864] a)
VO_2I (ml/min/m^2)	77 ± 29	55 ± 28	63 ± 20	70 ± 13
OER (%)	11.8 ± 3.4	7.5 ± 3.7	7.3 ± 2.4	8.2 ± 1.5

Data are expressed as mean ± standard deviation or median [range]. a) Within a row, values significantly differ ($p < .05$) from the respective preinsufflation values. BE, base excess; CaO2, arterial oxygen content; CL, systemic respiratory compliance; DO2I, oxygen delivery; ETISO, end-tidal isoflurane concentration; ETCO2, end-tidal carbon dioxide; Hb, hemoglobin; HCO3−, bicarbonate concentration; MV, minute ventilation; OER, oxygen extraction ratio; PaCO2, partial pressure of arterial carbon dioxide; PaO2, partial pressure of arterial oxygen; Paw, peak airway pressure; RR, respiratory rate; VO2I, oxygen consumptionb) Within a row, significant differences ($p < .05$) from the previous values

Ⅳ. DISCUSSION

Both hypotheses in the present study were accepted; a retroperitoneal insufflation pressure of ≤10 mmHg did not compromise cardiopulmonary function in mechanically ventilated healthy dogs positioned in sternal recumbency with the abdomen unsupported. Although the hemodynamic changes were observed during the retroperitoneal insufflation, all values remained within normal reference ranges. Insufflation at 10 mmHg increased the transvesically measured IAP to a near-equivalent value. The mechanical impact on the pulmonary system was minimal, with an increase in $PaCO_2$ observed with an increase in retroperitoneal insufflation pressure.

I have found that IAP at baseline and that at an insufflation pressure of 5 mmHg were nearly the same, whereas IAP at 10 mmHg was significantly elevated. According to previous studies, the normal IAP measured using the trans-vesical method ranges from 0 to 7 mmHg in dogs (Smith and Sande 2012, Jang et al. 2018), which was similar to the baseline value of IAP in this study. Changes in both IAP and retroperitoneal pressure returned to baseline after gas removal. In humans, retroperitoneal insufflation up to 15 mmHg resulted in no change in trans-vesical IAP, with higher pressures (20 - 24 mmHg) inducing a small pressure increase (3.0 mmHg) from baseline (Giebler et al. 2000). Similarly, IAP increased from 0 mmHg to 3 mmHg during retroperitoneal insufflation at 15 mmHg in pigs

(Chiu et al. 1995). The contrasting findings in humans and pigs could be attributed to the retroperitoneal fascial compartmentalization, which restrict distention of the retroperitoneal space by simple CO_2 insufflation tracking along the fascial planes and, presumably, prevent pressure transmission from the retroperitoneal cavity. Indeed, surgeons require special balloon devices for initial distention of this potential space (Keeley and Tolley 1999, Giebler et al. 2000, Callender et al. 2009, Fraser et al. 2018). However, the canine retroperitoneum does not have fascial compartments, does not work as a pressure buffer, and seems to be more compliable, thus enabling CO_2 insufflation at pressures $\leq$15 mmHg to create a potential space in a pressure-dependent manner (Johnston 1990, Jeong et al. 2016).

In the present study, an insignificant increase in SI combined with a significant increase in HR may have raised the CI at an insufflation pressure of 10 mmHg and after gas removal. During the study, HR, SI, MAP, and mPAP exhibited an increasing trend with an increase in retroperitoneal pressure. Although changes in cardiovascular variables initiated at a pressure of 5 mmHg, IAP did not change. Moreover, CI, MAP and mPAP remained significantly elevated after decompression, with insignificant increases in SI, HR, and recovery of IAP to baseline. Thus, mechanical impact of retroperitoneal insufflation seemed limited.

Another possible etiology could be sympathetic activity associated with the pain response or hypercarbia (Rasmussen et al.

1978, Marcovich et al. 2001, Gerges et al. 2006). Nociceptive stimulation during laparoscopy is thought to be related to surgical manipulation of the visceral organs or stretching of the abdominal muscles (Sato et al. 2000, Park and Okano 2015, Scott et al. 2018). Although the visceral organs were not manipulated throughout the study, retroperitoneal insufflation in dogs causes abdominal distention in terms of height and width in healthy dogs with increasing pressure (Jeong et al. 2016), presumably, stimulating the sympathetic system. A study in humans also showed that an increasing retroperitoneal insufflation pressure without surgical intervention may have caused sympathetic stimulation, with an increase in HR, and MAP but they considered mild hypercarbia and light depth of anesthesia rather than abdominal distention as a source of sympathetic stimulation (Giebler et al. 1996). In the present study, the ET_{ISO} value remained unchanged throughout the measurement period. Moreover, during instrumentation period, surgical stress including catheterization and trocar placement did not induce pain response in terms of increases in HR, MAP, and RR in the study dogs. However, the inadequate depth of anesthesia during insufflation remains problematic due to the lack of opioid analgesics and the fixed level of inhalant anesthesia.

Notably, $PaCO_2$ in our dogs increased by only 0.7 mmHg at a lower pressure, whereas it increased by approximately 5 mmHg at a higher pressure. Another canine study involving laparoscopy documented comparable increases in $PaCO_2$ with no increase in HR

(Ivankovich et al. 1975), whereas other studies in dogs and cats attributed an increase in HR to reflex tachycardia for the compensation of a decreased stroke volume and maintenance of the cardiac output, which was not observed in the current study. (Duke et al. 1996, Shih et al. 2015).

Sympathetic tone contributes to vessel constriction; however, a relevant increase in the vascular resistance was not observed in the present study, probably because the vascular tone is determined by a multitude of factors such as the insufflation pressure, type of anesthetic gas, $PaCO_2$ level, and neuro-humoral regulation during laparoscopy (Rasmussen et al. 1978, Kaklamanos et al. 2000). Previous studies in humans have reported varied responses in terms of the systemic and pulmonary vascular tones during retroperitoneal insufflation (Giebler et al. 1996, Giebler et al. 1997). I also identified significant increases in PAOP. This change reflected a centrally redistributed blood volume or an increased intrathoracic pressure transmitted from the retroperitoneal space. Both factors may have contributed to changes in our experiment, given that insignificant increases in SI and P_{aw} were confirmed in all dogs. The findings in other human studies (Giebler et al. 1996, Giebler et al. 2000) showed that increases in CVP and PAOP were associated with increased venous return and an increased physical impact of insufflation on ventilation.

Regarding respiratry function, I fixed the ventilator settings for RR and TV throughout the measurement period to determine the mechanical impact of insufflation on the respiratory function and maintain normocarbia before measurements. Although trends regarding increased P_{aw} and decreased systemic lung compliance existed during insufflation, both of which were reversible after decompression, the magnitude of pressure transmission in the study dogs seemed clinically negligible and was not statistically significant. In contrast, P_{aw} increased significantly in humans at pressures (e.g., 12–15 mmHg) achieved with fixed ventilator settings; this was thought to result from anatomical sharing of the cranial border of the retroperitoneal space with the dorsal border of the diaphragm (Nadu et al. 2005, Lorenzo et al. 2006). Minute ventilation was constant, with no increase in DS and VO_2I throughout the study period. Therefore, the trend for a $PaCO_2$ increase with respiratory acidosis mainly originated from direct absorption through the retroperitoneum. Considering that CO_2 absorption in a body cavity is determined by its diffusibility and the perfusion capability of the cavity walls (Lister et al. 1994, Giebler et al. 1996), the insufflation pressure-dependent increase in $PaCO_2$ can be attributed to enlargement of the retroperitoneal space, which increases the absorptive surface area. Oxygenation was well maintained because PaO_2 and DO_2I did not decrease at any point. Alterations in DO_2I paralleled the changes in CI at a pressure of 10 mmHg and after desufflation. As DO_2I is a

product of CI and CaO_2, a significant increase in CI increased DO_2I because CaO_2 was not affected by any insufflation pressure.

The cardiopulmonary effects of retroperitoneal insufflation were not influenced by the approach side (left and right), although these findings may have resulted from type 2 statistical error due to the small number of dogs included. However, recruiting more dogs in each group is not likely to induce clinically different physiological consequences based on the approach side because the dogs were positioned in sternal rather than lateral recumbency. A previous canine study showed that retroperitoneal space volumes were not significantly different with right and left approaches at pressures of 5 and 10 mmHg (Jeong et al. 2016). A study in humans reported that the approach side did not affect the hemodynamic consequences and resulted in subtle differences without clinical relevance (Giebler et al. 2000).

This study had several limitations. First, the sequence of insufflation pressures could not be randomized because insufflation enlarges the retroperitoneal space, and a high pressure followed by a low pressure may affect the cardiopulmonary results. Second, the equilibration period for each insufflation pressure was only 5 min; therefore, the cardiopulmonary effects at a fixed retroperitoneal insufflation pressure for a prolonged period would be different. Finally, all dogs included in this study had no cardiopulmonary diseases or other pathologies. Thus, veterinarians must exercise

caution when extrapolating the study findings to dogs with cardiopulmonary diseases.

In summary, these findings suggest that retroperitoneal insufflation up to 10 mmHg does not induce detrimental cardiopulmonary effects and is well-tolerated in mechanically ventilated healthy dogs positioned in sternal recumbency with the abdomen unsupported. Cardiostimulatory activity may be observed during retroperitoneal insufflation; this becomes more evident at higher pressures. Therefore, maintenance of a low retroperitoneal pressure (5 mmHg) could aid in stabilization of the cardiovascular system, and meticulous intraoperative management of anesthesia during insufflation may be necessary with higher pressure (10 mmHg). Further studies should elaborate on the causes of sympathetic stimulation during retroperitoneal insufflation in sternal recumbency with the abdomen unsupported.

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Ⅵ. Abstract in Korean

개에서의 이산화탄소 후복강 주입시 발생하는 심폐기능의 변화

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본 연구는 복부 지지가 없는 흉와 자세를 한 개에서 이산화탄소의 후복강 주입 시 발생하는 심폐기능의 변화에 대하여 평가한 연구이다. 8 마리의 건강한 실험 비글견에서 전신마취가 진행되었다. 심장 박출량 측정과 혼합 정맥혈의 채취를 위한 폐동맥 카

테터를 경정맥을 거쳐 폐동맥에 장착하였으며 경방광 방식으로 복압측정을 위한 요도카테터를 장착하였다. 분시 환기량을 고정한 후, 후복강 내의 이산화탄소 압력을 0, 5, 10 mmHg로 차례로 증가시켰으며, 마지막에는 배기하였다. 모든 심폐기능 변수들은 이산화탄소 주입 전, 주입 후 각 압력이 유도된 지 5분 후에 측정되었다. 10 mmHg에서, 경방광 복압은 insufflation 압력과 거의 동일하였다. 심폐기능은 실험기간 동안 악화되지는 않았으나, 심장박출지수, 평균혈압 그리고 폐동맥압이 정상범위 내에서 증가하였다. 동일한 압력에서, 호기말 이산화탄소 분압, 동맥내 이산화탄소 분압, 그리고 산소전달지수는 증가한 반면에, pH는 감소하였다. 심장박출지수, 평균혈압 그리고 산소전달지수는 배기 후에도 실험 전의 수치로 회복되지 않았다. 결론적으로, 기계적으로 환기가 되는 흉와 자세의 개에서 후복강 내 이산화탄소 주입은 이상을 유발하지는 않지만, 후복강 압력이 증가하면 교감신경의 흥분이 유발될 수 있다.

주요어 : 후복강 이산화탄소 주입, 심박출량, 심혈관계 변화, 개

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