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Original contribution

Comparison of volume-controlled and pressure-controlled ventilation in steep Trendelenburg position for robot-assisted laparoscopic radical prostatectomy☆

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Abstract
Study Objective: To compare the effects of volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) on respiratory mechanics and hemodynamics in steep Trendelenburg position.
Design: Prospective, randomized clinical trial.
Setting: University hospital.
Patients: 34 ASA physical status 1 and 2 patients undergoing RLRP.
Interventions: Patients were randomly allocated to either the VCV (n = 17) or the PCV group (n = 17). After induction of anesthesia, each patient's lungs were ventilated in constant-flow VCV mode with 50% O_2 and tidal volume of 8 mL/kg; a pulmonary artery catheter was then inserted. After establishment of 30° Trendelenburg position and pneumoperitoneum, VCV mode was switched to PCV mode in the PCV group.
Measurements: Respiratory and hemodynamic variables were measured at baseline supine position (T1), post-Trendelenburg and pneumoperitoneum 60 minutes (T2) and 120 minutes (T3), and return to baseline after skin closure (T4).
Main Results: The PCV group had lower peak airway pressure (AP_{peak}) and greater dynamic compliance (C_{dyn}) than the VCV group at T2 and T3 ($P < 0.05$). However, no other variables differed between the groups. Pulmonary arterial pressure and central venous pressure increased at T2 and T3 ($P < 0.05$). Cardiac output and right ventricular ejection fraction were unchanged in both groups.
Conclusions: PCV offered greater C_{dyn} and lower AP_{peak} than VCV, but no advantages over VCV in respiratory mechanics or hemodynamics.

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1. Introduction

Since the introduction of the computer-enhanced robotic surgical system in 2001, robot-assisted laparoscopic radical prostatectomy (RLRP) has been used frequently in the treatment of prostate cancer. RLRP offers advantages over conventional surgery such as sparing nerves, shorter hospital stay, reduced blood loss, and less postoperative pain [1,2]. However, to maximize the surgical visual field, RLRP usually requires that the patient be placed in a steep Trendelenburg position, which results in significantly increased airway pressure [3].

Volume-controlled ventilation (VCV) has been widely used as a positive-pressure ventilation (PPV) method during anesthesia, but this method does increase airway pressure during Trendelenburg position and pneumoperitoneum. On the other hand, pressure-controlled ventilation (PCV) not only decreased peak airway pressure (AP_{peak}), it also improved arterial oxygenation in patients at risk of barotrauma, such as those in respiratory failure or receiving one-lung ventilation. It provided high initial flow rates that afforded more rapid and uniform alveolar inflation [4-6].

The aim of this study was to investigate whether PCV has any advantages over VCV regarding respiratory mechanics and hemodynamics in patients undergoing RLRP.

2. Materials and methods

After approval from the Institutional Review Board of Yonsei University College of Medicine, written, informed consent, including insertion of radial and pulmonary artery catheters, was obtained from 34 ASA physical status 1 and 2 patients undergoing RLRP. Patients were randomized to the VCV group or PCV group according to a table of random numbers. Patients with a history of myocardial infarction, valvular heart disease, chronic obstructive or restrictive pulmonary disease, heavy smoking, neurological disease, renal insufficiency, or who had a body mass index (BMI) > 31 kg/m^2 were excluded from the study.

Patients were premedicated with midazolam 0.05 mg/kg intramuscularly one hour before arrival at the operating room (OR). In the OR, glycopyrrolate 0.1 mg was given intravenously (IV) and standard monitoring devices were applied. Anesthesia was induced with propofol 1.5 mg/kg, remifentanil 1.0 μg/kg, and rocuronium 0.9 mg/kg. After induction of anesthesia and intubation, the patient's lungs were ventilated in constant-flow VCV mode by a Primus Ventilator (Dräger Medical, Lübeck, Germany). Ventilator settings were tidal volume (V_T) 8 mL/kg, inspiratory/expiratory (I/E) ratio 1:2, inspired oxygen concentration (FIO_2) 0.5 with air, and 2.0 L/min of inspiratory fresh gas flow. End-inspiratory pause and positive end-expiratory pressure (PEEP) were not used. Respiratory rate (RR) was adjusted to maintain an end-tidal CO_2 pressure ($P_{ET}CO_2$) of 38 ± 2 mmHg. Anesthesia was maintained with sevoflurane 1.0 vol% to 2.0 vol%, remifentanil 0.1 - 0.3 μg/kg/min, and rocuronium 5 to 10 μg/kg/min. A 20-gauge (G) radial artery catheter was inserted, and a thermodilutional pulmonary artery catheter (PAC; Swan-Ganz CCOmbo CCO/SvO_2; Edwards Lifesciences LLC, Irvine, CA, USA) was inserted into the right internal jugular vein. A forced-air warming system (Bair-Hugger; Arizant, Inc., Eden Prairie, MN, USA) maintained body temperature at 36.0° - 37.0°C.

Twenty minutes after patients underwent induction of anesthesia in the supine position with VCV (time T1, baseline), arterial O_2 pressure (PaO_2), arterial CO_2 pressure ($PaCO_2$), arterial O_2 content (CaO_2), and mixed venous O_2 content (CvO_2) were measured by arterial and mixed venous blood sampling in both groups. At the same time, hemodynamic variables, including heart rate (HR), central venous pressure (CVP), mean arterial pressure (MAP), mean pulmonary arterial pressure (MPAP), pulmonary capillary wedge pressure (PCWP), cardiac index (CI), right ventricular ejection fraction (RVEF), right ventricular end-diastolic volume index (RVEDVI), and respiratory variables, including RR, AP_{peak}, mean airway pressure (AP_{mean}), and $P_{ET}CO_2$, were recorded.

Carbon dioxide pneumoperitoneum was induced with 15 ± 5 mmHg of intraabdominal pressure using the da Vinci Robot Surgical System (Intuitive Surgical, Sunnyvale, CA, USA), and then 30° Trendelenburg position was established. In the VCV group, the ventilator setting was continued throughout the study; in the PCV group, PCV mode was chosen to achieve V_T 8 mL/kg, with RR was adjusted to maintain $P_{ET}CO_2$ 38 ± 2 mmHg. Inspired oxygen concentration, I/E ratio, and V_T were held constant throughout the study in both groups. At 60 minutes and 120 minutes after the establishment of 30° Trendelenburg position and pneumoperitoneum, all the measurements were repeated. Immediately after the surgical specimen was removed from the abdominal cavity, PCV mode was changed to VCV mode while the CO_2 was removed; the patient was returned to the supine position. At skin closure, all the measurements were repeated in both groups. The pressure transducers were located at the level of the right atrium during all phases of the study and were recalibrated after each position change. Arterial and mixed venous blood samples were analyzed with an automated blood gas analyzer (Stat Profile CCX; Nova Biomedical, Waltham, MA, USA).

Dynamic compliance (Cdyn) was calculated with the following equation: $C_{dyn} = V_T / \left(AP_{peak} - PEEP\right)$. Physiologic dead space (V_d/V_t) was calculated according to the Hardman and Aitkenhead equation: $V_d / V_t = 1.14 \ (PaCO_2 - P_{ET}CO_2) / PaCO_2 - 0.005$ [7]. Intrapulmonary shunt fraction (Q_s/Q_t) was determined using the formula: $Qs / Qt = (CcO_2 - CaO_2) / (CcO_2 - CvO_2)$, where CcO_2 = capillary O_2 content calculated assuming that pulmonary capillary O_2 partial pressure is equal to alveolar O_2 partial pressure.