

# The Effect of Pressure Controlled Ventilation on Pulmonary Mechanics in Prone Patients Undergoing Elective Spine Surgeries: Comparative Study with Volume Controlled Ventilation

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## Abstract

**Background:** As patients turned into prone position experienced more decrease in lung compliance than those on supine position, this prospective, randomized study was designed to compare the effect of PCV and volume-controlled ventilation (VCV) on lung mechanics and hemodynamics in the prone position using the Wilson frame during elective lumbar spine surgery.

**Patients and Methods:** Sixty patients scheduled for elective lumbar spine surgery were randomly allocated to receive mechanical ventilation using either the VCV (n=30) or PCV (n=30) mode. Respiratory variables (peak airway pressure, mean airway pressure, shunt fraction, alveolar-arterial oxygen gradient). Dynamic compliance (C<sub>dyn</sub>) of the respiratory system was calculated as VT/ (P<sub>peak</sub>-PEEP). The alveolar dead space-to-tidal volume ratio (VD/VT) will be estimated using the Hardman and Aitkenhead equation:  $VD/VT = 1.135 - (PaCO_2 - ET/CO_2) / (PaCO_2 - 0.005)$ .

**Results:** The P<sub>peak</sub> in the PCV group was lower than that in the VCV group throughout the study period (p-value=0.961 and 0.0109 at supine position and prone position, respectively) and was increased at prone position compared with supine position in both groups. C<sub>dyn</sub> was decreased from supine to prone position in both groups. However, the C<sub>dyn</sub> in the PCV group was higher than that in the VCV group during the study period however it is only statistically significant after 1.5 and 2hrs. The arterial oxygen tension was comparable between the 2 groups during the study period.

**Conclusions:** PCV provides lower P<sub>peak</sub> compared with VCV when the ventilator is set to deliver the same tidal volume and variable respiratory rate to maintain a constant end-tidal carbon dioxide tension in patients undergoing posterior lumbar spine surgery in the prone position using the Wilson frame.

**Key Words:** Prone position – Pressure-controlled ventilation – Volume-controlled ventilation.

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## Introduction

**PRONE** positioning of a patient under anesthesia is a safe way of ensuring optimum surgical access for a number of procedures, providing that the risks are fully understood. Common procedures requiring prone positioning are back surgery, pilonidal sinus surgery and some types of ankle surgery e.g Achilles tendon repair. An understanding of the changes in physiology and the particular risks associated with the prone position is vital eg: Cardiovascular system: The most important feature of turning a patient prone under anesthesia is a drop in cardiac output. Respiratory system: Prone positioning has a broadly positive effect on the respiratory system providing that abdominal compression is avoided [1].

Functional residual capacity and arterial oxygen tension both increase. This is partially the reason why prone positioning [2] has been used in intensive care settings for patients with poor lung function when an anesthetized patient is turned to the prone position, dynamic compliance (C<sub>dyn</sub>) decreases and peak airway pressure (P<sub>peak</sub>) increases and Potential sources of injury.

There are a number of body structures that can be injured these are generally as a result of direct pressure to structures on which body weight would not normally rest e.g.: Eyes, nose and nerves [3].

The earliest mechanical ventilators used on humans were pressure controllers. They were not truly pressure-limited; rather they were pressure-cycled, terminating the inspiratory phase when a set pressure was achieved. However pressure pre-set ventilation fell from favour because of the inability to monitor delivered tidal volume (VT)

and to control minute ventilation (VE) [4]. New ventilators that used volume-control were developed. This allowed clinicians better control and regulation of both VT and VE [5]. During anesthesia the use of volume-controlled ventilation (VCV) is common, as this has been the only available mode on ventilators for a long time. This mode utilizes a constant flow to deliver a target tidal volume (VT) and thus insures a constant minute ventilation, although this may necessitate high-pressures in certain conditions. The mechanical consequences of reduced lung compliance and chest wall compliance (acute respiratory distress syndrome ARDS, obesity) added to the reduction of functional residual capacity induced by the surgery (muscle relaxation, trendelenburg, pneumoperitoneum) explain both the impaired alveolar ventilation and the subsequent high-pressure [6-8].

Debate over the most efficient and safest control mode has continued ever since [9].

### Patients and Methods

This study was done in the Neurosurgical Theater in Kasr El-Aini Hospital including 60 patients suffering from lumbar disc prolapse, after obtaining informed written consent from the patients and approval of the Ethical and Scientific Committee of Anesthesia Department in Cairo University. This study was held between 2013 to 2014.

#### Inclusion criteria:

- Adult patients of both sex (20-50 years old).
- Patients undergoing spine surgeries in prone position.
- Patients of American Society of Anesthesiologists' physical status class I & II.
- Patients with ideal body weight (body mass index 19:25 kg/m<sup>2</sup>).

#### Exclusion criteria:

- Patient refusal.
- Patient with obstructive (e.g. chronic obstructive pulmonary diseases, bronchial asthma) or restrictive chest problems (e.g. Pulmonary fibrosis, pregnant patients) or deformity.
- Patients with cardiovascular diseases (e.g. uncontrolled hypertension, ischemic heart diseases, mild to moderate valvular disease).

#### Randomization of study groups:

The patients were randomly allocated into two equal groups each one includes 30 patients by closed envelope chosen by the surgeon.

- *Group V:* Ventilated by volume controlled ventilation mode with a tidal volume 10ml/kg.
- *Group P:* Ventilated by pressure controlled ventilation mode, adjusting the peak airway pressure to deliver tidal volume 10ml/kg on supine position and readjusted after turning to prone position to deliver the same tidal volume.

#### Anesthetic technique:

All patients were fasting from for 6 to 8 hours before surgery. On the day of surgery all patients were premedicated with midazolam 2mg IV, and ranitidine 50 mg administered IV (slowly) 30 minutes before arriving into the operating room (OR).

On arrival to operating room ideal body weight estimated from the following equation:  $50 + 0.91 \times (\text{height in cm} - 152.4)$  for men and  $45.5 + 0.91 \times (\text{height in cm} - 152.4)$  for women [10].

On the operating table monitors were applied to the patients for continuous measuring of the heart rate and rhythm by ECG, oxygen saturation using pulse oxymetry and non invasive blood pressure by oscillometry.

For all patients, IV induction using propofol of 2mg/kg, fentanyl of 2 µg/kg and atracurium 0.5mg/kg. Muscle relaxation was confirmed 3-5 minutes after administering atracurium.

A wire-reinforced endotracheal tube was used, its site was confirmed by auscultation and continuous monitoring of end tidal CO<sub>2</sub> using capnogram. Anesthesia was maintained by O<sub>2</sub> 2L/min (Fio<sub>2</sub> 100%), isoflurane 1% inspired concentration, continuous IV infusion of atracurium at a rate of 0.5mg/kg/hr. Morphine 0.1mg/kg was given.

Mechanical ventilation was set to deliver the tidal volume (VT) in the volume controlled ventilation (VCV) group and the Ppeak (peak airway pressure) in the pressure controlled ventilation (PCV) group was set initially to deliver a VT of 10mL/kg of ideal body weight. The RR in both groups adjusted to maintain an end tidal carbon dioxide tension (ETCO<sub>2</sub>) between 33 and 36mm Hg, and the inspiratory to expiratory time (I/E) ratio was set to 1:2.

Radial artery cannulation using a 20 gauge arterial catheter to allow for arterial blood sampling. A urinary catheter inserted to measure hourly urine output.

After positioning patients in the prone position on the Wilson frame, the Ppeak was reset to match the initial expired VT in the PCV group.

At the end of the operation and repositioning the patient to supine position emergence and reversal of muscle relaxant using Atropine 0.2mg/kg and neostigmine 0.04mg/mg.

After extubation, patients remained one hour in the recovery room then plain postero-anterior chest x ray done to detection occurrence of any basal atelectasis in both groups.

*Measured Variables:*

*Respiratory variables:*

- 1- *Peak airway pressure:* (Continuously measured but recorded after induction of anesthesia in the supine position (Tsupine) and 30 minutes after the prone positioning (Tprone) then every 30 minutes).
- 2- *Shunt fraction, alveolar-arterial oxygen gradient:* (estimated after induction of anesthesia in the supine position (Tsupine) and 30 minutes after the prone positioning (Tprone) then every 30 minutes from the following equations).

*Shunt fraction (the physiological shunt is rarely over 4%). Calculated from the equation:*

$$Qs/Qt = (CcO_2 - CaO_2) / (CcO_2 - CvO_2)$$

Where (Qs) is the shunted blood (blood not participating in gas exchange) (QT) is the total cardiac output, (CvO<sub>2</sub>) is oxygen content of the venous blood, (CaO<sub>2</sub>) is oxygen content of the arterial blood, (CcO<sub>2</sub>) is the content of oxygen in pulmonary capillary and it is estimated by plugging in 100% as the saturation (1.00 for the math) since the PcO<sub>2</sub> (pulmonary capillary PO<sub>2</sub>) can be assumed to be high enough to assure 100% saturation.

The PcO<sub>2</sub> itself cannot be directly measured so we use PAO<sub>2</sub> (from the alveolar air equation) in its place:

$$PAO_2 = (FiO_2 * (P_{atmos} - P_{H_2O}) - (PaCO_2 / RQ)).$$

The FiO<sub>2</sub> is the fraction of inspired oxygen (usually as a fraction, but entered here as a percentage for ease of use).

P<sub>atmos</sub> is the ambient atmospheric pressure, which is 760 torr at sea level. P<sub>H<sub>2</sub>O</sub> is water vapor pressure at 37°C and is equal to 47mmHg. The respiratory quotient (RQ) is the ratio of CO<sub>2</sub> eliminated divided by the O<sub>2</sub> consumed, and its value is typically 0.8 but can range from 0.7 to 1.0 and the PaCO<sub>2</sub> is the CO<sub>2</sub> partial pressure in the arterial blood.

This means that  $CcO_2 = 1.39 \times Hb + 0.003 \times PAO_2$ .

3- *Arterial blood gas and venous blood gas analysis:* (After induction of anesthesia in the supine position (Tsupine) and 30 minutes after the prone positioning (Tprone) then every 30 minutes).

4- *Dynamic compliance:* (C<sub>dyn</sub>) of the respiratory system was calculated (after induction of anesthesia in the supine position (Tsupine) and 30 minutes after the prone positioning (Tprone) then every 30 minutes) as VT/(P<sub>peak</sub>-PEEP) [10].

5- *The alveolar dead space-to-tidal volume ratio (VD/VT) was estimated:* (After induction of anesthesia in the supine position (Tsupine) and 30 minutes after the prone positioning (Tprone) then every 30 minutes) using the Hardman and Aitkenhead equation:  $VD/VT = 1.135 \times (PaCO_2 - ET/CO_2) / (PaCO_2 - 0.005)$  Normal VD/VT is less than 0.33 (<33%).

**Results**

*Sixty patients were enrolled in the study.*

Only 57 patients completed the study there were 26 male and 31 female patients with a mean age of 53.17±7.27 years, all patient were ASA 1 and 2.

There were no statistical differences in age (p-value 0.056), male to female ratio (p-value 0.435), and BMI between the two groups (p-value 0.595).

Table (1): Patient characteristics. Data are presented as mean ± standard deviation (SD).

	Volume controlled ventilation	Pressure controlled ventilation
Age (year)	53.71±7.27	45.78±7.45
Weight (Kgm)	65.25±7.87	64.11±9.45
Hight (Cm)	165.38±11.94	161.11±10.54
BMI (kgm/m <sup>2</sup> )	23.87±1.68	24.59±1.17
Duration of surgery (hours)	2.36±0.42	2.44±0.38

Table (2): Gender distribution in both groups.

	Group			
	Volume controlled ventilation		Pressure controlled ventilation	
	Count	%	Count	%
Sex:				
Female	13	50.0	18	66.6
Male	15	50.0	11	33.3

As for ventilatory and oxygenation parameters:

1- The peak airway pressure (*P<sub>peak</sub>*): There was no statistical differences between the two groups in both; supine position: Mean peak airway pressure was 20mmHg in volume controlled group and 19mmHg in pressure controlled group (*p*-value 0.961),

In prone position: Mean peak airway pressure was 25mmHg in volume controlled group and 22.12mmHg in pressure controlled group (*p*-value 0.109).

2- Respiratory rate: (Breaths\min.) in the PCV group mean  $\pm$  SD (10.1  $\pm$  1.0) in supine position and (9.8  $\pm$  1.0) in prone position, was not significantly higher compared with the VCV group (9.9  $\pm$  1.6) in supine position and (8.9  $\pm$  1.3) in both groups.

3- Tidal volume (ml): In volume controlled mean  $\pm$  SD in supine position (589  $\pm$  90) and (566  $\pm$  93) in prone position and in pressure controlled group it was (568  $\pm$  139) in supine position and (507  $\pm$  121) in prone position.

4- Minute volume: (L/min.) mean  $\pm$  SD was (5.6  $\pm$  1.3) during supine position and (5.2  $\pm$  1.2) during prone position in volume controlled group and in pressure controlled group it was (5.6  $\pm$  1.5) and (4.9  $\pm$  1.2) during supine and prone position respectively, so both VT and MV decreased after prone positioning in both groups but with no statistically significance.

5- Dynamic compliance (*C<sub>dyn</sub>*): (mL/cm H<sub>2</sub>O)

- Was decreased with no statistically significant on turning patient from supine position to prone position in both study groups.
- *C<sub>dyn</sub>* in PCV was higher than in VCV but with no statistic significant as shown in graph.
- Mean  $\pm$  SD was (27.91  $\pm$  6.67) and (31.89  $\pm$  6.55) during supine position in volume controlled group and pressure controlled group respectively (*p*-value 0.335).
- (21.96  $\pm$  4.21) and (27.42  $\pm$  5.73) during prone position for volume controlled group and pressure controlled group respectively (*p*-value 0.075).

However, after 1.5hrs and 2hrs of prone positioning: *C<sub>dyn</sub>* in PCV group was statistically significant higher than VCV as shown in graph.

- *C<sub>dyn</sub>* in (mL/cm H<sub>2</sub>O) difference between between VCV and PCV during Prone position, every 30min.

- *C<sub>dyn</sub>* as (mL/cm H<sub>2</sub>O) 1.5 hour after turning patient to prone position (*p*-value 0.043).
- Mean  $\pm$  SD (22.52  $\pm$  4.21) and (32  $\pm$  4.93) for volume and pressure controlled group respectively.
- 2 hours after turning into prone position (*p*-value 0.026).
- Mean  $\pm$  SD (26.1  $\pm$  2.76) and (34.9  $\pm$  4.56) for volume and pressure controlled group respectively.

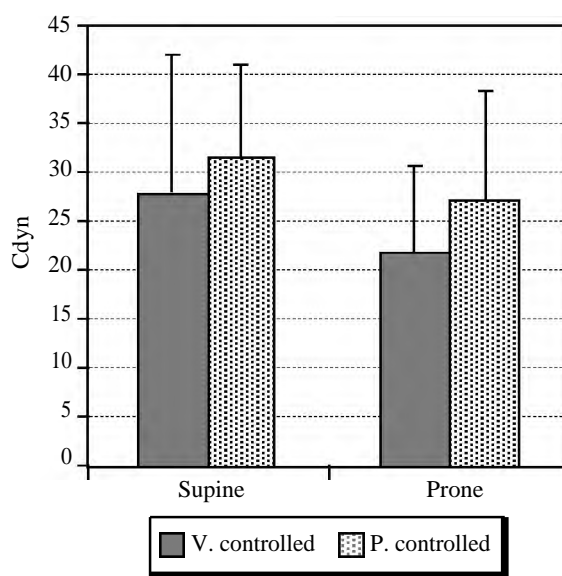


Fig. (1): Changes in *C<sub>dyn</sub>* in (mL/cm H<sub>2</sub>O) from supine to prone position in both groups.

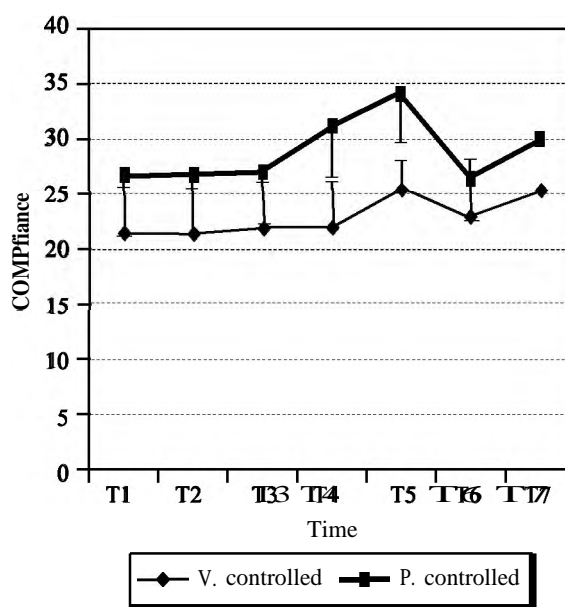


Fig. (2): Graph showing the statistically difference between both groups in *C<sub>dyn</sub>* only after 1.5hr and 2hrs of Tprone.

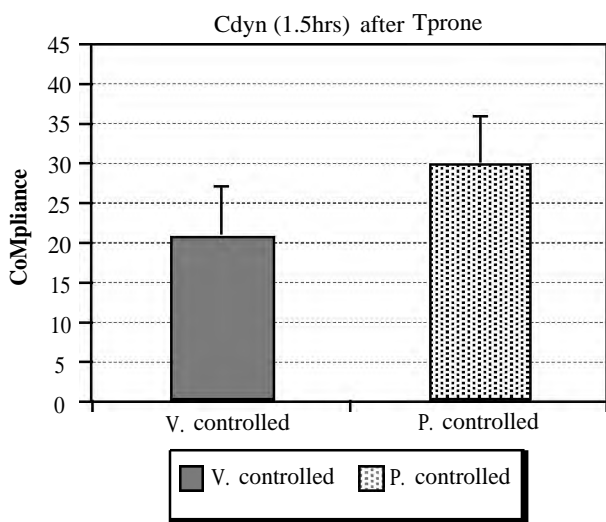


Fig. (3): Cdyn in (mL/cm H<sub>2</sub>O) after 1.5hrs. of prone position in both groups.

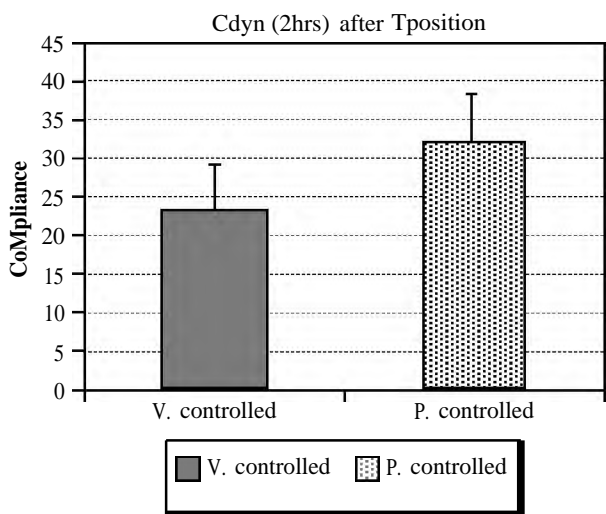


Fig. (4): Cdyn in (mL/cm H<sub>2</sub>O) after 2hrs. of prone position in both groups.

- 6- PaO<sub>2</sub> (mmHg): Were comparable between both group through out the study.
- 7- VD/VT(%) were comparable between the 2 groups during the study: Mean±SD was (28.6±5.4) and (27.1±3.8) for volume controlled group in supine and prone position respectively and (27.3±4.3) and (26.8±4.5) in supine and prone position respectively.
- 8- Oxygen saturation (SpO<sub>2</sub>): Was maintained above 96% in all patients during the study period.
- 9- There was no statistical differences between two groups concerning shuntfraction%: In supine position mean±SD was (2.3±0.22) in supine position and (2.42±0.26) in prone position and p-value was (p-value 0.773) and (p-value 0.7) for both supine and prone position respectively.

## Discussion

When an anesthetized patient is turned to the prone position, ETCO<sub>2</sub> decreases and peak airway pressure (Ppeak) increases unless the abdomen hangs [11-13]. The Wilson frame is a curved frame that supports the chest and pelvis along the lateral edges. Even though the frame partially compresses the anterior abdominal wall and therefore does not allow the abdomen to hang completely. This in turn may increase Ppeak and decrease Cdyn [13].

Authors hypothesized that, patients in the PCV group would have lower Ppeak compared with the VCV group when they are turned to the prone position, if the same tidal volume is to be delivered with variable respiratory rate (RR) to maintain a constant end-tidal CO<sub>2</sub> [14].

Therefore, this study was designed to compare the effect of PCV and VCV on lung mechanics in the prone position using the Wilson frame during posterior lumbar spine surgery.

As regard respiratory variables; in our study, PCV was used to attenuate the increase in Ppeak during the prone position peak was decreased but with no statistically significant (in supine position mean peak airway pressure was 20cmH<sub>2</sub>O in volume controlled group and 19cmH<sub>2</sub>O in pressure controlled group, in prone position mean peak airway pressure was 25cmH<sub>2</sub>O in volume controlled group and 22cmH<sub>2</sub>O in pressure controlled group) which agrees with Mirum Kim et al., [15] that found Ppeak increased after prone positioning in both groups. Ppeak in PCV group was lower than in VCV group (Ppeak (cmH<sub>2</sub>O) [15].

On the other hand Palmon SC et al., [13] research on the effect of the prone position on pulmonary mechanics; Seventy-seven adult patients that were divided into three groups according to body mass index: Normal <or=27kg/m<sup>2</sup>, heavy 28-31 kg/m<sup>2</sup>, and obese >or=32kg/m<sup>2</sup>.

Patients were placed in the prone position, a Wilson frame was used, they found that the Ppeak in the obese group (BMI >32kg/m<sup>2</sup>) was significantly higher than that in the normal group (BMI ≥27kg/m<sup>2</sup>) in the supine and prone positions during VCV; Mean ± SD: (normal group 19±3 to 25±5cm H<sub>2</sub>O) during both supine and prone positions respectively and obese group was 27±4 to 34±7cm H<sub>2</sub>O) in supine and prone position respectively. Patients with a BMI >30kg/m<sup>2</sup> were excluded from our study to avoid additional confounding factors, and further studies is needed to elucidate the difference between VCV and PCV with regard to pulmonary mechanics in obese patients [13].

Casati, et al., [16] who did their study on one hundred and five ASA I-II patients, scheduled for elective surgical procedures were studied in order to evaluate the effect of different surgical positions on physiological pulmonary dead space and arterial to end-tidal carbon dioxide gradient.

Patients were divided into four groups according to their position on the operating table: Supine position (acting as control group, n=33), 20 degree Trendelenburg position, lateral position and prone position with convex saddle frame, they found that the arterial to ETCO<sub>2</sub> gradient was higher in the prone position compared with the supine position and so RR decreased in prone position [16].

Also agree with Magi, et al., [17] who did a Prospective study, to compare PaCO<sub>2</sub>, ETCO<sub>2</sub>, pH, Ppeak in a group of 10 patients undergoing elective intervention for lumbar disk herniation in prone position and in a control group of 10 patients undergoing interventions for elective non-traumatologic orthopaedic surgery of the lower limbs in supine position; reported that the arterial to ETCO<sub>2</sub> gradient was higher in the prone position compared with the supine position; mean PaCO<sub>2</sub> 35.26mmHg (SD 3.045), mean ETCO<sub>2</sub> 3.46mmHg (SD 1.898) in supine group and prone group: Mean PaCO<sub>2</sub> 30.3mmHg (SD 5.819), mean ETCO<sub>2</sub> 1.4mmHg (SD 4.445) [17].

As RR adjustment was based on ETCO<sub>2</sub>, the decrease in ETCO<sub>2</sub> must have resulted in the decrease in RR.

Palmon et al., [13] have reported an 18% decrease in C<sub>dyn</sub> (dynamic compliance) when patients were turned to the prone position on the Wilson frame during VCV. This is consistent with the results of our study, in which the C<sub>dyn</sub> decreased by about 20% in the VCV group after prone positioning.

But in our study the C<sub>dyn</sub> in the PCV group was significantly higher compared with the VCV group only during prone positioning [13].

These results are dissimilar to those of a recent study done by Choi et al., [18] on Eighteen patients, no major obstructive or restrictive pulmonary disease, were allocated randomly in two groups. In the first group, one lung ventilation was started by VCV and the ventilator was switched to PCV after 30 minutes. In the second group, the modes of ventilation were performed in the opposite order in the prone position, they found that PCV fail to provide advantages compared with VCV with regard to respiratory variables including pul-

monary compliance in both groups. But this study was performed on patient with one lung ventilation needed surgeries in contrary to our study [18].

Also in this study we found that there is no statistical difference in shunt fraction between supine position (*p*-value 0.773) and prone position (*p*-value 0.7) which is disagree with Pappert et al [19] which was found that prone positioning caused a decrease in shunt perfusion of 11 ± 5% and a concomitant increase of normal VA/Q (ventilation/perfusion) by 12 ± 4% after 30min in most of patients [19].

In conclusion, finally from this study we can conclude that PCV may offer a better option for patients receiving anaesthesia in prone position compared to VCV. This is due to its superior effect on lung compliance specially after 1.5hr and 2hrs duration of surgery in such position. Further studies are needed including larger number of patients to prove such benefit.

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## تأثير التهوية الميكانيكية عن طريق التحكم بالضغط على وظائف التنفس في المرضى الموضوعين على الوجه الذين يخضعون لعمليات العمود الفقري الإختيارية دراسة مقارنة مع التهوية الميكانيكية عن طريق التحكم بالحجم

عند وضع المريض تحت تأثير المخدر على الوجه باستخدام هيكل ويلسون فإن الليونة الديناميكية للرئة تقل وتزداد قيمة ضغط الهواء داخل الممرات الهوائية.

أن التنفس الصناعي عن طريق التحكم بالضغط يقلل من قيمة ضغط الهواء داخل الممرات الهوائية.

إن الهدف من هذه الدراسة هو التهوية الميكانيكية للرئة عن طريق التحكم بالحجم والتهوية الميكانيكية للرئة عن طريق التحكم بالضغط وتأثيرها على ديناميكية الرئة في مرضى عمليات العمود الفقري الإختيارية عند وضعهم على الوجه.

أدرج في هذه الدراسة ٦٠ من المرضى أجريت لهم جراحات العمود الفقري الإختيارية وتم توزيعهم عشوائياً على مجموعتين المجموعة VCV وتضم ٣٠ مريضاً وأستخدمت فيها التهوية الميكانيكية للرئة عن طريق التحكم بالحجم والمجموعة PCV وتضم ٣٠ مريضاً وأستخدمت فيها التهوية الميكانيكية للرئة عن طريق التحكم بالضغط.

النتائج : ٦٠ مريض استكملوا الدراسة. حجم الهواء الكلي وحجم الهواء في الدقيقة وضغط ثاني أكسيد الكربون في هواء الزفير لم يظروا فروقاً هامة بين المجموعتين.

أعلى قيمة لضغط الهواء في الممرات الهوائية كان أقل في المجموعة PCV من المجموعة VCV ( $p = 0.109$  &  $p = 0.961$ ) في الوضع على الظهر والوضع على الوجه على التوالي.

الليونة الديناميكية للرئة انخفضت في كلا المجموعتين ما بين الوضع على الظهر والوضع على الوجه. ولكنها أعلى في مجموعة PCV من مجموعة VCV على مدار الدراسة.

وأظهرت فروقاً هامة بعد ساعة ونصف وساعتين من الوضع على الوجه ( $p = 0.26$  &  $p = 0.023$ ) على التوالي.

ضغط الأكسجين في الدم لم يظروا فروقاً هامة بين المجموعتين.