Pulmonary gas exchange is well preserved during robot assisted surgery in steep Trendelenburg position

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Abstract : *Introduction :* During robot assisted hysterectomies and prostatectomies, surgical exposure demands the application of a CO_2 pneumoperitoneum with a very steep Trendelenburg position (40 degrees). The extent to which oxygenation and ventilation might be compromised intra-operatively remains poorly documented.
Methods : Dead-space ventilation and venous admixture were determined in 18 patients undergoing robot assisted hysterectomy (n = 6) or prostatectomy (n = 12). Anesthesia was maintained with desflurane in O_2 or O_2/air, with the inspired O_2 fraction left at the discretion of the attending anesthesiologist. Controlled mechanical ventilation was used, but 15 min after assuming the Trendelenburg position and up until resuming the supine position pressure controlled ventilation was used. Dead-space ventilation and venous admixture were determined using Bohr's formula and Nunn's iso-shunt diagram, respectively, at the following 7 stages of the procedure : 15 min after induction ; 5 min after applying the CO_2 pneumoperitoneum (intra-abdominal pressure 12 mm Hg) but while still supine ; 5, 60, and 120 min after assuming the Trendelenburg positioning ; and 5 and 15 min after reassuming the supine position.
Results : Venous admixture did not change. Dead-space ventilation increased after Trendelenburg positioning, and returned to baseline values after resuming the supine position. However, individual patterns varied widely.
Discussion : The lung has a remarkable yet incompletely understood capacity to withstand the effects of a CO_2 pneumoperitoneum and steep Trendelenburg position during general anesthesia. While individual responses vary and should be monitored, effects on dead-space ventilation and venous admixture are small and should not be an obstacle to provide optimal surgical exposure during robot assisted prostatectomy or hysterectomy.

Introduction

The impact of a CO_2 pneumoperitoneum and moderate degrees of head-up or head-down tilt on pulmonary gas exchange has been well described (1-2). However, during robot assisted hysterectomies and prostatectomies, surgical exposure demands the application of a CO_2 pneumoperitoneum with a very steep Trendelenburg position (40 degrees – fig. 1) that may occasionally extend beyond 3 hours. While most patients apparently tolerate this combination well, the extent to which oxygenation and ventilation might be compromised intra-operatively in this extreme Trendelenburg position remains poorly documented. We therefore determined dead-space ventilation and venous admixture in patients undergoing robot assisted hysterectomy or prostatectomy using Bohr's formula and Nunn's iso-shunt diagram, respectively (3).

Methods

After obtaining IRB approval and informed consent, 18 patients undergoing robot assisted hysterectomy (n = 6) or prostatectomy (n = 12) were enrolled. All patients were premedicated with oral alprazolam (1 mg on the evening before and

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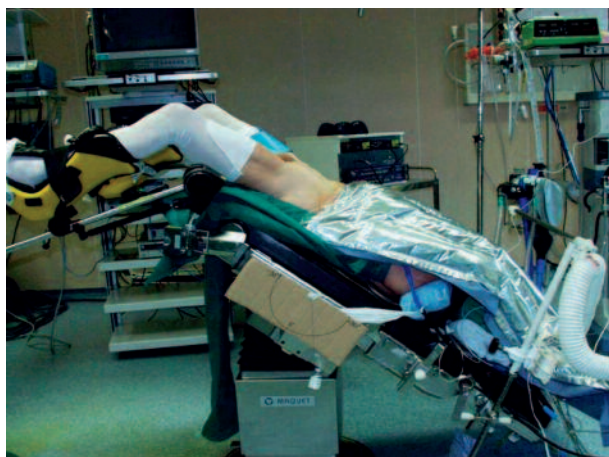E-mail : jcnwahendrickx@yahoo.com

Fig. 1. — The degree of Trendelenburg deemed optimal by the surgical team is 40 degrees.

0.5 mg on the morning of surgery). After applying routine monitors and establishing IV access, patients were preoxygenated by inhaling 100% O_2. Anesthesia was induced intravenously with propofol (3 mg/kg) and sufentanil (0.1 µg/kg), and tracheal intubation was facilitated by rocuronium (0.6 mg/kg). The ADU® anesthesia machine (General Electric, Helsinki, Finland) was modified with a mixing bottle (courtesy of Jim Philip, Boston, MA, USA). The mixing "bottle" is a 550 ml self made plexiglass box, containing several fenestrated baffles to ensure adequate mixing of the expired gases, and provided with a sampling port that allows mixed-expired gas analysis. The mixing bottle was inserted between the expiratory limb of the circle system and the expiratory gas port of the anesthesia machine, just proximal to the expiratory valve. The ventilation mode was controlled with mechanical ventilation (without PEEP), but 15 min after assuming the Trendelenburg position and up until resuming the supine position pressure controlled ventilation (without PEEP) was used, with the pressure titrated to maintain what the anesthesiologist judged acceptable end-tidal CO_2 concentrations.

Anesthesia was maintained with desflurane in O_2 or O_2/air, with the inspired O_2 fraction (F_IO_2) left at the discretion of the attending anesthesiologist. An arterial catheter was inserted in the left radial artery to monitor blood pressure and to obtain arterial blood samples. Dead-space (including apparatus and physiologic dead-space) ventilation and venous admixture were determined at the following 7 stages of the procedure : 15 min after induction ; 5 min after applying the full CO_2 pneumoperi-

toneum (intra-abdominal pressure 12 mm Hg) but while still supine ; 5, 60, and 120 min after assuming the Trendelenburg positioning ; and 5 and 15 min after reassuming the supine position.

Dead-space (ratio of dead-space over tidal volume, expressed in %) was calculated with Bohr's formula (3) using an arterial blood sample (analyzed with a CO-oximeter – ABL700™ Series, Radiometer Copenhagen, Brønshøj, Denmark) and a mixed expired gas sample from the mixing bottle (analyzed with the GE Compact Airway Module M-CAiOV, GE, Helsinki, Finland). The ratio of dead-space over tidal volume, expressed in %, was calculated as the arterial PCO_2 minus mixed-expired PCO_2 divided by the arterial PCO_2 or (P_aCO_2 - PCO_2)/P_aCO_2. Because the fresh gas flow of the ADU® enters the circle system distal to the inspiratory valve of the circle system, a continuous fresh gas flow is present both during the in- and -expiratory phase. To avoid dilution of the expired mixture with fresh gas, the fresh gas flow was discontinued when the mixed-expired CO_2 concentration was measured, and the arterial blood sample was only drawn after the mixed-expired concentration had reached a constant value on the monitor display (most often after 60 seconds or less). Pulmonary shunt was calculated with Nunn's iso-shunt diagram (3) using the F_IO_2 and the corresponding arterial PO_2 value from the arterial blood sample. To examine to what extent the $P_{E'}CO_2$ reflects the P_aCO_2, the ratio of the end-expired over arterial PCO_2 ($P_{E'}CO_2$/P_aCO_2) was calculated.

Dead-space and intrapulmonary shunt at the 7 stages were compared using ANOVA followed by Holm-Sidak to examine between group differences for normally distributed data, or ANOVA on ranks for non-normally distributed data (Kruskal-Wallis) followed by Holm-Sidak's or Dunn's test where appropriate to examine between group differences, with results presented as mean (standard deviation).

RESULTS

The patients' age, height, and weight were 57 (11) yr, 169 (6) cm, and 76 (12) kg respectively. In two patients, surgery did not last long enough to obtain data 120 min after assuming the Trendelenburg positioning. In addition, sampling error prevented calculation of dead-space and shunting in 2 instances each.

Venous admixture did not change throughout the experiment (fig. 2, table 1). Dead-space
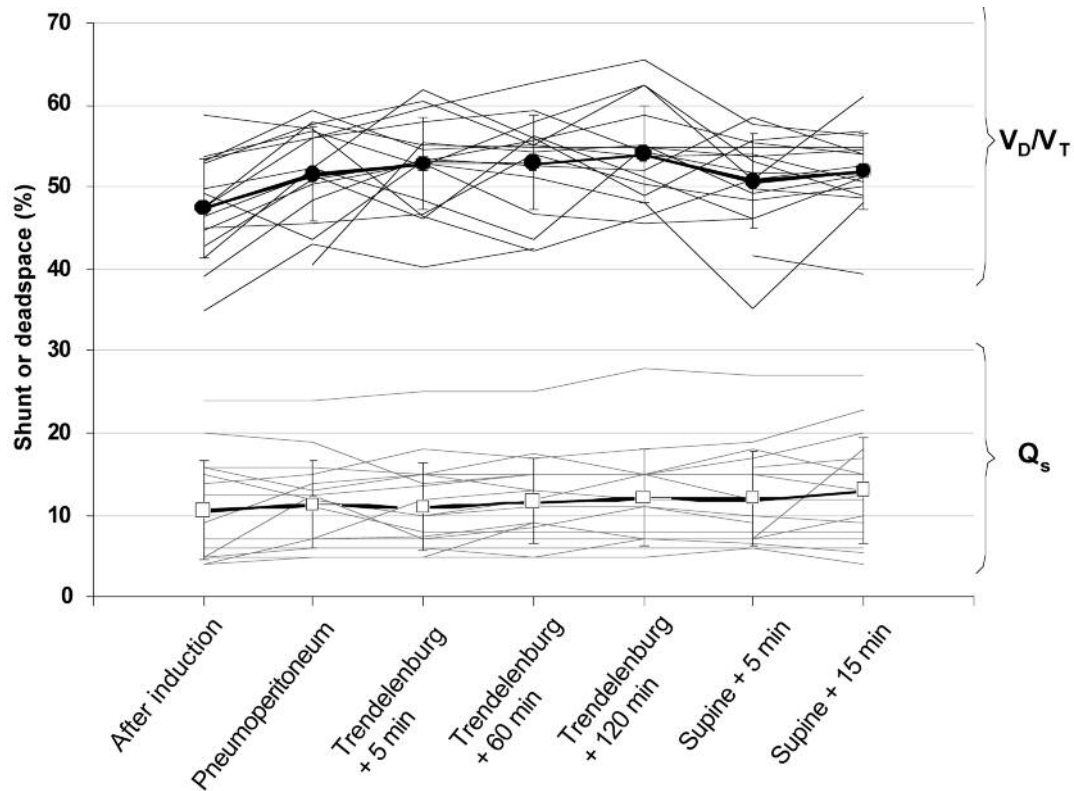
Fig. 2. — Venous admixture (%) and dead space ventilation (expressed as dead space/tidal volume or V_D/V_T, %). Q_s = venous admixture, mean (•) and standard deviation (bars). V_D/V_T = dead-space ventilation, mean (○) and standard deviation (bars).

ventilation increased after Trendelenburg positioning, and returned to baseline values after resuming the supine position. However, individual patterns varied widely (fig. 2, table 1). $P_{E'}CO_2/P_aCO_2$ did not change, but again there was important interindividual variability.

DISCUSSION

We found that pulmonary gas exchange is well preserved after assuming steep Trendelenburg position during a 12 mmHg pneumoperitoneum for robot assisted surgery.

The approximately 50% dead-space ventilation (including apparatus dead-space) throughout the procedure is almost identical to the 51% reported by Nunn (4). The 10% venous admixture we found is of the order of magnitude expected after induction of anesthesia (4). Half of this venous admixture is caused by atelectasis resulting in absolute shunt, and the other half by dispersion of the distribution of perfusion to alveoli with low ventilation/perfusion ratios resulting in ventilation/perfusion mismatch (4). Even though a CO_2 pneumoperitoneum and steep Trendelenburg position are expected to worsen atelectasis and further

reduce the functional residual capacity of the lung, venous admixture did not change, and changes in dead space ventilation were modest (which is also indicated by the absence of $P_{E'}CO_2/P_aCO_2$ changes). Other authors already found that increasing intra-abdominal pressure to 14 mm Hg with more moderate degrees of head-up (+ 20 degrees) or head-down (– 20 degrees) did not significantly modify physiologic dead space or venous admixture (5-7). Even more surprisingly, ANDERSSON et al. (8) found that, despite increasing atelectasis, a CO_2 pneumoperitoneum transiently *reduces* venous admixture, thereby *increasing* arterial oxygenation (9). Why a CO_2 pneumoperitoneum would increase arterial oxygenation despite increasing atelectatic lung area on CT by 66% (range, 11-170%) has not been elucidated. ANDERSON et al. suggest that the CO_2 pneumoperitoneum might improve ventilation/perfusion matching because the increased intra-abdominal pressure transmitted to the thorax could decrease perfusion in those areas where shunting was prevalent before pneumoperitoneum. This theory was supported by a decreased dispersion of blood flow after induction of pneumoperitoneum, which indicates better matching (8). ANDERSSON et al. found that during pneumoperitoneum, lung tissue volume increases while total lung volume and

Respiratory variables and derived indices. Results are presented as mean (SD)

Parameter (unit)		(unit)	Event							p
			After induction	After pneumo-peritoneum	After Trendelen-burg	60 min after Trendelen-burg	120 min after Trendelen-burg	Resumption of supine position	15 min after supine	
	End-tidal CO_2 (mmHg)	(mmHg)	33 (2)[a]	34 (3)[b]	39 (3)[a, b]	35 (4)	36 (4)	37 (7)	35 (5)	0.014
	Arterial PCO_2 (mmHg)	(mmHg)	39 (4)[c, d]	41 (4)	46 (4)[c]	44 (6)	45 (6)	46 (8)[d]	45 (5)	0.006
	Mixed-expired PCO_2 (mmHg)	(mmHg)	20 (1)	20 (2)	21 (2)	20 (2)	20 (2)	23 (5)	21 (2)	0.099
	Inspired O_2 concentration (%)	(%)	83 (18)	77 (18)	77 (16)	80 (17)	80 (17)	77 (18)	78 (15)	0.476
	Arterial PO_2	(mmHg)	368 (132)	330 (128)	327 (145)	325 (129)	312 (122)	302 (123)	287 (123)	0.625
	Hemoglobine (g%)	(g%)	12.7 (1.4)	12.8 (1.5)	12.9 (1.3)	13 (1.5)	13.3 (1)	12.7 (1.4)	12.4 (1.6)	0.658
	pH		7.39 (0.03)[e]	7.37 (0.03)	7.33 (0.02)	7.37 (0.1)	7.33 (0.05)	7.32 (0.06)	7.32 (0.05)	< 0.001
	End-tidal/arterial PCO_2		0.85 (0.05)	0.82 (0.05)	0.85 (0.07)	0.80 (0.09)	0.79 (0.07)	0.80 (0.06)	0.79 (0.08)	0.114

[a] and [b] differ from one another

[c] and [d] differ from one another

[e] "after induction group" differed from all groups except the group "60 min after Trendelenburg".

functional residual capacity decrease. Because the volume of open blood vessels is larger than that of closed vessels, the authors argue that the observed increased tissue volume is caused by opening of previously closed vessels *after* applying the pneumoperitoneum. Opening of these previously closed vessels would explain the increase in arterial oxygenation. We would argue that one might expect the opposite effect after deflating the pneumoperitoneum : in three of our patients venous admixture worsened by more than 5% after deflating the peritoneum, but it is difficult to analyse the relative contribution of deflating the abdomen and resuming the supine position because they clinically often coincide or differ only by 5-10 minutes.

It remains remarkable that lung function does not become more impaired under these non-physiological conditions. Even in the one patient with a 25% venous admixture after induction of anesthesia (see outlier in fig. 1), venous admixture did not worsen after applying a pneumoperitoneum or steep Trendelenburg position.

While the degree of Trendelenburg (40 degrees) is more pronounced than in most other studies, our results can only confirm that even a very steep Trendelenburg position does not further impair gas exchange. Despite decreases in pulmonary compliance and functional residual capacity, the effects of Trendelenburg position on gas exchange are small or non-existent, even in obese patients (10).

While these results seem reassuring, it has to be appreciated that, while *average* gas exchange is unaltered, there is considerable interindividual variability. This caveat has been shared by other authors (11-12). At some stage during the procedure, the individual patient may therefore benefit from a higher F_IO_2, an alveolar recruitment maneuver with or without the application of PEEP (e.g. after resuming the supine position), or an increase in minute ventilation. It is imperative to carefully monitor the arterial saturation with pulse oximetry and the end-expired CO_2 concentration, and if warranted, use arterial blood gas analysis to assess the alveolar-arterial O_2 and CO_2 gradients. Still, the intra-operative effects of CO_2 peritoneum and steep Trendelenburg in particular on dead-space ventilation and venous admixture are small and should not be an obstacle to provide optimal surgical exposure during robot assisted prostatectomy or hysterectomy.

Summarized, the lung has a remarkable yet incompletely understood capacity to withstand the effects of a CO_2 pneumoperitoneum and steep Trendelenburg position during general anesthesia. While individual responses vary and should be monitored, effects on dead-space ventilation and venous admixture are small and should not be an obstacle to provide optimal surgical exposure during robot assisted prostatectomy or hysterectomy.

References

1. Joris J. L., *Anesthesia for laparoscopic surgery (chapter 57).* In : Miller R. D., ed. *Anesthesia, 6th edition.* New York, Churchill Livingstone, 2005, pp. 2286.
2. Faust R. J., Cucchiara R. F., Bechtle P. S., *Patient positioning (chapter 28).* In : Miller R. D., ed. *Anesthesia, 6th edition.* New York, Churchill Livingstone, 2005, pp. 1162.
3. Lumb A. B., *Nunn's Applied Respiratory Physiology,* Butterworth-Heinemann, 6th ed., 2005, pp 120-121, pp. 125.

4. Lumb A. B., *Nunn's Applied Respiratory Physiology*, Butterworth-Heinemann, 6th ed., 2005, pp. 311.

5. Tan P. L., Lee T. L., Tweed W. A., *Carbon dioxide absorption and gas exchange during pelvic laparoscopy*, CAN. J. ANAESTH., **39**, 677-681, 1992.

6. Bures E., Fusciardi J., Lanquetot H., Dhoste K., Richer J. P., Lacoste L., *Ventilatory effects of laparoscopic cholecystectomy*, ACTA ANAESTHESIOL. SCAND., **40**, 566-573, 1996.

7. Odeberg-Wernerman S., Sollevi A., *Cardiopulmonary aspects of laparoscopic surgery*, CURR. OPIN. ANESTHESIOL., **9**, 529, 1996.

8. Andersson L. E., Bååth M., Thörne A., Aspelin P., Odeberg-Wernerman S., *Effect of carbon dioxide pneumoperitoneum on development of atelectasis during anesthesia, examined by spiral computed tomography*, ANESTHESIOLOGY, **102**, 293-299, 2005.

9. Andersson L., Lagerstrand L., Thörne A., Sollevi A., Brodin L. A., Odeberg-Wernerman S., *Effect of CO_2 pneumoperitoneum on ventilation-perfusion relationships during laparoscopic cholecystectomy*, ACTA ANAESTHESIOL. SCAND., **46**, 552-560, 2002.

10. Sprung J., Whalley D. G., Falcone T., Warner D. O., Hubmayr R. D., Hammel J., *The impact of morbid obesity, pneumoperitoneum, and posture on respiratory system mechanics and oxygenation during laparoscopy*, ANESTH. ANALG., **94**, 1345-1350, 2002.

11. McMahon A. J., Baxter J. N., Kenny G., O'Dwyer P. J., *Ventilatory and blood gas changes during laparoscopic and open cholecystectomy*, BR. J. SURG., **80**, 1252-1254, 1993.

12. Wahba R. W., Mamazza J., *Ventilatory requirements during laparoscopic cholecystectomy*, CAN. J. ANAESTH., **40**, 206-210, 1993.