Hemodynamic physiology during perioperative intracranial hypertension
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The influence of steep Trendelenburg position and CO2 pneumoperitoneum on cardiovascular, cerebrovascular and respiratory homeostasis during robotic prostatectomy.

Modified from

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Chapter 6

Abstract

**Background**: The steep (40 degree) Trendelenburg position optimizes surgical exposure during robotic prostatectomy. The goal of the current study was to investigate the combined effect of this position and CO$_2$ pneumoperitoneum on cardiovascular, cerebrovascular and respiratory homeostasis during these procedures.

**Methods**: Physiologic data were recorded during the whole operative procedure in 31 consecutive patients who underwent robotic endoscopic radical prostatectomy under general anaesthesia. Monitoring included HR, MAP, CVP, SpO$_2$, Pe’CO$_2$, P$_{plat}$, tidal volume, compliance and minute ventilation. Arterial blood samples were taken to determine the Arterial-to-End-Tidal CO$_2$ Gradient. Continuous regional cerebral tissue oxygen saturation (SctO$_2$) was determined by near-infrared spectroscopy.

**Results**: While patients were in the Trendelenburg position, all investigated parameters remained within a clinically acceptable range. The Cerebral Perfusion Pressure decreased from 77 mmHg at baseline to 71 mmHg (p=0.07), and SctO$_2$ increased from 70 % to 73 % (p<0.001). The Pe’CO$_2$ increased from 4.12 kPa to 4.79 kPa (p<0.001) and the arterial-to-Pe’CO$_2$ tension difference increased from 1.06 kPa in the normal position to a maximum of 1.41 kPa (p<0.001) after two hours in the Trendelenburg position.

**Conclusion**: The combination of prolonged steep Trendelenburg position and CO$_2$-pneumoperitoneum was well tolerated by the patients. Haemodynamic and pulmonary parameters remained within safe limits. Regional cerebral oxygenation was well preserved and the cerebral perfusion pressure remained within the limits between which cerebral blood flow is usually considered to be maintained by cerebral autoregulation.
The influence of steep Trendelenburg Position

Introduction

A new surgical need
The use of robotic endoscopic radical prostatectomy has the potential to improve the surgical outcome and to reduce complications compared to open radical prostatectomy.\textsuperscript{1,2} To facilitate this surgery, the patient must be placed in a steep (40°) Trendelenburg position for several hours, and this, combined with the CO\textsubscript{2} pneumoperitoneum, is likely to cause significant, potentially adverse, cardiovascular and neurophysiologic changes.

A new clinical challenge
The combination of steep Trendelenburg positioning and pneumoperitoneum during robotic prostatectomy is known to induce intracranial hypertension\textsuperscript{3}. Additionally, previous studies have reported that it causes a significant reduction of cerebral tissue oxygen saturation (SctO\textsubscript{2}) in elderly patients\textsuperscript{4} and in patients with pre-existing raised intracranial pressure (ICP)\textsuperscript{5}. Patients presenting for robotic surgery are usually elderly, and are thus patients in whom the procedure may upset the critical balance between cerebral oxygen supply and demand\textsuperscript{6}. In circumstances such as these, near-infrared spectroscopy (NIRS) can be used to assess regional cerebral tissue oxygen saturation (SctO\textsubscript{2}), which gives an indication of the regional balance between cerebral oxygen supply and demand. Previous work, using a first-generation NIRS-device\textsuperscript{6}, demonstrated a slight relative increase in SctO\textsubscript{2}.

Since PaCO\textsubscript{2} is an important determinant of cerebral blood flow, maintenance of normocarbia is essential for the preservation of cerebrovascular homeostasis. When pulmonary parameters are relatively stable, the end-tidal CO\textsubscript{2} tension (Pe'CO\textsubscript{2}) gives an acceptable estimate of the PaCO\textsubscript{2} - the arterial-to-end-tidal CO\textsubscript{2} tension gradient is \textasciitilde0.67 (0-1.33) kPa and does not correlate with PaCO\textsubscript{2}\textsuperscript{7}. The combination of steep Trendelenburg positioning and pneumoperitoneum influences pulmonary physiology in several ways. Maintenance of normocarbia usually requires adjustments in ventilator settings, and it is uncertain if the Pe’CO\textsubscript{2} is a clinically acceptable estimate of arterial PCO\textsubscript{2} pressure upon which to judge the adequacy of the ventilator settings.

In patients in the supine position the cerebral perfusion pressure (CPP) is determined as the difference between the mean arterial pressure (MAP) and the greater of the central venous pressure (CVP) and intracranial pressure (ICP)\textsuperscript{8}. Therefore, in the context of the steep Trendelenburg position, where CVP is likely to be equivalent to, or greater than the ICP, it is appropriate to estimate the CPP from the MAP and CVP\textsuperscript{8}. The aim of this study was to investigate the influence of the combination of steep Trendelenburg position and pneumoperitoneum during robotic prostatectomy on cerebrovascular, respiratory and haemodynamic homeostasis. Additionally, we sought to determine the value of Pe’CO\textsubscript{2} readings as an estimate of arterial PaCO\textsubscript{2} in this setting.
Methods

Patients
After Institutional Ethics’ Committee approval (Ethics’ Committee, OLV Clinic, Aalst, Belgium) and written informed consent was obtained, 31 consecutive patients who underwent robotic endoscopic prostatectomy in steep Trendelenburg position were included. No premedication was administered.

Procedure and data recording
Upon arrival in the operating theatre, standard monitoring was applied: ECG, pulse oximetry and non-invasive automated arterial blood pressure. After anaesthesia was induced with propofol (1–2 mg kg\(^{-1}\)) and sufentanil (0.25 µg kg\(^{-1}\)), rocuronium (0.6 mg kg\(^{-1}\)) was administered and the trachea intubated. Anaesthesia was maintained with 1 MAC of sevoflurane. Additional boluses of sufentanil and rocuronium were administered as required at the discretion of the clinician. The lungs were ventilated in volume control mode with an \(\text{O}_2/\text{air}\) mixture (\(\text{F}_{\text{I}}\text{O}_2 40\%\)) and a PEEP of 5 cm H\(_2\)O. The tidal volume was adjusted to achieve a Pe’CO\(_2\) between 4.0 and 4.7 kPa. The heart rate was monitored continuously via the ECG.

After induction, a 20-gauge arterial catheter (Arterial Cannula, REF 682245, Becton Dickinson, Swindon, UK) was inserted percutaneously into a radial artery. The catheter was connected via a 150-cm long (1.5 mm internal diameter) rigid pressure tubing, filled with saline, to a continuous-flush pressure-transducer system (Becton Dickinson Critical Care Systems, Singapore) to monitor beat-to-beat blood pressure and for arterial blood sampling. The right internal jugular vein was cannulated with a two-lumen central venous catheter (Arrow International Inc., Reading, PA) for monitoring of central venous pressure. The external acoustic meatus was used as the zero reference point for both pressure transducers, to allow a precise determination of the cerebral perfusion pressure, independent of patient positioning. Both systems were calibrated against atmospheric pressure and both pressure transducers were connected to an S5-monitor (Datex-Ohmeda, Helsinki, Finland).

Cerebral oximetry sensors (FORE-SIGHT Adult Dual sensor kit – 01-06-0018, CAS Medical Systems Inc, Branford, Connecticut, USA) were placed bilaterally according to the manufacturer’s instructions. The rSO\(_2\) value was continuously recorded at 0.5 Hz using the NIRS FORE-SIGHT monitor (CAS Medical Systems Inc, Branford, Connecticut, USA).

Normothermia was maintained with a forced-air warming system. Once stable profiles of capnography and blood pressure were reached, ventilatory and drug delivery settings were left unchanged. All vital signs were monitored using an S5-monitor and data from the monitor were recorded via Collect Software (Datex-
The influence of steep Trendelenburg Position

Ohmeda, Helsinki, Finland) for subsequent offline analysis. All variables were recorded numerically at 0.2 Hz.

A custom-made foam pillow (60x30x15cm) was placed under the head, firmly positioned behind the shoulders, and immobilized using standard shoulder supports. The patient’s legs were placed in urologic leg-holders (MAQUET GmbH & Co. KG, Rastatt, Germany) and the thighs abducted sufficiently to accommodate the robotic system.

Subsequently, the abdominal cavity was insufflated with CO₂ to a pressure of 10 mmHg, and the patient was placed in mild Trendelenburg position after which the trocars were located at the classical points. Finally, the patients were slowly placed in steep Trendelenburg position (40° from horizontal, the maximal angle the surgical table allows for). The start time of the maximal Trendelenburg position was defined as T. All operations were performed on the same table with the same degree of Trendelenburg.

The surgeon performed the procedure with the da Vinci Robot Surgical System (Intuitive Surgical, Sunnyvale, CA). A transperitoneal approach was used for performing the operation. The intraperitoneal pressure was adjusted by the surgeon as needed. At the end of the procedure, the position of the table was normalized and the pneumoperitoneum was released. The surgical wounds were closed and the patient was awakened either in the operating room/theatre or in the recovery room.

During the procedure, arterial blood samples were taken for blood gas analysis (Radiometer 715, Radiometer Medical APS, Brønshøj, Denmark) just before induction of the pneumoperitoneum, at 30 minute intervals during steep Trendelenburg positioning, and 15 minutes after resuming the supine position.

In the recovery room, any peripheral or central neurological complications were noted. The patients were discharged to the ward after evaluation by the anaesthetist, with particular attention being paid to the brachial plexus (clinical assessment) and cognitive functions (Aldrete score¹⁰). Duration of stay in both the recovery room and the hospital as well as the need for blood transfusions were recorded.

**Data analysis**

In subsequent offline analysis, the electronic data were converted to ASCII format, imported into Microsoft Excel and synchronized at 0.2 Hz. The following parameters were investigated: Heart Rate (HR), MAP, CVP, Peripheral oxygen saturation (SpO₂), Pe’CO₂, Plateau Pressure (Pplat), Tidal Volume (TV), compliance, Minute Volume (MV) and SctO₂. A moving-window median smoothing algorithm was used with a window of 1 minute and moving at 5 second steps. After graphical representation, a visual inspection of the data plots was performed to correct atypical erratic values caused by artifacts. The CPP was calculated as the difference between MAP and CVP. All curves were first synchronized with induction of Trendelenburg position.
Chapter 6

represented as T, and then later re-synchronised upon resumption of the supine position represented as S (Figure 1 & 2) and for each patient the mean and standard deviation were determined at 5 minute intervals.

The baseline value, reported as T-10, was defined as the average value during the 5 min interval 10 – 5 minutes before steep Trendelenburg repositioning (i.e. during the period when the patient was still in horizontal position, just prior to shallow Trendelenburg).

The Arterial-to-End-TidalCO\textsubscript{2} tension difference was calculated as the difference between the measured arterial CO\textsubscript{2} tension and the mean of the Pe’CO\textsubscript{2} values during the minute before an arterial blood sample was taken.

Statistical analysis
PaCO\textsubscript{2} and Pe’CO\textsubscript{2} data were analyzed using the Pearson correlation test for paired comparisons. The relationship between PaCO\textsubscript{2} and Pe’CO\textsubscript{2} was also determined by linear regression. Statistical significance level was set at 5 %. Data were analyzed using SPSS 16.0 software (SPSS Inc., Chicago, IL, USA).

Results

A full data set was acquired for each of the 31 patients enrolled. Data were normally distributed and are presented as mean (SD). Patient age was 62 (49 - 76) years. The total time spent in steep Trendelenburg position was 159 (70) min. Table 1 shows the perioperative changes of the following parameters measured before, during, and after the Trendelenburg period: Heart Rate (HR), Invasive Mean Arterial Pressure (MAP) and Central Venous Pressure (CVP) – measured at the level of the mid-ear, Cerebral Perfusion Pressure (CPP), Peripheral oxygen saturation (SpO\textsubscript{2}), Regional cerebral tissue oxygen saturation (SctO\textsubscript{2}), end-tidal CO\textsubscript{2} (Pe’CO\textsubscript{2}), Plateau Pressure (P\textsubscript{plat}), Tidal Volume, Compliance and Minute Volume of the patients in the period before (Pre-Tren), during (Tren) and after (Post-Tren) institution of steep Trendelenburg position. The values are shown in table 1 as mean(SD) of the 31 patients included in the study. Significantly different from pre-Trendelenburg period (p<0.05) are indicated with *.
Table 1: perioperative changes of the investigated parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-Tren</th>
<th>Tren</th>
<th>Post-Tren</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>62(12)</td>
<td>63(10)</td>
<td>68(11) *</td>
</tr>
<tr>
<td>MAP (mmHg)</td>
<td>79(14)</td>
<td>95(10) *</td>
<td>76(9)</td>
</tr>
<tr>
<td>CVP (mmHg)</td>
<td>8 (4)</td>
<td>26(6) *</td>
<td>8(6)</td>
</tr>
<tr>
<td>CPP (mmHg)</td>
<td>71(11)</td>
<td>70(12)</td>
<td>69(13)</td>
</tr>
<tr>
<td>SpO₂ (%)</td>
<td>98(1)</td>
<td>98(1)</td>
<td>98(1)</td>
</tr>
<tr>
<td>SctO₂ (%)</td>
<td>70(4)</td>
<td>73(4) *</td>
<td>74(5) *</td>
</tr>
<tr>
<td>Pe’CO₂ (kPa)</td>
<td>4.12(0.40)</td>
<td>4.79(0.40) *</td>
<td>4.92(0.40) *</td>
</tr>
<tr>
<td>Pplat (cmH₂O)</td>
<td>14(4)</td>
<td>26(5) *</td>
<td>15(4)</td>
</tr>
<tr>
<td>Tidal Volume (ml)</td>
<td>542 (53)</td>
<td>529(66)</td>
<td>551(70)</td>
</tr>
<tr>
<td>Compliance (ml/cm H₂O)</td>
<td>50(1)</td>
<td>23(5) *</td>
<td>45(13) *</td>
</tr>
<tr>
<td>Minute Volume (L)</td>
<td>7(1)</td>
<td>7(1)</td>
<td>8(1) *</td>
</tr>
</tbody>
</table>

The course of the investigated parameters is shown in Figures 1. For each parameter, the evolution of the value in individual patients (thin line) and of the average value (thick line) is shown. All data are synchronized at the moment of initiating Trendelenburg positioning (T). Values are shown from 10 minutes before T to 240 minutes after T. The average value is shown up to 180 minutes of Trendelenburg position. At reassuming the supine position, the curves are resynchronized (S) and values are shown for another 20 minutes.

**Haemodynamical parameters**

In the first five minutes after Trendelenburg positioning, the MAP and CVP increased by 33.7 and 22.7 mmHg thus increasing the calculated CPP by 11 mmHg. During the next hour, the MAP and CVP decreased modestly. After resuming the supine position, both the MAP and CVP decreased precipitously but to the same extent, leading to a short-lived decrease in CPP to 61 (12) mmHg immediately after reassuming the supine position. Within three minutes, however, the CPP recovered to baseline values.

Shallow Trendelenburg positioning and induction of the pneumoperitoneum increased the HR from 61(11) to 68(14) bpm (p<0.01). At T5 (5 minutes after the start of the steep Trendelenburg position), HR had decreased to 60(11) bpm (p<0.01). From T5 to T120, HR did not change (p>0.1). After return to the supine position, HR increased above baseline, 68(11) bpm (p<0.01).
Figure 1: Evolution of the individual patient values (fine lines) and the average value (thick line) of HR, MAP, CVP, CPP, SpO$_2$, SctO$_2$, Pe’CO$_2$, Pplat, Tidal Volume and Compliance.

Oxygenation parameters
The arterial oxygen saturation was stable throughout the procedure - mean SpO$_2$ was 98(1) %. The SctO$_2$ did change throughout the procedure. From $T_{-5}$ to $T_0$, the SctO$_2$ remained stable at 70(4) %. Between $T_0$ and $T_{35}$ it increased gradually to 73(5) % ($p<0.01$), and it increased even further to 74 (5) % after resuming the supine position ($p<0.01$). In all cases and throughout the duration of the procedure, SctO$_2$
values remained well above the threshold value of 55% above which cerebral ischaemia is very unlikely\textsuperscript{11}.

**Ventilation parameters**

The $\text{Pe'}\text{CO}_2$ concentration increased from 4.12 (0.40) kPa at $T_{10}$ to an average of 4.79 (0.40) kPa during Trendelenburg position ($p<0.001$). There were 178 paired $\text{Pe'}\text{CO}_2$-$\text{PaCO}_2$ values. The arterial-to-$\text{Pe'}\text{CO}_2$ gradient increased from 1.06 (0.40) kPa before Trendelenburg positioning to 1.46 (0.53) kPa after 120 minutes of steep Trendelenburg ($p<0.001$). $\text{Pe'}\text{CO}_2$ and $\text{PaCO}_2$ were highly correlated. The correlation coefficients (linear regression) before, during, and after Trendelenburg positioning were 0.68 ($p<0.0001$), 0.84 ($p<0.0001$) and 0.58 ($p<0.002$), respectively. Further analysis was conducted in order to identify the range of $\text{Pe'}\text{CO}_2$ values in which accuracy would be maximized in relation to $\text{PaCO}_2$. Figure 3 shows the regression lines for the pre-, peri- and post-Trendelenburg period, respectively.

The respiratory plateau pressure ($P_{\text{Plat}}$) gradually increased from 14(4) cm H$_2$O at $T_{10}$ to 20(5) cm H$_2$O after applying a moderate CO$_2$ peritoneum during moderate Trendelenburg positioning, and then further to 26(6) cm H$_2$O at $T_5$. Thereafter, it remained stable at 26(5) cm H$_2$O throughout the Trendelenburg period. After reinstitution of supine position, $P_{\text{Plat}}$ returned to 15(4) cm H$_2$O, which was not different ($p>0.1$) from the baseline value. Reciprocally, the compliance decreased gradually from 50(15) ml/cm H$_2$O at $T_{10}$ to 23(6) ml/cm H$_2$O at $T_0$ and remained stable at 23 (5) ml/cm H$_2$O throughout the Trendelenburg period. After reinstitution of supine position, the compliance returned to 45(13) ml/cm H$_2$O, which is significantly ($p<0.01$) lower than the baseline value.

**Arterial-to-End Tidal CO$_2$ tension gradient**

Figure 2 shows the evolution of Arterial-to-End Tidal CO$_2$ tension gradient measured just before induction of the peritoneum (S), subsequently at 30 minute intervals after Trendelenburg (T1-T9) and 15 (S1) and 30 (S2) minutes after reassuming the supine position.

![Figure 2: Evolution of Arterial-to-End Tidal CO$_2$ tension gradient.](image-url)
Figure 3 shows the relationship between PaCO$_2$ and Pe'CO$_2$. Linear regression lines are shown for the pre-, peri- and post-Trendelenburg period. The regression lines in the three periods deviate significantly. In the pre-Trendelenburg and post-Trendelenburg period, the slope of the regression line is lower than the unity line, while in the Trendelenburg period, the slope is steeper than the unity line. This observation indicates that during Trendelenburg position, there is a stronger underestimation of the true carboxaemia at higher levels of Pe'CO$_2$. Our data suggest that in these circumstances, maintaining a Pe'CO$_2$ between 4.0-4.66 kPa will result in a PaCO$_2$ between 4.66-6.00 kPa.

None of the patients showed any signs of brachial plexus injury. No patient required blood transfusion. All patients could leave the post-anaesthesia care unit after 224(49) minutes with an Aldrete score of 10/10 and were discharged from hospital after the urinary catheter was removed on day 6.

**Discussion**

*Haemodynamical considerations*

Compared with the classical open procedure, robotic endoscopic radical prostatectomy may offer many benefits.$^{1,2}$ Steep Trendelenburg position (40°) optimizes surgical exposure during robotic prostatectomy, and although apparently well tolerated by most patients, the combined effect of this extreme Trendelenburg position and CO$_2$ pneumoperitoneum during these long procedures has not been completely defined. In this observational study of a group of 31 patients undergoing robotic prostatectomy we observed that although the steep Trendelenburg position
combined with a CO₂ pneumoperitoneum did statistically significantly influence cardiovascular, cerebrovascular and respiratory homeostasis, all investigated parameters remained within a clinically acceptable range. During institution of steep Trendelenburg position, the MAP and CVP increased significantly. Firstly, the observed increase in pressure is the result of increased hydrostatic pressure at the external auditory meatus caused by the tilting of the table. In addition, because the MAP increased a greater absolute amount than the CVP (34 versus 23 mmHg respectively), at least part of the increase in MAP must also be caused by increased cardiac output and/or systemic vascular resistance. O’Malley and colleagues demonstrated that these changes are caused by an increased intra-abdominal pressure compressing the aorta and increasing the afterload, possibly further enhanced by humoral factors. Secondly, trans-esophageal Doppler measurements have shown a significant increase in stroke volume when patients are placed in the steep Trendelenburg position. This is consistent with our observation of a concomitant increase in MAP and decrease in HR after institution of steep Trendelenburg position.

Since there is a greater increase in MAP than in CVP, the CPP increases significantly after institution of steep Trendelenburg position, compared to the baseline value. Over subsequent hours, the MAP, CVP and HR remained stable. After reassuming the supine position, both the MAP and CVP decreased significantly, but remained within acceptable ranges. During the whole procedure, the CPP remained well above what is considered to be the lower limit for autoregulation of cerebral blood flow. Although the SpO₂ decreased modestly during steep Trendelenburg position, it also remained well within safe values (above 90 %) in all patients during the whole procedure.

**Oxygenation considerations**

Near-infrared spectroscopy (NIRS) technology has recently been developed to enable continuous and noninvasive monitoring of regional cerebral tissue oxygen saturation for several indications. The different absorption characteristics of oxygenated and deoxygenated haemoglobin for different wavelengths of light allow determination of the balance between cerebral oxygen supply and demand. The first generation of NIRS devices used two LED-sources to estimate the regional oxygen saturation. These devices have recently been used to assess the trend of SctO₂ during robotic prostatectomy. An important limitation of this technique is that absolute values are relatively unreliable. Although the trends in first-generation SctO₂ values provide some useful information, the interpretation of these values, and the identification of threshold values with high sensitivity and specificity for ischaemia is difficult. The second generation of NIRS devices, applied in our study, uses a combination of four monochromatic LASER beams – each of which comprises a very narrow spectrum of light frequencies – which facilitates the accurate measurement of absolute values of SctO₂ and a more secure determination of safe threshold values.
In our patients, SctO$_2$ remained well above the safe threshold value of 55% in each patient, throughout the duration of the procedure. After institution of Trendelenburg position and CO$_2$ insufflation, the SctO$_2$ increased significantly. NIRS estimates the oxygen saturation of arterial and venous blood haemoglobin in the frontal cortex. In its algorithm, a 70% venous blood fraction is assumed$^{11}$. During these procedures with increased resistance to cerebral venous drainage, a relative increase in venous blood fraction is likely but would tend to result in a decrease in calculated SctO$_2$.

Soon after institution of Trendelenburg position, an increase of the SctO$_2$ is observed. This was probably caused by a combination of increased CPP, and an increase in Pe’CO$_2$, together resulting in increased cerebral blood flow and consequently in a decreased oxygen extraction ratio. If an extra-peritoneal surgical approach is undertaken, a more prominent increase in Pe’CO$_2$ may be expected. These findings are consistent with the results from Park and coworkers$^6$ using a first generation NIRS device. In their study, they concluded that the cerebral oxygenation increased slightly during a combined pneumoperitoneum and Trendelenburg position and that PaCO$_2$ should be maintained within normal limits in that situation. The increase in Pe’CO$_2$ towards the end of the procedure is a possible explanation for the increase in SctO$_2$ since the resulting vasodilatation, associated with an essentially unchanged CPP, would tend to increase cerebral blood flow and consequently SctO$_2$.

**Ventilation considerations**

Maintaining a physiologic arterial CO$_2$ tension is of special concern during this combination of altered respiratory physiology and CO$_2$ pneumoperitoneum. In addition to increasing the ICP, an increased Pe’CO$_2$ during steep Trendelenburg positioning causes choroidal vasodilatation and an increase in intraocular pressure$^{16}$. Beyond the obvious concern of preserving overall metabolic homeostasis and optimal brain perfusion, maintaining an acceptable Pe’CO$_2$ tension is therefore imperative to minimize the risk of serious ocular consequences, such as complete bilateral visual loss$^{17}$. Whereas Pe’CO$_2$ monitoring has proven to be an acceptable alternative to arterial blood gas PCO$_2$ in many clinical circumstances, the utility of Pe’CO$_2$ monitoring in the assessment and management of patients with a combined steep Trendelenburg position and CO$_2$ peritoneum has remained largely undefined. Therefore, we examined the level of agreement between PaCO$_2$ and Pe’CO$_2$ to determine if Pe’CO$_2$ analysis is a sufficient guide for the management of the ventilation strategy in this clinical setting.

The arterial-to-Pe’CO$_2$ tension difference of 1.06 kPa in normal position increases to a maximum of 1.41 kPa after two hours in Trendelenburg position and tends to decrease back to normal pre-Trendelenburg values thereafter. The steeper slope of the regression line (figure 3) in Trendelenburg position reflects an underestimation by the Pe’CO$_2$ of the PaCO$_2$ at higher Pe’CO$_2$ levels.
As expected, the plateau pressure increased with institution of the pneumoperitoneum and Trendelenburg position. There was no significant additional increase in pressure during the course of the operation. After reinstitution of the supine position, the plateau pressure returned to a level slightly above baseline values. Equivalently, the pulmonary compliance dropped from a 50 ml/cm \( \text{H}_2\text{O} \) baseline value to 23 ml/cm \( \text{H}_2\text{O} \) after Trendelenburg positioning and \( \text{CO}_2 \) insufflation and remained stable during the Trendelenburg period. After reinstitution of the supine position, a moderate residual loss of pulmonary compliance was observed. This is probably caused by basal atelectasis, a residual cephalad displacement of the diaphragm and restriction in diaphragmatic mobility\(^{18}\).

**Positioning considerations**

Brachial plexus injury due to prolonged caudad displacement of the shoulders is a possible complication of robotic prostatectomy positioning\(^{19}\) and is of special concern. The use of a support system which limits this caudad pressure on the shoulders (because part of the patient’s weight is supported by the spinal column) may prevent patients from developing brachial plexus injuries.

**Conclusion**

We found that a combination of prolonged steep Trendelenburg position and \( \text{CO}_2 \)-pneumoperitoneum was well tolerated. Haemodynamic and pulmonary parameters remained within physiologic limits. Regional cerebral oxygenation was well preserved and the cerebral perfusion pressure remained above the lower limit of the cerebral autoregulation. Maintaining a \( \text{Pe’CO}_2 \) between 3.40-4.66 kPa results in a \( \text{PaCO}_2 \) between 4.66-6.00 kPa. No peripheral or central nervous deficits were detected following the procedure.
References

Addendum to Chapter 6

Discussion concerning chapter 6 between Dr Andrew George and our group as published in

In response to our article in the British Journal of Anaesthesia, an interesting letter was sent to the editor by Dr. Andrew George, concerning a possible strategy to attenuate the postoperative confusional state after steep Trendelenburg position.

I read with interest your article on the effect of steep Trendelenburg position.

My surgeon does a lot of Laparoscopic Abdominal work. These procedures can last up to six hours and involves a steep head down Trendelenburg and left or right tilt, to the extremes of the table mechanism. I agree with their findings regarding the changes in stroke volume and cardiac function and was extremely pleased to see their results regarding cerebral oxygen saturations. They do briefly mention changes in ICP (intra cranial pressure) but do not elaborate further. It is my impression from many cases of this sort that the ICP does rise and despite relative normocapnoea and blood pressure maintenance some of these patients suffer an acute confusional state post operatively.

Since the addition of dexamethasone 8mg into our post operative nausea and vomiting regime this only occurred in the diabetic patients who were not given dexamethasone. Due to this observation I now give all my patients dexamethasone and monitor and treat the changes in the blood sugar as appropriate. Further once the surgeons have finished the laparoscopic part of the surgery and are closing the abdominal wounds I use a reverse Trendelenburg, as much as surgery allows, until the end of surgery. This appears to prevent any postoperative acute confusion. Have the investigators noticed anything similar and how do they manage these patients and this problem?

In response to this letter, we confirmed our experience concerning the postoperative confusional state. The report of successful use of dexamethasone for preventing this confusion is very interesting in two different aspects.

On the one hand, if confirmed in a controlled study, it could be used as a clinical tool. However, one should consider the possible side effects with regard to the possible influence of immuno-suppression on tumour recurrence. Since the confusional state is a benign condition that recovers spontaneously, potentially harmful medical interventions should be considered carefully.

On the other hand if corticoid treatment significantly diminishes the confusional state, then it suggests that the potential pathogenesis of this state may involve cerebral inflammation and/or oedema. Since these processes can have delayed secondary harmful effects, dexamethasone may form part of a potential preventive strategy for delayed postoperative cognitive dysfunction.

We responded the interesting comments of Dr. George as follows:
We thank Dr. George for his interest in our article and his interesting comments.

We also commonly observe a short-lived period of postoperative confusion after prolonged Trendelenburg positioning. While we do not have personal experience with dexamethasone for this indication, in our clinical practice we do tend to keep the patients sedated for another 60 minutes after long procedures.

The hypothesis that this confusional state may be caused by cerebral oedema prompted us to perform a follow-up study in which we focused on cerebral perfusion. In this study (currently undergoing peer review) we did not show an influence on cerebral perfusion parameters, but of course this does not exclude a degree of cerebral oedema. Thus the idea, of using dexamethasone to prevent the confusional state by attenuating oedema, is interesting and is worthy of further scientific investigation as to its efficacy and safety (e.g. with regard to the possible influence of immuno-suppression on tumour recurrence).

While we understand the rationale for head up positioning at the end of the procedure, we would advise caution with this approach, since sudden reverse Trendelenburg positioning in patients who frequently have relative hypovolemia and may have cerebral oedema, may impair cerebral perfusion.
Addendum to Chapter 6

Multiple choice exam for Continuous Medical Education credits from the UK Royal College of Anaesthetists.
During the editing process of the April 2010 issue of the British Journal of Anaesthesia, the manuscript entitled “The influence of steep Trendelenburg position and CO\textsubscript{2} pneumoperitoneum on cardiovascular, cerebrovascular and respiratory homeostasis during robotic prostatectomy”, which forms chapter 6 of this thesis, was selected by the editors of the BJA as one of two articles worthy of CME (Continuing Medical Education) credits from the Royal College of Anaesthetists (RCoA, UK). In the UK doctors must gain a certain number of CME credits per year to be able to maintain their license to practice. The intended audience comprises anaesthetists and others involved in anaesthesia, critical care and pain.

For this purpose, fifteen multiple choice questions were formulated. The questions affirm knowledge of the topics covered. CME questions are published online (www.oxforde-learning.com/bja).

Question 1
Cerebral perfusion pressure (CPP): is determined by mean arterial pressure (MAP) and either central venous pressure (CVP) or intracranial pressure (ICP)  
○ True  ○ False

Question 2
Cerebral perfusion pressure (CPP): decreases after induction of pneumoperitoneum and the steep Trendelenburg position  
○ True  ○ False

Question 3
Cerebral perfusion pressure (CPP): is the main determinant of cerebral tissue oxygen saturation (SctO\textsubscript{2})  
○ True  ○ False

Question 4
Cerebral perfusion pressure (CPP): decreases after table position normalization at the end of the procedure  
○ True  ○ False

Question 5
Cerebral perfusion pressure (CPP): can be influenced by the pressure in the pneumoperitoneum  
○ True  ○ False

Question 6
Regional cerebral tissue oxygen saturation determined by near infrared spectroscopy: is measured using pulsatile flow through the grey matter of the frontal cortex.  
○ True  ○ False

Question 7
Regional cerebral tissue oxygen saturation determined by near infrared spectroscopy: always decreases in the steep Trendelenburg position because of a relative increase in the venous blood fraction  
○ True  ○ False

Question 8
Regional cerebral tissue oxygen saturation determined by near infrared spectroscopy: can give trend values but not absolute values  
○ True  ○ False
Question 9
Regional cerebral tissue oxygen saturation determined by near infrared spectroscopy: can be determined by passing laser beams through the brain
O True O False

Question 10
Regional cerebral tissue oxygen saturation determined by near infrared spectroscopy: increases when PaCO₂ increases
O True O False

Question 11
With induction of the combined steep Trendelenburg position and pneumoperitoneum: the arterial-to-end tidal tension difference increases with increasing PaCO₂.
O True O False

Question 12
With induction of the combined steep Trendelenburg position and pneumoperitoneum: sliding of the patient from the table can safely be prevented with classical shoulder supports
O True O False

Question 13
With induction of the combined steep Trendelenburg position and pneumoperitoneum: eye injuries are of special concern
O True O False

Question 14
With induction of the combined steep Trendelenburg position and pneumoperitoneum: there is a loss in pulmonary compliance, which does not spontaneously recover completely after normalization of the table position
O True O False

Question 15
With induction of the combined steep Trendelenburg position and pneumoperitoneum: CO₂ resorption will be greater with a transperitoneal than with an extraperitoneal surgical approach
O True O False

The correct answers are provided at the end of the evaluation.

Question 1
True. The CPP is determined as the difference between the MAP and the greater of the CVP and ICP. In the context of the steep Trendelenburg position, it is appropriate to estimate the CPP from the MAP and CVP.

Question 2
False. The increase of the hydrostatic pressure at the cerebral level is equal in the MAP and CVP. However, because of increased afterload and preload, the MAP increases more than the CVP, resulting in a net increase in CPP.
Question 3
False. As long as the CPP is within the autoregulation zone, the CBF will be independent of the CPP. In this surgical procedure, the PaCO2 is the main determinant of the SctO2.

Question 4
True. A sudden drop in venous return causes a decrease in the MAP. Administration of intravenous fluid should be considered.

Question 5
True. The intraperitoneal pressure has influence on the venous return and on the vascular resistance, thus influencing the MAP and the CVP.

Question 6
False. Converse to the pulse oximetry of arterial oxygen saturation, the SctO2 measures the mixed venous and arterial oxygen saturation. A 70% venous blood fraction is assumed.

Question 7
False. In this study, the SctO2 even slightly increased. A decrease in SctO2 should not be attributed to a shift in blood fractions and other causes should be considered.

Question 8
False. First generation devices only give trend values. Second generation devices are able to give absolute values.

Question 9
True. Second generation NIRS devices use four different wavelengths of monochromous laser light to determine the absolute value of the cerebral tissue oxygen saturation.

Question 10
True. Hypercapnia increases the cerebral blood flow and consequently increases the fraction of arterial blood and decreases the oxygen extraction ratio. This results in an increased SctO2.

Question 11
True. Maintaining a Pe’CO2 between 4.0-4.7 kPa will result in a PaCO2 between 4.7-6.00 kPa.

Question 12
False. Extra support of the spinal column should be provided to limit caudad displacement of the shoulders to prevent brachial plexus injury.

Question 13
True. Hypercapnia and increased intracranial pressure cause choroidal vasodilatation and increase intraocular pressure, which may lead to ocular injuries.

Question 14
True. There is residual loss in pulmonary compliance. Therefore a recruitment manoeuvre at the end of the procedure may be beneficial.

Question 15
False. If an extra-peritoneal surgical approach is undertaken, a more prominent increase in Pe’CO2 may be expected.