Effects of steep Trendelenburg position for robotic-assisted prostatectomies on intra- and extrathoracic airways in patients with or without chronic obstructive pulmonary disease

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Editor’s key points
- Prolonged use of the steep Trendelenburg position during surgery can cause upper airway oedema and reduced lung compliance.
- This study found that airway resistance and nasal flow decreased at 2 h after robotic prostatectomy.
- These changes had resolved by 24 h but were more marked in patients who also developed conjunctival oedema.
- In these patients, chemosis after surgery is associated with upper airway oedema.

Background. The use of the steep Trendelenburg position and abdominal CO₂-insufflation during surgery can lead to significant reduction in pulmonary compliance and upper airway oedema. The postoperative time course of these effects and their influence on postoperative lung function is unknown. Therefore, we assessed intra- and extrathoracic airway resistance and nasal air flow in patients with or without chronic obstructive pulmonary disease (COPD) during robotic-assisted prostatectomy.

Methods. In 55 patients without and 20 patients with COPD spirometric measurements and nasal resistance were obtained before operation, 40 and 120 min, and 1 and 5 days after operation. We measured vital capacity (VC), forced expiratory volume in 1 s (FEV1), maximal mid-expiratory and inspiratory flow (MEF50, MIF50), arterial oxygen saturation, and nasal flow. The occurrence of postoperative conjunctival oedema (chemosis) was also assessed.

Results. In patients without COPD, MEF50/MIF50 increased and nasal flow decreased significantly after surgery (P<0.0001) and normalized within 24 h. VC and FEV1 decreased after operation with a nadir at 24 h and recovered to normal until the fifth day (P<0.0001). In patients with COPD, changes in MEF50/MIF50 and nasal flow were similar, while changes in VC and FEV1 lasted beyond the fifth day (P<0.0001).

Conclusions. Robotic-assisted prostatectomy in the steep Trendelenburg position led to an increase in upper airway resistance directly after surgery that normalized within 24 h. The development of chemosis can be indicative of increased upper airway resistance. In patients without COPD, VC and FEV1 were reduced after surgery and recovered within 5 days, while in patients with COPD, the alteration lasted beyond 5 days.

Keywords: airway resistance; head-down tilt; prostatectomy, robotic assisted; pulmonary disease, chronic obstructive; respiratory function tests; surgical procedures, minimal invasive

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Minimal invasive robotic-assisted prostatectomies offer fast recovery, low postoperative pain scores, minimal blood loss, and good functional results.¹–⁴ Therefore, robotic-assisted prostatectomies have found widespread acceptance and are already the preferred technique for this type of surgery.¹–⁴ However, during surgery, this technique requires the steep Trendelenburg position and abdominal gas insufflation. The steep Trendelenburg position for several hours can lead to expression of oedema of the head and neck and reduction in pulmonary compliance,⁵–⁷ and might lead to oedema of the upper airway. In fact, there has already been reported a case of severe dyspnoea because of an upper airway oedema with the need for reintubation of the patient.⁸

In 2006, Chiu and colleagues⁹ demonstrated that fluid shifts from the lower body increases pharyngeal resistance in healthy subjects. Increased upper airway resistance compromises inspiration more than expiration and can clinically be diagnosed by inspiratory stridor. For quantification of changes in upper airway resistance, measurements of the ratio of maximal expiratory flow divided by maximal inspiratory flow at 50% of vital capacity (VC) (MEF50/MIF50) have been established.¹⁰ In addition, measurements of nasal flow can give information about the resistance in the uppermost part of the airway.

Besides alteration of upper airway resistance, robotic-assisted prostatectomies in the Trendelenburg position can lead to significant reduction in pulmonary compliance.⁵–⁷ Therefore, not only upper airway resistance is affected, but also pulmonary ventilation. Because patients with an already compromised pulmonary function might be even more at risk to suffer from altered lung function, we not only evaluated
lungs function in patients free of pulmonary disease but also in patients with chronic obstructive pulmonary disease (COPD).\textsuperscript{11–13}

Overall, to evaluate the influence of robotic-assisted prostatectomy in the Trendelenburg position, we assessed parameters of intra- and extrathoracic resistance and nasal airflow, directly after surgery and during the following week. Our primary hypothesis was that there was no change in the ratio of MEF50 over MIF50, as a parameter of extrathoracic airway resistance, directly after surgery compared with preoperative baseline.

**Methods**

**Patients**

After approval by the local ethics committee (Chamber of Physicians of Nordrhein, Düsseldorf, Germany, Registration-Number 114/2009), 60 patients without COPD and 20 patients with COPD were enrolled in this study. All of the patients with COPD were already diagnosed with COPD before surgery by their internists or pulmonologists. Diagnoses were made according to the GOLD classification.\textsuperscript{14} Subsequently, the diagnosis was confirmed by their history of symptoms and their baseline lung function measurements. Based on our baseline lung function measurements, we enrolled three patients with COPD stage I, 14 patients with stage II, and three patients with stage III (Fig. 1).\textsuperscript{16}

All patients were undergoing a robotic-assisted prostatectomy and gave their informed written consent to participate in this study. None of the patients had a history of significant cardiac diseases or obstructive sleep apnoea syndrome.

**Methods**

Lung function measurements were performed with a spirometer (pneumotachograph, VIASIS, Würzburg, Germany). On the day before surgery, in all patients baseline VC, forced expiratory volume in 1 s (FEV1), maximal expiratory flow at 50% of the VC (MEF50), and maximal inspiratory flow at 50% of the VC (MIF50) were assessed in the sitting position. In addition, nasal flow was measured separately for the right and left side at the end of each measurement.\textsuperscript{15–17}

With respect to the influence of a change in posture from the sitting to supine position,\textsuperscript{18,19} all subsequent measurements were performed in the supine position with the upper body tilted upwards by 40°. According to international guidelines, the best of three measurements was used for analysis.\textsuperscript{20}

**Protocol**

On the morning of surgery, lung function measurements and nasal flow were recorded in the supine position. Before surgery, a peripheral i.v. cannula was sited and standard monitoring (ECG, non-invasive arterial pressure measurement, pulse oximetry) was applied. Twenty-six of the patients without COPD and all of the patients with COPD received a low-thoracic epidural catheter at T9/10 or T10/11 thoracic vertebral interspace. After the placement of the epidural catheter, general anaesthesia was induced with propofol, remifentanil, and mivacurium and maintained with isoflurane and remifentanil. Mechanical ventilation was set to a tidal volume of 6–8 ml kg\textsuperscript{−1} body weight and an end-expiratory pressure of 5–7 cm H\textsubscript{2}O according to the attending anaesthetist with the intention to achieve normoventilation (end-expiratory CO\textsubscript{2} of <38 mm Hg).

In patients without an epidural catheter, neuromuscular block was maintained with repeated administration of mivacurium. Train of four was controlled at the end of surgery and the patients’ trachea was extubated when the train of four showed a recovery to >95% from baseline.

Forty minutes after extubation of the trachea, the first lung function and nasal flow measurements were performed in the recovery room and repeated after 120 min, 24 h, and after 5 days. Always at the time of the lung function measurements, pain (Numerical Rating Score, with 0 for no pain and 10 for worst imaginable pain) and the presence of conjunctival oedema (chemosis) were assessed. Chemosis was assessed as clinically present or not. In the case of questionable chemosis formation, it was described as ‘no chemosis’. According to the ophthalmological score for chemosis, ‘No’ would include grades 0 and 1, while ‘Yes’ would include grades 3 and 4.\textsuperscript{21}

**Data analysis**

Sample size calculation was based on the primary hypothesis that there is no significant difference in the MEF50/MIF50 ratio with a difference to detect of minimal 0.10. Calculations were based on an \( \alpha \)-error of 0.05, a \( \beta \)-error of 0.8, and a standard deviation of 0.15. The result was a minimal number of 19 patients. We rounded the number to 20 for the group of patients with COPD and enrolled 60 patients free of pulmonary disease.

In addition, three secondary hypotheses were tested. First, there was no difference in VC within each group when values before and after surgery were compared. Secondly, there was no difference in FEV1 within each group when values before and after surgery were compared. Thirdly, there was no difference in nasal flow within each group when values before and after surgery were compared.

The primary hypothesis was tested by analysis of variance (ANOVA) for repeated measurements followed by a post hoc test with the Bonferroni correction for multiple testing. Patients’ characteristics were tested by Student’s t-test. Null hypotheses were rejected and significant differences assumed with \( P<0.05 \).

In addition, we tested for a statistical difference between patients with or without chemosis with respect to the ratio of MEF50/MIF50 or nasal flow before vs directly after surgery. The effects of chemosis on nasal flow and MEF50/MIF50 were tested by repeated-measures ANOVA.

Data are presented as mean and 95% confidence intervals or as box plots as indicated.
Results

Patient characteristics

Five of the patients without COPD were excluded because of incomplete data sets. Two patients were not able to follow commands and perform lung function measurements in the first two postoperative hours. Another two patients refused to perform postoperative measurements on the day of surgery. One patient was not available after operation for the last two measurements.

Characteristics of the patients, duration of surgery, and the amount of intraoperative fluid administration are presented in Table 1. There were no statistical differences in the lung function measurements, nasal flow, and oxygen saturation between patients with or without epidural anaesthesia.

Primary outcome measure

As the primary outcome measurement, the ratio of MEF50 divided by MIF50 was assessed. There was a significant difference for both groups over time and a constant difference between patients with normal lung function and patients with COPD ($P<0.0001$; Fig. 2).

Secondary outcome measures

According to the diagnosis of COPD, baseline measurements on the day before surgery of VC and FEV1 differed significantly...
between the groups \(P<0.0001\); Table 2). These data describe the baseline of the two groups and are not included in the analysis of repeated measurements. VC and FEV1 changed significantly with a change in posture from sitting to supine for both groups \(P<0.0001\) for patients without COPD and \(P=0.0013\) and \(<0.0001\) for patients with COPD).

Compared with the baseline in the supine position at the morning of surgery, VC and FEV1 decreased significantly after operation with a nadir at 24 h \(P<0.0001\); Fig. 3 and Table 3. Albeit not statistically significant with respect to repeated measurements, VC and FEV1 were still reduced at the fifth day by 2% (VC) and 1% (FEV1) for patients without and by 8% (VC) and 9% (FEV1) for patients with COPD, respectively (Fig. 3 and Table 3). The decline in FEV1 at 24 h after operation correlated with BMI in patients with COPD \((R=0.44)\).

**Nasal flow**

Nasal flow was not different between the groups \((P=0.9472\) for inspiratory flow and \(P=0.7740\) for expiratory flow), but decreased significantly after surgery for both groups and normalized after 24 h \((P<0.0001\) for inspiratory and expiratory flow; Fig. 4). The reduction in nasal flow correlated with the occurrence of chemosis directly after surgery. For patients without chemosis, nasal flow decreased slightly from 384 (303–465; 95% CI) to 360 ml s\(^{-1}\) (257–463), while nasal flow in patients with chemosis decreased significantly from 408 (311–505) to 225 ml s\(^{-1}\) (124–326); \(P=0.0209\).

**Oxygen saturation**

Arterial oxygen saturation was measured at the beginning of the measurements before forced respiratory manoeuvres for lung function measurements. There was a significant difference between patients with and without COPD at baseline \((P=0.0150)\).

The oxygen saturation decreased significantly for both groups after operation \((P<0.0001)\) and was still reduced after 24 h and recovered to baseline during the subsequent 5 days for both groups (Table 3).
Pain score

Pain level of the patients was evaluated before each lung function measurement. In four patients without COPD, additional pain medicine had to be administered to achieve a pain score of 2 or less.

Chemosis

Chemosis was described in 18 out of 55 patients free of COPD and seven out of 20 patients with COPD. Chemosis resolved in all patients within 24 h. Patients with chemosis showed a significant difference in MEF50/MIF50 ratio between baseline and 40 min after surgery compared with patients without obvious chemosis. In patients without chemosis, the ratio increased from 0.77 (0.66–0.88; 95% CI) to 1.06 (0.89–1.23), while the ratio increased in patients with chemosis from 0.79 (0.62–0.97) to 1.44 (0.97–1.92); P = 0.0111.

Discussion

In both groups, resistance of the upper airway (as indicated by the ratio of MEF50/MIF50) increased and nasal flow decreased directly after surgery with a subsequent return to baseline within 24 h. After robotic-assisted prostatectomies, VC and FEV1 were significantly reduced with a nadir at 24 h but did not fully recover to baseline within 5 days.

Robotic-assisted prostatectomy has found widespread popularity and acceptance over the last decade. Because of the fast recovery of the patients, more and more patients with significant co-morbidities were treated in clinics with robotic programmes. The fast recovery after this type of surgery has even led to the idea of the same-day surgery. However, during surgery, patients have to undergo rather extreme conditions with the Trendelenburg position of 40–45° head-down in combination with abdominal insufflation of CO2. These conditions lead to a reduced pulmonary compliance and oedema of the head and neck. There has been even one report of a significant upper airway oedema after surgery with the need for reintubation. In patients with COPD, these changes might be even more relevant.

Therefore, we assessed airway resistance in three different generations of the airways. We measured VC and FEV1 to assess changes of the intrathoracic airways, the ratio of MEF50/MIF50 as an indicator of extrathoracic airways, and nasal flow as the upper most part of the airways. There have been several studies of postoperative lung function describing minor decreases in VC and FEV1 after lower abdominal surgery within the range of our results. This phenomenon is also reflected in low arterial oxygen saturation after the first night. We can only speculate that the patients suffer from residual ventilation/perfusion mismatch close to the diaphragm because of general anaesthesia and increased abdominal pressure resulting in hypoventilation during the first night. In accordance with a previous study in patients with COPD, the decline in FEV1 correlated directly with the BMI.

Nevertheless, patients free of COPD regained their full lung function within 5 days. Only patients with COPD still had a reduced VC (8%) and FEV1 (9%) at the end of their hospital stay. Therefore, VC and FEV1 are not more compromised after robotic-assisted surgery than after similar lower abdominal surgery. Only in patients with COPD, we should be aware of a prolonged reduction in lung function and might recommend respiratory therapy beyond 1 week.

Our interest in this topic was raised by a case report of increased upper airway resistance after robotic-assisted surgery and complaints of several patients about compromised nasal breathing often combined with chemosis and swelling of eye lids. What we found was a significant increase

Table 3 VC and arterial oxygen saturation (SO2) of 20 patients with and 55 patients without COPD (control) before and after robotic-assisted prostatectomy [mean; 95% confidence interval (CI)]

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>40 min</th>
<th>120 min</th>
<th>24 h</th>
<th>5 days</th>
<th>P-value</th>
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<tbody>
<tr>
<td>VC (COPD) (litre; CI)</td>
<td>3.35 (2.98–3.73)</td>
<td>2.64 (2.32–2.96)</td>
<td>2.82 (2.50–3.14)</td>
<td>2.63 (2.32–2.94)</td>
<td>3.05 (2.77–3.33)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>VC (control) (litre; CI)</td>
<td>4.28 (4.10–4.46)</td>
<td>3.45 (3.21–3.69)</td>
<td>3.74 (3.51–3.97)</td>
<td>3.28 (2.95–3.61)</td>
<td>3.35 (3.13–3.57)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SO2 (COPD) (%) (CI)</td>
<td>95 (93–97)</td>
<td>89 (87–91)</td>
<td>92 (91–93)</td>
<td>93 (91–95)</td>
<td>95 (94–96)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SO2 (control) (%) (CI)</td>
<td>96 (95–97)</td>
<td>91 (90–92)</td>
<td>93 (92–94)</td>
<td>94 (93–95)</td>
<td>96 (95–97)</td>
<td>&lt;0.0001</td>
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Fig 4 Box plot of the nasal flow of patients without pulmonary disease (blue boxes; n = 55) and patients with COPD (green boxes; n = 20) over time. Nasal flow was significantly reduced after surgery and returned to baseline within 24 h.
in the upper airway resistance expressed by the increase in the MEF50/MIF50 and a significant decrease in nasal flow. Both changes have not been fully reversed after 2 h but were resolved at the control after 24 h. However, with repositioning of the patients in 30° head-up position, the alterations already start to improve within the first 2 h.

Overall, this development seems to be independent of pre-existing pulmonary disease and shows some correlation with the expression of chemosis. The increase in the MEF50/MIF50 ratio and alterations of nasal flow correlated with the expression of chemosis. Therefore, our results support the recommendations for a restrictive intraoperative fluid management.5 7 Moreover, patients with substantial chemosis formation should be watched carefully for upper airway oedema.

There are several limitations to our study. Most important, lung function measurements in the first hours after operation can be hampered by reduced vigilance of the patients, residual neuromuscular block, and pain.33

First, we were fully aware that manoeuvres such as VC and FEV1 measurements are highly dependent on the cooperation of the patients and might be altered by postoperative effects of general anaesthesia. However, based on previous studies which presented reliable measurements 20–30 min after tracheal extubation and pilot measurements in patients before the start of the study, we felt confident that patients could perform deep breath and forced manoeuvres 40 min after tracheal extubation.32 33

However, two patients were slightly disorientated and not able to perform reliable measurements even after 120 min. Consequently, these two patients were excluded from the analysis.

Secondly, residual neuromuscular block could be excluded in patients with epidural anaesthesia because they received only a last short-acting neuromuscular blocking agent for intubation of their trachea. In the other half of the patients, accelerometry was performed at the end of surgery and showed percentages of 97% and more, which makes an influence of residual neuromuscular block on lung function measurements 40 min later, unlikely.33

Thirdly, to rule out the influence of pain on lung function measurements, lung function measurements were performed when patients described their pain with a pain score of < 3 after a deep breath. For patients, who underwent thoracic or upper abdominal surgery, significant differences in postoperative lung function between patients with or without additional epidural anaesthesia have been described. However, in our study, we only had patients with lower abdominal endoscopic surgery in whom significant differences in postoperative lung function have not been observed.28 29 Furthermore, with an intraindividual comparison, every patient has served as his own control and the choice of pain therapy should not have influenced our results.

In conclusion, we found two separate aspects that alter airway resistance and lung function after robotic-assisted prostatectomy in the steep Trendelenburg position independent of pre-existing pulmonary diseases. On the one hand, we found an early resolving increase in upper airway resistance because of airway oedema, which corresponded to some degree with the expression of chemosis and, on the other hand, a longer lasting affection of VC and FEV1. The decrease in VC and FEV1 was more pronounced in patients with COPD and could be demonstrated even 5 days after surgery.

Authors’ contributions
O.F.K. and W.K. performed lung function measurements, recruited patients, and contributed to the manuscript. A.B. contributed to the design of the study and performed lung function measurements. M.M. and D.K. gave their urological input to the study design and contributed equally to the manuscript and to the logistics of the study. H.G. initiated the study, wrote the study proposal for the ethics committee, calculated the final statistics, and wrote the main part of the final manuscript.

Declaration of interest
None declared.

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