



The impact of obesity on pulmonary deterioration in patients undergoing robotic-assisted laparoscopic prostatectomy

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Abstract

Obesity affects respiratory and hemodynamic function in anesthetized patients. The aim of this study was to evaluate the influence of the body mass index (BMI) on pulmonary changes in a permanent 45° steep Trendelenburg position (STP) during robotic-assisted laparoscopic prostatectomy (RALP). 51 patients undergoing RALP under standardized anesthesia were included. Perioperative pulmonary function and oxygenation were measured in awake patients (T_0), 20 min after the induction of anesthesia (T_1), after insufflation of the abdomen in supine position (T_2), after 30 min in STP (T_3), when controlling Santorini's plexus in STP (T_4), before awakening while supine (T_5), and after 45 min in the recovery room (T_6). Patient-specific and time-dependent factor on ventilation and predicted peak inspiratory pressure (PIP), driving pressure (P_{driv}) and lung compliance (LC) in a linear regression model were calculated. PIP and P_{driv} increased significantly after induction of capnoperitoneum (T_{2-4}) ($p < 0.0001$). In univariate mixed effects models, BMI was found to be a significant predictor for PIP and P_{driv} increase and LC decrease. Obese patients a BMI $> 31 \text{ kg/m}^2$ reached critical PIP values $\geq 35 \text{ cmH}_2\text{O}$. Postoperative oxygenation represented by the $\text{PaO}_2/\text{FiO}_2$ ratio was significantly decreased compared to T_0 ($p < 0.0001$). Obesity in combination with STP and capnoperitoneum during RALP has a profound effect on pulmonary function. Increased PIP and P_{driv} and decreased LC are directly correlated with a high BMI. Changes in PIP, P_{driv} and LC during RALP may be predicted in relation to patient's BMI for consideration in the preoperative setting. *Trial registration number* Z-2014-0387-6. Registered on 8 July 2014.

Keywords Lung compliance · Driving pressure · Obesity · Peak inspiratory pressure · Robotic-assisted laparoscopic prostatectomy · Steep Trendelenburg position

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Abbreviations

ASA	American Society of Anesthesia
BE	Base excess
BMI	Body mass index
etCO ₂	End tidal CO ₂
FiO ₂	Inspiratory fraction of oxygen
LC	Lung compliance
MAP	Mean arterial blood pressure
MV	Minute ventilation
PaCO ₂	Partial arterial carbon dioxide fraction
PaO ₂	Partial arterial oxygen fraction
P _{driv}	Driving pressure
PEEP	Positive end-expiratory pressure
PIP	Peak inspiratory pressure
RALP	Robotic-assisted laparoscopic prostatectomy
STP	Steep Trendelenburg position
TIVA	Total intravenous anesthesia
TOF	Train-of-four

1 Background

Prostate cancer is the second most common cancer in men (31.1%) and the fifth leading cause of cancer death (11%) worldwide [1]. Depending on the tumor entity, prostate resection is one possible treatment option. Robotic-assisted laparoscopic prostatectomy (RALP) is a common and increasingly used alternative to open prostatectomy because of benefits such as minimal invasion, better short-term outcome, and improved functional results [2, 3]. RALP requires at least Trendelenburg positioning (STP) with a 23°–35° gradient and CO₂ pneumoperitoneum. The steeper the positioning—thus improving intraabdominal view to reduce bleeding, the better the surgical conditions [4]. STP may lead to pathophysiological changes such as pulmonary dysfunction with formation of atelectasis and increasing airway pressure [5].

Obesity represents a growing health and socioeconomic risk factor worldwide. The World Health Organization classifies adults with a body mass index (BMI) of 25 as overweight and adults with a BMI above 30 as severely overweight (obesity) [6]. According to the Federal Statistical Office in 2013, 62% of German male adults are overweight (BMI ≥ 25 kg/m²) and 17% obese (BMI ≥ 30 kg/m²) [7]. Obesity has been associated with many types of comorbidities, for instance type 2 diabetes mellitus, cardiovascular disease, stroke, and several entities of cancer [8]. Studies on prostate cancer mortality have found consistent associations between obesity and mortality [9, 10]. A meta-analysis showed a slightly increased risk of developing prostate cancer with each 5-unit increase in the BMI [11].

Generally, obesity is associated with a reduction in lung volume and capacity as compared to normal weight subjects.

This concern above all total lung capacity, expiratory reserve volume, functional residual capacity and forced expiratory volume after first second [12–14]. Furthermore obesity results in lower values of partial pressure of arterial oxygen (PaO₂) and higher values of partial pressure of arterial carbon dioxide (PaCO₂) [15]. In accordance with these pulmonary changes obesity is associated with increased work of breathing. These physiological changes are heightened during anesthesia due to the negative impact on the pulmonary mechanics of diaphragm impedance by the abdomen with a change in lung volume [16]. Pelosi et al. reported that the BMI is an important determinant of lung volume, respiratory mechanics, and oxygenation for anesthetized patients in the supine position [17]. Meininger et al. [18] found significantly impaired arterial oxygenation in overweight patients (BMI ≥ 25 and < 30) during RALP.

The aim of this study was to investigate the impact of the BMI and a permanent 45° STP on pulmonary changes (measured by peak inspiratory pressure [PIP], driving pressure [P_{driv}], lung compliance [LC]), and oxygenation (measured by the PaO₂/FiO₂ ratio) in patients undergoing RALP. Based on results we wanted to establish to predict pulmonary changes in dependence of the individual BMI during the different stages of RALP. The hypothesis of this study was that obesity (BMI ≥ 30 kg/m²) negatively affects pulmonary function measured by PIP, P_{driv}, and LC and subsequently results in poorer ventilation.

2 Methods

This single-center prospective nonrandomized study was approved by the local institutional review board (Protocol No. 14-101-0107) and registered at the local Center for Clinical Studies (Z-2014-0387-6. Registered on 8 July 2014). Informed consent was obtained from 51 patients scheduled for elective prostatectomy at the Department of Urology in Regensburg, Germany. All patients were recruited between January 2015 and August 2015. Main exclusion criteria were pre-existing eye disease (diabetic retinopathy, glaucoma, and retinal detachment), age > 80 years, BMI > 40, American Society of Anesthesia (ASA) physical status > III, known cardiac insufficiency, severe pre-existing lung disease such as COPD GOLD III or IV, and pulmonary hypertension.

2.1 Anesthesia protocol and surgical technique

The anesthesia protocol, standardized for drugs used during RALP, was exclusively conducted by the same two anesthesiologists throughout the entire study. Drug dosing was based on the calculated ideal body weight. Patients received 2 mg of midazolam for premedication and 0.1 mg of piritramide per kilogram (kg) body weight for the placement of

a radial artery catheter for invasive blood pressure measurement under additional local anesthesia. Anesthesia was induced with propofol (2–3 mg/kg), remifentanyl (1.5 µg/kg bolus and continuous application of 0.3 µg/kg/min), and rocuronium (0.5 mg/kg). After tracheal intubation with a 7.5 or 8.0 mm endotracheal tube, anesthesia was maintained with propofol (5 to 6 mg/kg) as total intravenous anesthesia (TIVA). A Bispectral Index™ (BIS Vista Monitor, Aspect Medical, Germany) between 40 and 50 was upheld during anesthesia; remifentanyl was reduced to 0.2 µg/kg/min after anesthesia induction. Arterial blood pressure was kept stable using norepinephrine or volume with a maximum decrease of 20% of its pre-induction value. All patients received volume-controlled ventilation with positive end-expiratory pressure (PEEP) between 5 and 8 mmHg, using an inspiration to expiration ratio of 1:1, a basic respiratory rate of 10, and a constant tidal volume of 8 ml/kg ideal body weight. Respiratory frequency was set to keep the end tidal CO₂ (etCO₂) between 30 and 40 mmHg. The inspiratory fractions of oxygen (FiO₂) after the start of RALP were adjusted to maintain oxygen saturation above 96% or partial pressure of arterial oxygen (PaO₂) above 90 mmHg. Pneumoperitoneum was created by intraperitoneal insufflation of CO₂ to a value of 15 mmHg with the patient in supine position. All patients were then consequently placed in STP (45° from horizontal), which is the maximal Trendelenburg angle of the Maquet surgical table (Maquet®, MAQUET Vertrieb und Service Deutschland GmbH, Germany). Throughout the entire surgery, intraabdominal pressure was maintained at 15 mmHg using CO₂ insufflation. During preparation of the Santorini's plexus, intraabdominal pressure was increased up to a maximum of 25 mmHg to reduce venous bleeding. Surgery was always exclusively conducted by the same urologists. Application of crystalloid fluid was restrictive and limited to a maximum of 8–10 ml/kg ideal body weight before terminating vesico-urethral anastomosis. Before extubation all patients were placed in head up position (20°–30°) and received a recruitment maneuvers over 5–10 s. After extubation all patients were transferred to the recovery room under supplementation of oxygen over a face mask.

2.2 Measurements of pulmonary parameters and blood oxygenation

All patients were ventilated with the Primus Ventilator (Dräger Medical, Lübeck, Germany). Lung parameters and blood oxygenation were measured in each patient at pre-defined points in time (Table 1). The following respiratory parameters were registered during mechanical ventilation: fraction of inspired oxygen (FiO₂), minute volume (MV), respiratory rate, PIP, plateau pressure, PEEP, dynamic LC, and etCO₂. Blood gas was analyzed with the Radiometer ABL 800 Flex (Radiometer Medical, Copenhagen, Denmark). The following parameters were investigated: pH value, P_aO₂, PaCO₂, and base excess (BE). Based on PaO₂ and applied FiO₂, the P_aO₂/F_iO₂ ratio (also referred as P/F ratio or Horowitz index) was calculated. From applied oxygen via a face mask in awake patients, FiO₂ was calculated by means of the conversion tables of the EPIC II study [19]. The P/F ratio, which is used for assessing lung function in ventilated patients, is an indicator for hypoxemia. Additionally, we calculated P_{driv} as the difference between plateau pressure and PEEP. A PIP cut-off value of 35 cmH₂O and a P_{driv} cut-off value of 15 cmH₂O were evaluated as possible causes of peri- or postoperative pulmonary dysfunction [20–24]. For data analysis, patients were divided into two groups, namely overweight and obese: BMI < 30 kg/m² (group 1) and BMI ≥ 30 kg/m² (group 2).

2.3 Registration of postoperative hospital stay and pulmonary complications

Postoperatively, all patients were observed in the recovery room, 8 h later on the ward, and on the next day. The occurrence of conjunctival edema (chemosis) and pulmonary complications (e.g. pneumomediastinum, subcutaneous emphysema, pneumonia and pneumothorax) was recorded using clinical examination and reviewing the discharge letter and postoperative X-rays. Chemosis was assessed as clinically present or not. Patients with questionable chemosis

Table 1 Time points of measurement: respiratory parameters and blood gas analysis (BGA)

Time points of measurements		Respiratory parameters	BGA
T ₀	Awake patient in supine position before induction of anesthesia	–	X
T ₁	20 min after induction of general anesthesia in supine position	X	X
T ₂	After insufflation of the abdomen with CO ₂ in supine position	X	–
T ₃	After 30 min in 45° Trendelenburg position with the abdomen still insufflated with CO ₂	X	X
T ₄	Control of Santorini's plexus in 45° Trendelenburg position with CO ₂ still insufflated	X	X
T ₅	Anesthetized before awakening in supine position	X	–
T ₆	After 45 min in the recovery room	–	X

development were described as ‘no chemosis’. The length of postoperative hospital stay was also recorded.

2.4 Statistical analysis

Sample size consideration was based on the assumption that 50 patients yield robust effect estimates. To analyze the influence of age, BMI, and MAP on PIP, P_{driv} and LC, linear mixed models were used. Each variable was analyzed in a separate model, containing time as fixed factor and patient as random factor. Effect estimates of significant variables are presented as slopes (effect on PIP and P_{driv} per one unit change of the variable) with corresponding 95% confidence intervals. Linear regression models were conducted in order to predict the maximum intraoperative PIP, P_{driv} and the lung compliance in dependence of BMI, positioning the stage/stadium of operation. For an easier calculation of the predicted PIP, P_{driv} and the predicted lung compliance, BMI was centered on 20 kg/m^2 for all linear regression models. All reported p-values are two-sided, and a p-value of 0.05 was considered the threshold of statistical significance. Due to the explorative nature of this study, no adjustment for multiple testing was done. Data were analyzed using the software SAS 9.4 (SAS Institute Inc., Cary, NC) by a biomathematician.

3 Results

Fifty one men were enrolled in this study. Mean age of all patients was 63.7 years and the average BMI 28.4 kg/m^2 . Five patients were classified ASA I (9.8%), 38 patients (74.5%) ASA II, and eight patients ASA III (15.7%). A detailed description about the patients can be found in a previous publication [25]. 32 patients were enrolled in group 1 and 19 patients in group 2. The patient characteristics, duration of surgery and STP, and the respiratory parameters of both groups are listed in Table 2.

3.1 Influence of surgery and obesity on pulmonary changes during RALP

Mean PIP levels ($\text{cmH}_2\text{O} \pm \text{SD}$) for all patients at each point in time were $T_1 = 16.6 \pm 3.4$, $T_2 = 28.3 \pm 6.8$, $T_3 = 31.5 \pm 4.9$, $T_4 = 33.4 \pm 5.2$, and $T_5 = 21.2 \pm 4.8$. PIP rose significantly with increasing duration of RALP ($p < 0.001$), for instance PIP was twice as high at T_4 than at T_1 ($p < 0.001$). Obese patients ($\text{BMI} \geq 30 \text{ kg/m}^2$) had significantly increased PIP levels compared to non-obese patients ($\Delta = 5.6 \text{ cmH}_2\text{O}$ (95% CI 3.8, 7.4), $p < 0.001$). In obese patients, mean PIP levels reached values above $30 \text{ cmH}_2\text{O}$ almost during the entire duration of RALP (T_2 – T_4). With increased duration of STP and surgery and to keep etCO_2 stable, obese patients were

ventilated with significantly higher MV than non-obese patients ($\Delta = 0.6 \text{ l/min}$ (95% CI 0.18, 1.03), $p = 0.006$). Pairwise comparisons at each point in time are presented in Table 2.

Mean P_{driv} levels ($\text{cmH}_2\text{O} \pm \text{SD}$) for all patients were $T_1 = 10.2 \pm 3.2$, $T_2 = 21.8 \pm 5.6$, $T_3 = 24.6 \pm 4.9$, $T_4 = 26.5 \pm 5.1$, and $T_5 = 14.3 \pm 4.7$. With the start of intra-peritoneal insufflation of CO_2 (T_2), P_{driv} doubled compared to T_1 . In conformity with PIP for obese patients, P_{driv} was significantly higher in all stages of RALP ($\Delta = 5.3 \text{ cmH}_2\text{O}$ (95% CI 3.6, 7.0), $p < 0.001$). In obese patients, mean P_{driv} nearly reached $30 \text{ cmH}_2\text{O}$ in STP (T_3 – T_4) (Table 2). Mean PEEP levels ($\text{mmHg} \pm \text{SD}$) for all patients were $T_1 = 5.4 \pm 0.5$, $T_2 = 5.9 \pm 0.5$, $T_3 = 5.9 \pm 0.5$, $T_4 = 6.0 \pm 0.5$, $T_5 = 5.9 \pm 0.6$. The PEEP levels during RALP did not significantly differ between the different BMI groups ($p = 0.0635$), only a trend to higher PEEP values in obese patients were observed.

Mean LC levels ($\text{ml/mbar} \pm \text{SD}$) for all patients were $T_1 = 55.0 \pm 13.1$, $T_2 = 29.2 \pm 10.4$, $T_3 = 23.7 \pm 5.3$, $T_4 = 22.3 \pm 5.1$, and $T_5 = 40.5 \pm 10.0$. At the onset of capnoperitoneum, (T_2), LC had significantly decreased compared to T_1 ($p < 0.001$) and decreased by more than 50% during RALP. The worst LC level was measured at the end of STP (T_4). Obesity negatively affected LC and led to significant deterioration ($\Delta = 9.6 \text{ ml/mbar}$ (95% CI 6.2, 13.0), $p < 0.001$). Pairwise comparisons at each time point are also presented in Table 2.

Mean P/F ratios ($\text{mmHg} \pm \text{SD}$) for all patients were $T_0 = 558 \pm 133$, $T_1 = 447 \pm 147$, $T_3 = 367 \pm 121$, $T_4 = 343 \pm 107$, and $T_6 = 303 \pm 90$. Increasing duration of STP and surgery was associated with a significant decrease in the P/F ratio ($p < 0.001$). Despite the supply of oxygen via a face mask, the mean P/F ratio was significantly reduced at T_6 compared to T_0 ($p < 0.001$). In obese patients, the P/F ratio was significantly reduced intraoperatively compared to non-obese patients (Table 2). The two patient groups did not differ regarding age, the duration of STP and surgery (Table 2), or the levels for $F_i\text{O}_2$, etCO_2 , pH, and BE.

3.2 Prediction of pulmonary changes during RALP

Linear regression models provided the expected PIP, P_{driv} , and LC levels for each point in time of surgery depending on the patients’ BMI (Tables 3, 4, 5; Figs. 1, 2, 3). PIP levels of $> 35 \text{ cmH}_2\text{O}$ were registered at T_2 for eight patients (15.7% of all patients, 100% obese), at T_3 for 16 patients (31.4% of all patients, 81% obese), and at T_4 for 22 patients (43.1% of all patients, 64% obese). P_{driv} levels of $> 15 \text{ cmH}_2\text{O}$ were registered at T_2 for 42 patients (82.4% of all patients, 100% obese), at T_3 for 50 patients (98.0% of all patients, 100% obese), and at T_4 for 50 patients (98.0% of all patients, 100% obese).

Table 2 Patient demographics, operative variables, and ventilation parameters

	Group 1 BMI < 30	Group 2 BMI ≥ 30	P-value
Patients (n)	32	19	–
Age (years)	64.0 ± 8.3 (49–77)	63.0 ± 6.3 (53–74)	0.644
BMI (kg/m ²)	25.8 ± 2.2 (20.3–29.4)	32.7 ± 2.5 (30.1–38.4)	< 0.001*
Operative time (min)	210 ± 61 (120–357)	230 ± 54 (136–325)	0.256
Time of Trendelenburg position (min)	192 ± 60 (109–331)	209 ± 50 (128–320)	0.304
Peak inspiratory pressure (cmH ₂ O)			
T ₁	15.0 ± 2.2	19.3 ± 3.3	< 0.001*
T ₂	25.8 ± 6.4	32.6 ± 5.2	< 0.001*
T ₃	29.3 ± 4.3	35.3 ± 3.4	< 0.001*
T ₄	31.4 ± 4.8	36.8 ± 3.8	< 0.001*
T ₅	19.1 ± 4.0	24.7 ± 3.8	< 0.001*
Driving pressure (cmH ₂ O)			
T ₁	8.8 ± 2.2	12.6 ± 3.2	< 0.001*
T ₂	19.6 ± 4.6	25.6 ± 5.2	< 0.001*
T ₃	22.4 ± 4.3	28.3 ± 3.1	< 0.001*
T ₄	24.5 ± 4.8	29.8 ± 3.6	< 0.001*
T ₅	12.3 ± 4.0	17.7 ± 3.6	< 0.001*
Minute volume (l/min)			
T ₁	6.3 ± 0.6	7.0 ± 0.8	< 0.001*
T ₂	7.4 ± 0.9	8.0 ± 1.0	0.032*
T ₃	8.0 ± 0.9	8.5 ± 1.1	0.100
T ₄	8.5 ± 1.1	9.1 ± 0.9	0.065
T ₅	8.2 ± 1.2	8.9 ± 0.9	0.053
Lung compliance (ml/mbar)			
T ₁	60.7 ± 11.7	45.3 ± 9.0	< 0.001*
T ₂	32.2 ± 10.9	24.2 ± 7.3	0.007*
T ₃	26.0 ± 5.2	19.8 ± 2.7	< 0.001*
T ₄	24.3 ± 5.0	18.9 ± 3.1	< 0.001*
T ₅	45.4 ± 8.7	32.4 ± 5.9	< 0.001*
P _a O ₂ /F _i O ₂ ratio (mmHg)			
T ₀	578 ± 129	524 ± 137	0.167
T ₁	496 ± 138	366 ± 126	0.002*
T ₃	384 ± 95	338 ± 154	0.192
T ₄	368 ± 109	300 ± 90	0.027*
T ₆	316 ± 93	282 ± 85	0.200

Data are presented as mean ± SD, with ranges in parentheses, *p < 0.05

Table 3 Linear regression models of BMI on PIP

Time point	Constant (in cmH ₂ O) ^a	B (95% CI)	P-value, R ²
T ₁	11.79	0.57 (0.40, 0.74)	< 0.001, 0.49
T ₂	22.60	0.74 (0.39, 1.08)	< 0.001, 0.27
T ₃	24.51	0.84 (0.59, 1.09)	< 0.001, 0.48
T ₄	27.48	0.71 (0.41, 1.01)	< 0.001, 0.32

A PIP of 30 cmH₂O (22.60 + 10 × 0.74 = 30.0) is to be expected for patients with a BMI of 30 kg/m² at time point T₂

^aCentered on BMI = 20 kg/m²

3.3 Postoperative hospital stay and pulmonary complications

Length of stay was 7 days (range 6–8) for obese and 7 days (range 6–7) for non-obese patients without any statistical difference between the groups (p = 0.25). No pulmonary complications occurred in the recovery room, 8 h later on the ward, and during the first postoperative day. Nineteen patients (37.3%) showed profound chemosis without any difference between obese (7/19, 36.8%) and non-obese

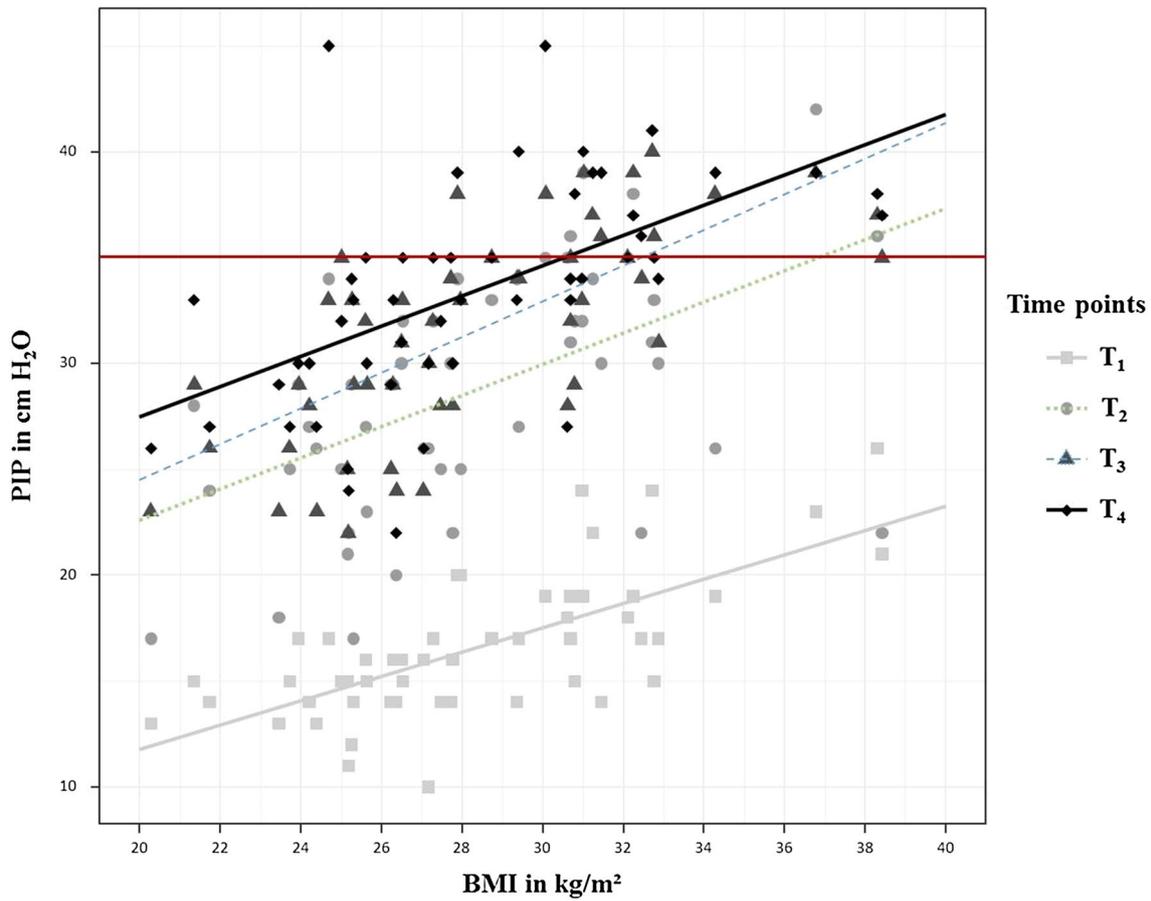


Fig. 1 Influence of BMI on PIP at each time point during RALP. Notes: horizontal red line represents the limit for possible lung damage

Table 4 Linear regression models of BMI on P_{driv}

	Constant (in cmH_2O) ^a	B (95%-CI)	P-value, R^2
T ₁	5.71	0.54 (0.40, 0.71)	<0.001, 0.45
T ₂	15.85	0.72 (0.37, 1.06)	<0.001, 0.26
T ₃	17.69	0.83 (0.58, 1.08)	<0.001, 0.48
T ₄	20.62	0.70 (0.40, 1.01)	<0.001, 0.31

A P_{driv} of 27.62 cmH_2O ($20.62 + 10 \times 0.70 = 27.62$) is to be expected for patients with a BMI of 30 kg/m^2 at time point T₄

^aCentered on BMI = 20 kg/m^2

Table 5 Linear regression models of BMI on lung compliance

Time point	Constant (in ml/mbar) ^a	B (95% CI)	P-value, R^2
T ₁	72.13	-2.06 (-2.76, -1.35)	<0.001, 0.41
T ₂	37.99	-1.05 (-1.72, -0.39)	0.003, 0.17
T ₃	30.58	-0.83 (-1.12, -0.53)	<0.001, 0.40
T ₄	28.65	-0.76 (-1.05, -0.48)	<0.001, 0.37

Lung compliance of 22.28 ml/mbar ($30.58 - 10 \times 0.83 = 22.28$) is to be expected for patients with a BMI of 30 kg/m^2 at time point T₃

^aCentered on BMI = 20 kg/m^2

patients (12/32, 37.5%). Chemosis had resolved in all patients within 24 h.

4 Discussion

Obesity is a growing problem in perioperative medicine. The aim of our study was to evaluate a possible correlation between a 45° STP and the BMI in respect of pulmonary

changes in patients during RALP. Furthermore, we examined the data during ventilation with a linear regression model to establish a model for predicting such changes. The STP of patients during RALP, which is necessary for endoscopic operations to allow optimal surgical access to the lower abdomen, is indeed more invasive than positioning for ‘open abdominal surgery’ [4]. However, STP causes pathophysiological changes in the hemodynamic and pulmonary system of the patients, presenting new challenges for the

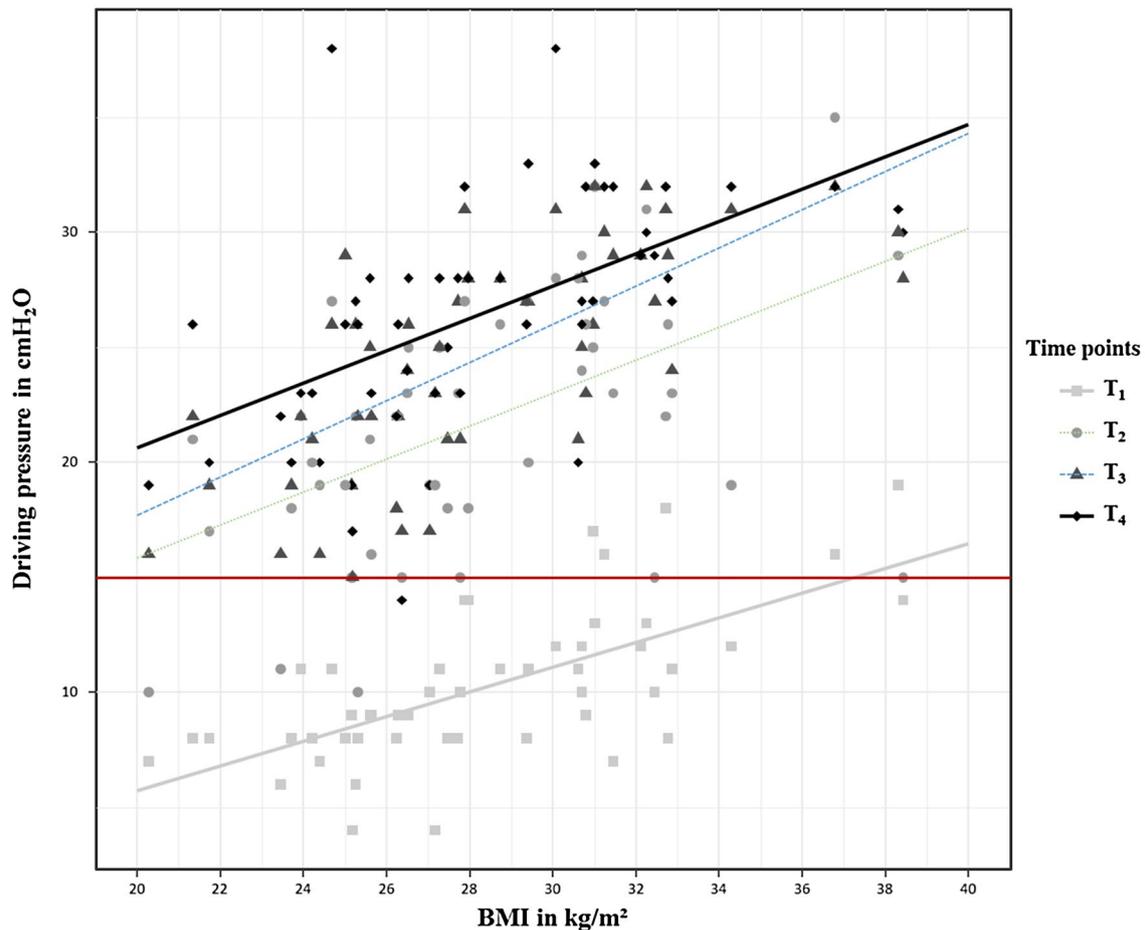


Fig. 2 Influence of BMI on P_{driv} at each time point during RALP. Notes: horizontal red line represents the known cut off for postoperative pulmonary complications

anesthesiologist during surgery. Particularly the increasing number of obese patients and their higher risk in the context of anesthesia need to be discussed between surgeons and anesthesiologists for every single patient to consider all risks involved. Already impaired pulmonary function, even in otherwise healthy patients, may increase the risk of pulmonary complications [26].

4.1 Surgical influences on respiratory parameters during RALP

The STP itself is an extreme position that causes an increase in PIP and P_{driv} levels. In our study, all patients were consequently positioned in a permanent 45° STP. The combination of a 45° STP and capnoperitoneum during RALP had a profound influence on respiratory parameters and significantly decreased LC. These findings are consistent with those of other studies [27, 28]. However, Suh et al. [29] observed that pneumoperitoneum alone

significantly reduced dynamic LC and increased PIP and plateau pressures without the influence of a 20° Trendelenburg position. Another study confirmed the effects of the degree of head-down angle (20°–30°) during RALP on PIP and LC levels [30]. In another study on obese patients (BMI > 35 kg/m²) undergoing laparoscopic surgery, an individual PEEP trial could decrease P_{driv} but led to PIP levels above 30 cmH₂O [31]. PEEP increments may be only protective when the increased PEEP levels result in a change in lung mechanics so that the same tidal volume can be delivered with lower P_{driv} [32]. Also during open abdominal surgery high level of PEEP and recruitment manoeuvres does not protect against postoperative pulmonary complications [33]. Unlike in the study by Nestler et al. [31], in our study no PEEP trial was conducted to avoid a critical elevation of PIP during STP. The same PEEP level was chosen for obese and non-obese patients for intergroup comparability and is comparable with the lower PEEP strategy of the PROBESE trial [34].

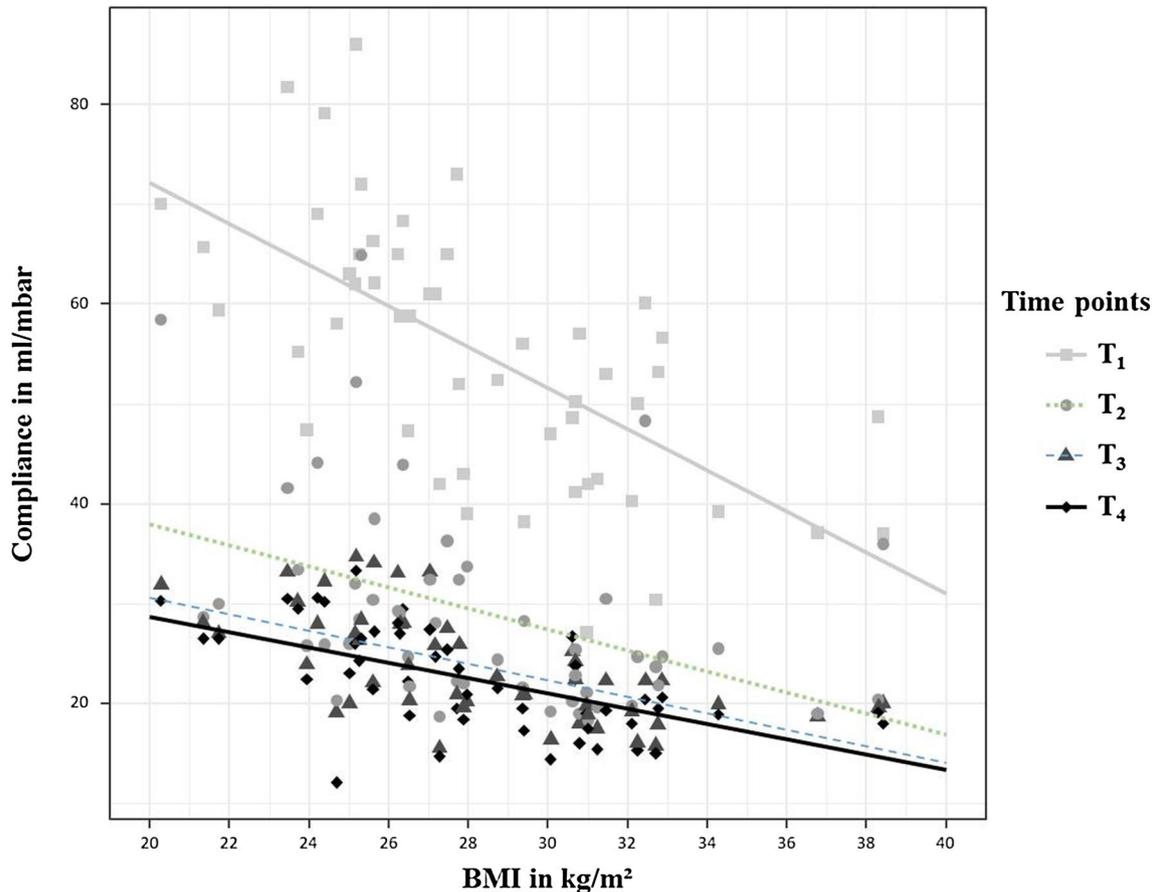


Fig. 3 Influence of BMI on lung compliance at each time point during RALP

4.2 Obesity as a risk factor for pulmonary deterioration during RALP

A more recent study has shown that the BMI represents the main risk factor for decreased lung compliance and high plateau pressures during robotic-assisted surgery in STP [35]. In our study, we observed a significant influence of obesity on PIP, P_{driv} , and LC levels during all stages of RALP. Moreover, PIP, P_{driv} , and MV levels in the ventilation of obese patients were significantly increased during RALP compared to those of non-obese patients. This finding is crucial for anesthesiologists. The potential risk of lung damage such as tension pneumothorax due to increased PIP and P_{driv} has to be weighed against better surgical conditions for the urologist.

The unphysiological STP required extremely invasive ventilation measured by PIP and P_{driv} and in combination with a longer duration of surgery may increase pulmonary complications. Wiltz et al. [36] found a significantly longer mean duration of surgery in obese patients compared to non-overweight and overweight men (234 vs. 217 vs. 214 min). Mikhail et al. [37] showed the same significant effect on

operative time for obese patients (353 vs. 298 vs. 296 min). In our study, we did not observe any negative effect of obesity regarding the duration of surgery or STP.

Obese patients are more likely to develop postoperative acute respiratory failure and have higher rates of pneumonia, prolonged mechanical ventilation and weaning difficulty [16]. The process of extubation after RALP must be as safe as possible. We prefer a recruitment maneuvers in a head up or reverse Trendelenburg position before extubation. The non-invasive ventilator support is an option to reduce post-extubation acute respiratory failure [38, 39].

4.3 Linear regression models for predicting pulmonary changes during RALP

Higher driving pressure (> 15 cmH₂O) has recently been found to be associated with more postoperative pulmonary complications in patients ventilated during surgery [23, 24]. Based on linear regression models and the BMI of each patient, the increase in P_{driv} and PIP and the decrease in LC can be calculated for different time points during RALP. Patients with a BMI of > 31 kg/m² showed critical PIP levels

over 35 cmH₂O in STP that were presumably caused by the abdominal organs being pressed against the lungs (Fig. 1). P_{driv} exceeded cut off values of 15 cmH₂O after the start of capnoperitoneum (T₂) but increased linearly with a raising BMI, reaching levels of > 30 cmH₂O in patients with a BMI of > 33 kg/m² (Fig. 2). However, our predicted PIP and P_{driv} levels may give clinical hints but are not suitable as a single parameter for therapeutic decisions. The distribution of fat tissue may vary in obese patients, and the prediction of PIP levels in our regression model may have been influenced by the preexisting lung condition of the individual patient.

4.4 Postoperative hospital stay and pulmonary complications

RALP conducted in STP increased upper airway resistance after surgery. However, resistance had returned to normal levels within 24 h. Kilic et al. described chemosis in 33% of patients. The development of chemosis can be indicative of increased upper airway resistance [26]. In our study, chemosis occurred in 37.3% of the patients without any difference between the two patient groups. Patients in our study showed impaired oxygenation represented by the P/F ratio during RALP, and oxygenation remained postoperatively impaired (Table 2). Elevated PIP levels of > 35 cmH₂O and P_{driv} levels of > 15 cmH₂O may occur in ventilated patients during STP that may results from perioperative (e.g. tension pneumothorax or pulmonary interstitial emphysema) or postoperative complications (e.g. acute lung injury) [23, 40, 41]. Two cases of severe dyspnea due to upper airway edema after RALP have been reported so far that required reintubation and prolonged mechanical ventilation respectively [42, 43]. Despite the 45° STP, we did not observe any peri- or postoperative pulmonary complications. Maybe the extremely invasive ventilation in STP a little bit more of 3 h was too short causing pulmonary complications. Also the restrictive fluid strategy avoids a pulmonary edema especially in obese patient undergoing RALP. The hospital length of stay was 7 days with no statistical difference between the different BMI groups. In two other studies, the average hospital length of stay was 1.2 days and 2.9 days [42, 44].

4.5 Limitations of the study

Due to the sample size, no firm conclusion can be drawn regarding pulmonary complications and hospital length of stay. Furthermore, there are limitations regarding the measurement of respiratory compliance. Potentially the measuring methods could not detect all pulmonary complications (e.g. atelectasis).

Nevertheless, to the best of our knowledge, the presented findings are the first results that can be used as a basis for a calculation model to preoperatively predict high PIP and

P_{driv} levels. Such prediction can be helpful in deciding whether STP is associated with a higher pulmonary risk for obese patients.

5 Conclusion

In our study, obesity in combination with STP and capnoperitoneum during RALP was associated with pulmonary deterioration. Increased PIP and P_{driv} and decreased LC levels were directly correlated with a high BMI. PIP and P_{driv} doubled and LC decreased by more than 50% during RALP in both patient groups. Obese patients had significantly higher PIP and P_{driv} levels and a lower LC level. No severe pulmonary complications occurred, and no age-related differences in lung function were observed. This study indicates the possibility of predicting pulmonary changes during RALP by means of linear regression models.

Availability of data and material All data generated or analyzed during this study are included in this published article and are available from the corresponding author on reasonable request.

Authors' contributions SB: Ethics approval, study design, data collection and analysis, drafted the manuscript and reviewed it for important intellectual content; MH: Idea for study, study design, patient recruitment, data collection and finally reviewed the manuscript for important intellectual content; FZ: Data analysis and interpretation, finally reviewed the manuscript for important intellectual content; TS: Made acquisitions, interpret data and finally reviewed the manuscript for important intellectual content; ML: Made acquisitions, interpret data and finally reviewed the manuscript for important intellectual content; MB: Made acquisitions, interpret data and finally reviewed the manuscript for important intellectual content; SD: Made acquisitions and interpret of data and finally reviewed the manuscript for important intellectual content; MP: Idea for study, study design, data collection and interpretation, patient recruitment and finally reviewed the manuscript for important intellectual content.

Compliance with ethical standards

Conflict of interest The authors declares that they have no competing interest in relation to this paper.

Ethics approval This study was approved by the local institutional review board of the University of Regensburg (Protocol No. 14-101-0107) and registered at the local Center for Clinical Studies (Z-2014-0387-6. Registered on 8 July 2014).

Informed consent After detailed explanation, written informed consent was obtained from 51 patients scheduled for elective prostatectomy at the Department of Urology in Regensburg.

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