Ultrasonographic evaluation of the postoperative airway edema after robotic prostatectomy: a single center observational study

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Abstract. – OBJECTIVE: During general anesthesia, different parts of the upper airway can change for various reasons, such as intravenous fluids, airway trauma due to airway devices used, stasis in tissues due to position, reactions to medications used, etc. For many reasons, edema in the airway or the surrounding tissue can narrow the airway. This study compares preoperative and postoperative ultrasound measurements of upper airway anatomy in patients with robotic radical prostatectomy in the Trendelenburg position.

PATIENTS AND METHODS: This study was conducted at the Health Sciences University Ankara City Hospital between May and December 2022. The preoperative and postoperative measurements of tongue thickness, midsagittal tongue cross-sectional area, tongue width, lateral pharyngeal wall thickness, parapharyngeal region thickness, and submental region thickness were analyzed and compared.

RESULTS: There was a difference between the preoperative and postoperative median sagittal tongue cross-sectional area, tongue volume values, LPW values, parapharyngeal region thickness, and neck circumference values. We found that the thickness of the submental region and the thickness of the parapharyngeal region increased as the amount of fluid administered intraoperatively increased.

CONCLUSIONS: Upper airway edema is the most challenging problem for anesthetists during extubation due to position and pneumoperitoneum. Restrictive fluid management may have beneficial effects in preventing clinically important airway edema.

Key Words:
Tongue edema, Robotic radical prostatectomy, Point care ultrasound, Postoperative airway edema.

Introduction

During general anesthesia, different parts of the upper airway size can change for various reasons, such as extravasation of intravenous fluids, airway trauma due to airway devices, stasis in tissues due to position, reactions to medications, etc. For many reasons, edema in the airway or the surrounding tissue can narrow the airway. Airway narrowing can lead to ventilation, intubation, or extubation difficulties. Postoperative dyspnea can also be a problem in some patients, particularly those with obstructive sleep apnea[1]. These patients may be candidates for a difficult airway if reintubation or respiratory support with supraglottic airway devices is required. Cardiovascular, respiratory, and neurological complications may develop due to lithotomy, deep Trendelenburg position, and capnoperitoneum.

Currently, non-metastatic prostate cancers can be effectively cured by radical prostatectomy, the primary treatment option[2]. Robot-assisted laparoscopic radical prostatectomy (RALRP) is preferred over open radical prostatectomy due to its benefits, such as decreased blood loss and transfusion rates, lower complication rates, and shorter hospitalization periods[3,4]. Because RALRP must be performed in a limited retroperitoneal space, a pneumoperitoneum, and a deep Trendelenburg position are required for better surgical visibility[5]. The clinical significance of postoperative airway obstruction and edema due to prolonged deep Trendelenburg positioning is unclear. Still, it is also essential to diagnose and treat upper airway obstruction immediately following surgery[6]. According to the literature, the Trendelenburg position causes a three-fold increase in central venous pressure compared to the baseline. When hydrostatic pressure increases, it can accumulate interstitial fluid in surrounding tissues, resulting in the development of periorbital and conjunctival edema. Also, it has been reported that edema can occur in the cervical and parapharyngeal tissues, leading to the narrowing of the upper airway[7].

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A point-of-care ultrasound (PoCUS) can conveniently assess the airway, a portable and noninvasive tool readily available[8,9]. Research studies[10] have revealed that in individuals with obstructive sleep apnea, magnetic resonance imaging has identified that airway constriction is primarily due to the thickening of the lateral parapharyngeal muscle wall (LPW). LPW is linked to several muscles and lymphoid tissues, which include the hypoglossal, styloglossal, stylohyoid, stylopharyngeal, palatoglossal, palatopharyngeal, and pharyngeal constrictors.

Scientific research[11,12] has demonstrated that the tongue consists of multiple muscles and can be monitored using ultrasound when a probe is positioned right beneath the chin. This technique allows for numerous measurements. Tongue edema can occur for various reasons, including primary anatomical defects, prolonged surgery, deep Trendelenburg position under general anesthesia, or excessive fluid administration during surgery. These factors can lead to complications during extubation. Regardless of the cause, early diagnosis and prompt intervention are critical to avoid respiratory problems caused by tongue edema[13,14].

To detect tongue edema, measuring the change in tongue volume may be beneficial based on the average sagittal cross-sectional area of the tongue width. In the literature, tongue volume has been used to diagnose difficult ventilation and intubation by ultrasound measurement in patients[11].

This study compares preoperative and postoperative ultrasound measurements of upper airway anatomy in patients scheduled for robotic radical prostatectomy in the Trendelenburg position.

Patients and Methods

This study was conducted at Health Sciences University Ankara City Hospital between May and December 2022. This study was approved by the Ankara City Hospital Human Research Ethics Committee (approval number: E1-21-2231, date: 15/12/2021) and was compatible with the Declaration of Helsinki. This study was registered at clinicaltrials.gov with registration number NCT05224895. All participants in the study gave written consent after being informed about the study procedures. The "Strengthening Reporting of Observational Studies in Epidemiology" (STROBE) checklist was utilized for a methodological assessment[15].

Patients aged 18-75 with ASA Physical Status I-III scheduled for robotic radical prostatectomy and who gave informed consent were eligible for this study. Patients who had a contraindication for the deep Trendelenburg position, a history of maxillofacial deformity, tumor or trauma, anticipated difficult airway, decompensated heart, respiratory, liver, or kidney diseases, or a cervical spine fracture, as well as those who refused to participate, were excluded.

Before the surgery, various factors were recorded, such as gender, age, body weight, height, neck circumference, and comorbidities, using the Charlson comorbidity index[16], American Society of Anaesthesiologists (ASA) score, modified Mallampati classification, and STOP-BANG risk score.

Ultrasound Measurements

All patients in the operating room underwent submental sonography using a portable ultrasound device (Aplio 500; Toshiba Medical Systems Corp, Tochigi-ken, Japan). The probe was positioned right beneath the chin in the median sagittal plane to obtain a clear median sagittal view of the tongue and adjusted accordingly (Figure 1). During ultrasonography, patients were instructed to lie on their backs without a pillow and fully tilt their heads. They were then asked to keep their mouth closed and hold their tongue loosely without making any sounds while lightly touching the tongue tips to the incisors. This position helps to maintain a consistent tongue position during the procedure.

The tongue's median sagittal cross-sectional area

To measure the sagittal cross-sectional area of the tongue, an ultrasound image was taken with a 6 MHz curvilinear probe placed under the chin on the mid-sagittal plane. The circumference of the tongue was traced on the image to obtain the measurement[17] (Figure 1: 1a, 1b, 1c).

Tongue width

The width of the tongue was measured by placing a 6 MHz curvilinear probe under the chin and measuring the distance to the farthest points at the center of the tongue (Figure 1: 1a, 1b, 1c).

Tongue volume

To obtain it, the tongue width was multiplied by the mid-sagittal tongue cross-sectional area[18].

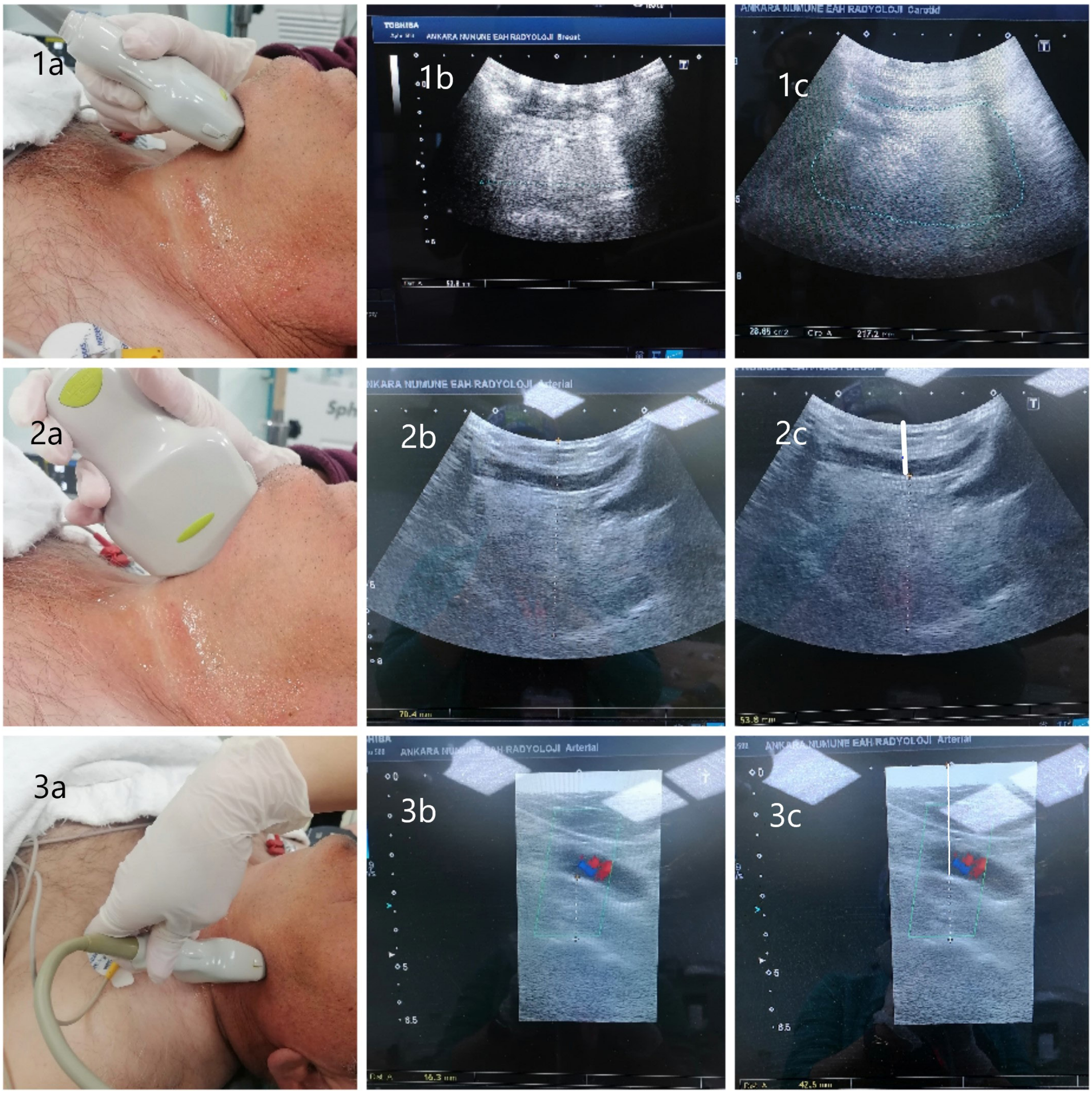

Figure 1. **1a**, Positioning of the ultrasound probe and sonographic anatomy of the suprahyoid airway in the transverse scan. **1b**, Blue dotted line: width of the tongue. **1c**, Blue dotted area: cross-sectional area of the tongue. **2a**, Positioning of the ultrasound probe and sonographic anatomy of the suprahyoid airway in the midsagittal scan. **2b**, White dotted line: tongue thickness. **2c**, White line: submental region thickness. **3a**, The ultrasound transducer was oriented transversely in the lateral neck. **3b**, White dotted line: ultrasound image of the lateral pharyngeal wall. The internal carotid artery is shown by Doppler imaging. **3c**, White line: parapharyngeal region thickness

Tongue thickness

During the supine position, the curvilinear ultrasound probe with a frequency of 6 MHz was positioned sagittally under the chin while the mouth remained closed. The patient's tongue was set naturally during the examination and remained still. The maximum vertical diameter was measured from the tongue's surface to the submental skin. The thickness of the tongue was noted when viewing the root of the tongue on the screen[19] (Figure 1: 2a, 2b, 2c).

Submental region thickness

The distance between the tongue's surface and the skin was measured using a 6 MHz curvilinear ultrasound probe placed under the chin in the sagittal plane[20] (Figure 1: 2a, 2b, 2c).

Lateral parapharyngeal wall thickness

To measure the thickness of the lateral parapharyngeal wall, a wide-band linear probe with a frequency range of 7-15 MHz was used. The probe was placed towards the external auditory canal in the cervical region to visualize the carotid artery branch. The lateral pharyngeal wall was visualized as a hyperechoic line. When the patient swallowed, vibration artifacts were observed, confirming the pharynx location. A precise value was determined by measuring the distance between the internal carotid artery and the echogenic surface of the pharynx[20]. The presence of the internal carotid artery was verified through Doppler (Figure 1: 3a, 3b, 3c).

Parapharyngeal region thickness

The distance between the internal carotid artery and the skin was measured (Figure 1: 3a, 3b, 3c).

Anesthesia Procedure

Vital clinical signs were monitored before the surgery through the standard monitoring techniques of the American Society of Anaesthesiologists (ASA), which included electrocardiograms, pulse oximetry, and noninvasive blood pressure measurements. Before administering anesthesia, the patient was adequately preoxygenated. The anesthesia included demizolam 1-2 mg, fentanyl 1-2 mcg/kg, propofol 2-2.5 mg/kg, and rocuronium 0.6 mg/kg. Following mask ventilation, laryngoscopy was carried out using a Macintosh blade 3 or 4, and the Cormacke-Lehane grade was documented. Data related to the study were recorded by an independent anesthetist with more than five years of clinical experience.

Throughout the surgery, the patient's systolic and diastolic invasive blood pressure, heart rate, peripheral oxygen saturation (SpO_2), and vital signs were monitored every 15 minutes. After the surgery, at the 0 and 2-hour marks, the operation time and the amount of fluid administered were calculated. To regulate fluids, we monitored all patients' pulse pressure variation (PPV) and stroke volume variation (SVV).

Following intubation, a tidal volume of 5-7 mL/kg, a respiratory rate of 12-15/min, and a PEEP of 5-7 mmHg were used for mechanical ventilation. The patient's anesthesia was maintained with desflurane and remifentanil infusion at 0.1-0.5 mcg/kg/min. The depth of anesthesia was monitored using a bispectral index (BIS) monitor. The patient was placed in the steep Trendelenburg position, and the abdomen was inflated with 12 mmHg CO_2 at constant pressure. The respiratory ratio was adjusted to maintain end-tidal CO_2 between 30- and 35-mm Hg during pneumoperitoneum, thereby regulating the minute volume (MV). The tidal volume and respiratory ratio were adjusted based on compliance values to achieve sufficient MV while ensuring that the maximum peak inspiratory pressure would not exceed 35 mmHg.

The surgery concluded with the deflation of the abdomen; afterward, the patient was placed in the supine position. Sugammadex 2-4 mg/kg was administered to reverse the effects of the neuromuscular agent. After the cuff leak test was performed, the patients were safely extubated. After extubation, the patient's neck circumferences and ultrasound measurements were repeated.

In the recovery room, various parameters were observed to evaluate respiratory status. These parameters include the need for airway support, upper airway obstruction, respiratory rate, use of accessory muscles, difficulty in swallowing or speaking, and the possibility of reintubation. Patients with SpO_2 below 90% despite using a 3 L/min O_2 nasal cannula were categorized as having severe hypoxia. Those with SpO_2 levels between 90-93% were considered to have mild to moderate hypoxia, while those with levels above 93% were categorized as normal. In the PACU, any of the criteria listed were classified as critical respiratory events (CRE):

1. Intervention is necessary for upper airway obstruction, which may involve jaw thrust or the use of an oral airway.
2. Despite active interventions such as increasing oxygen flows to over 3 L/min, using a high-flow oxygen surface application mask, verbal prompts to take deep breaths, and tactile stimulation, the patient's mild to moderate hypoxemia with a SpO_2 level of 93% to 90% did not improve.
3. Despite active interventions, including increased oxygen flows, use of a high-flow face mask, verbal prompting for deep breathing, and tactile stimulation, severe hypoxemia (SpO_2<90%) persisted with the help of a 3 L nasal cannula for oxygen delivery.
4. If the respiratory rate exceeds 20 breaths per minute, or if the patient is using accessory muscles or experiencing tracheal tug, it may indicate respiratory distress or impending respiratory failure.
5. The patient is having difficulty taking deep breaths, as requested by the PACU nurse.
6. The individual expresses concerns about ex-

periencing airway or upper airway muscle weakness, which may include difficulty with breathing, swallowing, or speaking.
7. Need for reintubation in the PACU.
8. After removing the tracheal tube, it should be clinically evaluated for evidence or suspicion of lung aspiration, such as hypoxemia and gastric contents in the oropharynx[21].

Sample Size Estimation

The study "Changes in airway dimensions after robot-assisted operations in steep Trendelenburg position"[23] found that the ASTN-H score at time T1 in patients undergoing robotic surgery was 0.69, and the ASTN-H value was 0.69. The T2 time was 0.72. This article calculated that at least 88 patients should be recruited at d=0.35 effect size, 90% power, and =0.05 error level.

Statistical Analysis

Descriptive statistics for continuous data included Mean Standard Deviation, Median, Minimum and Maximum values. Discrete data were presented in percentage values. The Shapiro-Wilk test was conducted on the consistent data to assess whether the data is normally distributed. To evaluate the difference between preoperative and postoperative measurements of continuous data, the paired-sample *t*-test was utilized for data that demonstrated a normal distribution. When dealing with data that did not follow a normal distribution, the Wilcoxon test was utilized. To compare continuous data in two groups, different statistical tests were used depending on the normality of the data. Student's *t*-test was applied to data that showed a normal distribution, while the Mann-Whitney U-test was used for data that did not fit a normal distribution. Cross tables were utilized to compare nominal variables among groups using Chi-square and Fisher's Exact tests.

The statistical evaluations were conducted using the IBM SPSS program, version 20 (IBM Corp., Armonk, NY, USA). A significance level of $p<0.05$ was deemed acceptable.

Results

Table I comprehensively describes the demographics of the 89 patients observed and analyzed in the study.

We recorded five ultrasound images and neck circumference measurements. The preoperative and postoperative measurements of tongue thickness, midsagittal tongue cross-sectional area, tongue width, lateral pharyngeal wall thickness, parapharyngeal region thickness, and submental region thickness were analyzed and compared. Table II displays the outcomes.

There was no correlation between the differences in the patient's preoperative and postoperative ultrasound measurements and patient age, duration of anesthesia, and hospital stay ($p>0.05$). A significant positive correlation was observed between the BMI values of the patients and the thickness difference of the pre-and postoperative parapharyngeal region (r=0.274, $p<0.01$).

There was a positive correlation between the amount of intraoperative fluid intake and the preoperative and postoperative thickness difference values of the submental region (r=0.212, $p<0.05$) and parapharyngeal region (r=0.215 $p<0.05$). As the crystalloid amounts of the patients increased, it was observed that the submental and parapharyngeal region thickness increased (Table III).

Discussion

Our study aimed to detect upper airway edema, which can cause critical respiratory events induced by a steep Trendelenburg position in patients undergoing robotic radical prostatectomy. Measurements of the tongue and parapharyngeal area were performed using ultrasound, which can result in a narrowing of the upper airways. No postoperative critical respiratory event occurred in our study's patients.

After analyzing the ultrasound measurements before and after the surgery, it was found that there was a significant increase in lateral wall thickness, parapharyngeal region thickness, and neck circumference. However, there was no significant decrease seen in tongue thickness and tongue width during the postoperative period.

In the postoperative period, statistically significant decreases in median sagittal tongue cross-sectional area and tongue volume were observed. Considering the surgical characteristics of robotic radical prostatectomy, it was found that the mean duration of anesthesia was 231.18±59.61 minutes, the mean total amount of fluid administered intraoperatively to the patients was 1,253.93±291.17 ml, and in the postoperative 7-day follow-up, no further deterioration in renal function was observed than the patients' preoperative status.

The patient's age, duration of anesthesia, and length of stay did not correlate with their pre- and

Table I. Patient characteristics.

n=89	Mean±SD Median (Min-Max)	
Age	65.93±6.34 67 (40-78)	
Weight	79.26±9.83 80 (50-118)	
Height	171.28±6.03 170 (160-190)	
BMI	27.02±3.18 26.77 (18.37-38.97)	
Charlson Comorbidity Index	5 (2-8)	
	n	**%**
ASA score		
2	78	87.6
3	11	12.4
Revised cardiac risk index		
Class 1	70	78.7
Class 2	12	13.5
Class 3	6	6.7
Class 4	1	1.1
Smoking		
no	86	96.6
yes	3	3.4
Mallampati score		
2	88	98.9
3	1	1.1
Cormack Lehane score		
Grade 2a	78	88.8
Grade 2b	6	6.7
Grade 3	4	4.5
Difficult Intubation		
no	86	96.6
yes	3	3.4
Stop-Bang score	4 (2-7)	
Duration of Anesthesia (min)	231.18±59.61 240 (100-360)	
Total Amount of Fluid (mL)	1,253.93±291.17 1,000 (500-2,000)	
	n	**%**
Preoperative GFR		
Normal	86	96.6
Mildly decreased	3	3.4
Postoperative GFR		
Normal	85	95.5
Mildly decreased	4	4.5

Standard Deviation (SD), Body Mass Index (BMI), American Society of Anesthesiologists physical status (ASA), Glomerular Filtration Rate (GFR).

postoperative variances. As patients' BMI values increased, so did the preoperative and postoperative lateral parapharyngeal wall thickness difference values and parapharyngeal thickness difference. We found that the thickness of the submental region and the thickness of the parapharyngeal region increased as the amount of fluid administered intraoperatively increased.

The literature mentions facial edema, chemosis, and upper airway edema can occur after ro-

Table II. Comparison of preoperative and postoperative ultrasound measurements and differences.

	Preoperative	Postoperative		Difference
	Mean±SD Med (Min-Max)	Mean±SD Med (Min-Max)	*p*-value	Mean±SD Med (Min-Max)
Tongue thickness	58.07±7.32 58.4 (43.2-75.0)	56.92±7.87 56.3 (39.2-73.9)	0.310 [a]	-1.14±10.54 -0.80 (-27.10-18.30)
Median sagittal tongue area (cm^2)	24.91±6.02 24 (13.1-46.39)	23.07±6.14 22.39 (11.42-42.46)	**0.022** [a]	-1.84±7.43 -2.29 (-21.10-14.36)
Tongue width (mm)	49.22±8.39 48.7 (29.4-70.2)	48.63±8.88 49.7 (32.2-73.7)	0.583 [a]	-0.59±10.11 -0.90 (-21.40-25.50)
Tongue volume (cm^3)	123.58±40.79 118.52 (53.91-305.71)	112.84±39.14 103.21 (54.65-286.61)	**0.036** [b]	-10.73±47.05 -9.94 (-176.73-103.04)
LPW	13.85±4.41 13.2 (5.3-30)	15.49±5.65 14.7 (14.9-36.9)	**0.003** [b]	1.63±4.84 1.0 (-11.20-19.30)
Submental region thickness	15.62±3.99 15.4 (3.1-27.3)	16.24±4.23 16 (2.8-27.9)	0.246 [a]	1.22±5.35 1.0 (-11.80-12.40)
Parapharyngeal region thickness	15.94±4.26 16.3 (3.9-28)	17.17±4.21 16.8 (4.8-31.1)	**0.033** [a]	0.62±5.06 0.5 (-11.8-13.2)
Neck circumference (cm)	43.46±2.81 43 (36-50)	43.75±2.80 43 (36-50)	**<0.001** [b]	1.22±5.35 1.0 (-11.8-12.4)

Standard Deviation (SD), Lateral pharyngeal wall thickness (LPW). [a]: Paired Samples *t*-test; [b]: Wilcoxon test.

botic laparoscopic prostatectomy surgeries. However, none of the imaging methods used to detect upper airway edema were mentioned. In a letter to the editor, Rewari and Ramachandran[6] stated that during their 8-year experience, they did not observe any larynx or upper airway edema in their patients. It has been suggested that patients undergoing surgery should be followed up with limited fluid therapy during the intraoperative period and kept in a head-up position after extubation. Our research findings indicate that during the robotic prostatectomy performed in a steep Trendelenburg position with restrictive fluid management, there was no tongue edema causing airway obstruction.

Bajaj et al[22] showed that in patients after robotic surgery performed in the steep Trendelenburg position, no stridor was observed after extubation or reintubation. In this study, out of all the patients, 31.6% had a positive cuff leak test, and 31% of patients showed signs of chemosis. Similarly, we did not observe any respiratory critical events after the operation.

Reddy et al[23] found a significant increase in tongue thickness and anterior neck tissue thickness in patients at the 2nd postoperative hour after robotic surgery performed in the steep Trendelenburg position. They found an increase in the thickness of the anterior neck tissue in correlation with the amount of fluid administered intraoperatively and the duration of the operation. Otherwise, our study found an increase in the soft tissue of the parapharyngeal area correlated with fluid.

Strengths

One of the strengths of our study is that bedside and easy-to-use ultrasonography has not been used in the literature to detect upper airway edema, which can lead to prolonged extubation or reintubation after robotic prostatectomy. Another strength is that we measured the tongue, the largest organ of the upper respiratory tract, in two planes to evaluate the edema with ultrasound measurements. Our study found an increase in neck circumference after a robotic radical prostatectomy. Still, when we detailed our ultrasound measurements, we saw that this increase was due to the rise in the parapharyngeal area and the thickness of the lateral pharyngeal wall. This increase also correlated with intraoperative fluid management; restrictive liquid regimens might reduce edema.

Limitations

A limitation of our study is that laryngeal edema observed postoperatively was not evaluated sonographically. Patients were extubated according to the cuff leak test, and the required imaging was not

Table III. Correlations between patients' age, BMI, duration of anesthesia, amount of intraoperative fluid and hospitalization, and preoperative and postoperative difference values of the patients.

	Age		**BMI**		**Duration of Anesthesia**		**Amount of intraoperative fluid intake**		**Hospitalization**	
Difference	r*	*p*	r*	*p*	r*	*p*	r*	*p*	r*	*p*
Tongue thickness	0.056	0.604	0.018	0.866	-0.044	0.685	-0.031	0.770	-0.103	0.338
Median sagittal tongue area (cm^2)	-0.039	0.715	-0.180	0.091	-0.143	0.182	-0.179	0.093	-0.095	0.377
Tongue width (mm)	0.050	0.639	0.101	0.345	0.108	0.315	-0.057	0.598	0.145	0.174
Tongue volume (cm^3)	0.021	0.847	-0.099	0.355	-0.048	0.653	-0.158	0.139	0.005	0.964
Lat. pharyngeal Wall thickness (LPW)	-0.028	0.796	0.086	0.423	0.044	0.685	-0.172	0.107	0.202	0.058
Submental region thickness	0.049	0.650	0.110	0.303	-0.085	0.426	**0.212**	**0.046**	-0.026	0.812
Parapharyngeal region thickness	0.021	0.843	**0.274**	**0.009**	0.104	0.334	**0.215**	**0.043**	-0.069	0.519
Neck circumference	-0.119	0.268	0.083	0.437	-0.044	0.684	0.142	0.184	0.032	0.767

Lateral pharyngeal wall thickness (LPW), Body Mass Index (BMI). *Spearman's coefficient of correlation.

performed. Another limitation of our study is that no ultrasound measurements were repeated in the second postoperative hour; however, the patients were observed for symptoms. The inability to confirm the airway edema with ultrasound can be seen in the 2nd postoperative hour.

Conclusions

We must be cautious about postoperative respiratory complications in robotic radical prostatectomy surgeries, which are now widely used and have the advantage of fewer complications and shorter hospital stays. Upper airway edema is the most challenging problem for anesthetists during extubation due to position and pneumoperitoneum. Our research focused on assessing upper airway edema severity and identifying the contributing factors. As a result, we have shown that restrictive fluid strategies and appropriate medication can prevent postoperative respiratory complications.

Conflicts of Interest

All the authors declare that there is no conflict.

Funding

This research received no external funding.

Informed Consent

A written informed consent was obtained from the participants for their willingness to participate in the study.

Ethics Approval

This study was regularly approved by the Ankara City Hospital Human Research Ethics Committee (approval number: E1-21-2231, date: 15/12/2021).

Authors' Contributions

Betül Güven Aytaç: conceptualization, formal analysis, writing-original draft, writing-review and editing, visualization. Özlem Balkiz Soyal: conceptualization, methodology, formal analysis, writing-original draft, writing-review and editing.

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