Journal of The Cardiovascular Thoracic Anaesthesia and Intensive Care Society

GKDA Derg 2022;28(1):70-80
DOI: 10.14744/GKDAD.2022.74317

Research Article / Araştırma

Evaluation of the Frequency of Atelectasis by Transthoracic Lung Ultrasound in Patients Undergoing Laparoscopic Bariatric Surgery Under General Anesthesia

Genel Anestezi Altında Laparoskopik Bariyatrik Cerrahi Geçiren Hastalarda Atelektazi Sıklığının Transtorasik Akciğer Ultrasonu ile Gösterilmesi

Derya Erol,[1] Mustafa Kemal Arslantaş,[2] Gülbin Töre Altun,[3] Pelin Çorman Dinçer,[4] Elif Aslı Karadeniz,[5] Hilmi Ömer Ayanoğlu[6]

[1]**Department of Anesthesiology and Reanimation, Hitit University, Erol Olçok Training and Research Hospital, Çorum, Turkey**
Hitit Üniversitesi, Erol Olçok Eğitim ve Araştırma Hastanesi, Anesteziyoloji ve Reanimasyon Kliniği, Çorum, Türkiye
[2]**Department of Anesthesiology and Reanimation, Demiroğlu Bilim University Faculty of Medicine, İstanbul, Turkey**
Demiroğlu Bilim Üniversitesi Tıp Fakültesi, Anesteziyoloji ve Reanimasyon Anabilim Dalı, İstanbul, Türkiye
[3]**Department of Anesthesiology and Reanimation, Group Florence Nightingale Hospitals, Kadıköy Florence Nightingale Hospital, Istanbul, Turkey**
Grup Florence Nightingale Hastaneleri, Kadıköy Florence Nightingale Hastanesi, Anesteziyoloji ve Reanimasyon Kliniği, İstanbul, Türkiye
[4]**Department of Oral & Maxilofacial Surgery, Marmara University Faculty of Dentistry, Istanbul, Turkey**
Marmara Üniversitesi, Diş Hekimliği Fakültesi, Ağız Diş ve Çene Cerrahisi Anabilim Dalı, İstanbul, Türkiye
[5]**Department of Anesthesia, Karakoçan State Hospitals, Elazığ, Turkey**
Karakoçan Devlet Hastanesi, Anestezi Kliniği, Elazığ, Türkiye
[6]**Department of Anesthesiology, Jiahui International Hospital, Shanghai, China**
Uluslararası Jiahui Hastanesi, Anesteziyoloji Bölümü, Şanghay, Çin

ABSTRACT

Objectives: Both obesity and laparoscopic surgical methods are predisposing factors for atelectasis. We aimed to evaluate with lung ultrasound (US), the incidence and location of atelectasis in patients undergoing laparoscopic bariatric surgery.

Methods: Patients (n=143) between the ages of 18 and 65, BMI ≥30, and ASA 2-3 who underwent laparoscopic bariatric surgery were included in our prospective observational study. According to the lung US protocol, a total of 12 areas (anterior, lateral, and posterior areas divided into upper and lower regions) were scanned in both hemithorax preoperatively and in the 1st h after surgery. In the perioperative period, vital parameters and mechanical ventilation parameters were recorded. The images were evaluated blindly by two anesthesiologists experienced in lung US according to the modified lung US scoring system (LUS).

ÖZ

Amaç: Hem obezite hem de laparoskopik cerrahi yöntemler atelektazi için predispozan faktörlerdir. Bu nedenle çalışmada, laparoskopik bariyatrik cerrahi geçiren hastalarda akciğer ultrasonu ile atelektazi gelişiminin ve insidansının değerlendirilmesi amaçlandı.

Yöntem: Prospektif gözlemsel bu çalışmaya, laparoskopik bariyatrik cerrahi uygulanan, 18-65 yaş arası, beden kitle indeksi ≥30 kg/m^2, ASA II-III olan 143 hasta dahil edildi. Akciğer ultrasonu protokolüne göre ameliyat öncesi ve ameliyat sonrası birinci saatte her iki hemitoraksta toplam 12 alan (üst ve alt bölgelere ayrılan ön, yan ve arka alanlar) tarandı. Perioperatif dönemde vital değerler ve mekanik ventilasyon değerleri kaydedildi. Görüntüler akciğer ultrasonu kullanımında deneyimli iki anestezi uzmanı tarafından modifiye akciğer ultrasonu skorlama sistemine (LUS) göre kör olarak değerlendirildi.

Please cite this article as: "Erol D, Arslantaş MK, Töre Altun G, Çorman Dinçer P, Karadeniz EA, Ayanoğlu HÖ. Evaluation of the Frequency of Atelectasis by Transthoracic Lung Ultrasound in Patients Undergoing Laparoscopic Bariatric Surgery Under General Anesthesia. GKDA Derg. 2022;28(1):70-80.

Address for correspondence: Mustafa Kemal Arslantaş, MD. Demiroğlu Bilim Üniversitesi Tıp Fakültesi, Anesteziyoloji ve Reanimasyon Anabilim Dalı, İstanbul, Türkiye

Phone: +90 505 224 21 19 **E-mail:** mkarslantas@gmail.com

Submitted Date: January 29, 2022 **Accepted Date:** February 10, 2022 **Available Online Date:** March 01, 2022

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ABSTRACT

Results: When the pre-operative and post-operative LUS scores were compared, we observed an increase in the LUS score in all areas except for both anterior upper areas ($p<0.001$). This increase was more pronounced, especially in the posterior and inferior parts of the lungs. We found the frequency of atelectasis to be 81.1%. The pCO_2 values were increased ($p<0.001$) while the pO_2 values were decreased ($p<0.001$) during the pneumoperitoneum and post-operative period as compared to the post-intubation period. During pneumoperitoneum, P_{peak} values were increased while compliance values were decreased.

Conclusion: Lung US can be used in the diagnosis of atelectasis in obese patients. Atelectasis is seen at a high rate in patients undergoing laparoscopic bariatric surgery.

Keywords: Atelectasis, bariatric surgery, laparoscopy, lung ultrasound, obesity

ÖZ

Bulgular: Ameliyat öncesi ve sonrası LUS skorları karşılaştırıldığında her iki ön üst alan hariç tüm alanlarda LUS skorunda artış gözlendi ($p<0,001$). Bu artış özellikle akciğerlerin arka ve alt kısımlarında daha belirgindi. Atelektazi gelişme sıklığı %81,1 idi. Entübasyon sonrasına göre pnömoperitonyum süresince ve postoperatif dönemdeki pCO_2 değerleri artarken ($p<0,001$), pO_2 değerleri azaldı ($p<0,001$). Pnömoperitonyumla P_{peak} değerleri artarken kompliyans değerleri azaldı.

Sonuç: Akciğer ultrasonu obez hastalarda atelektazi tanısında kullanılabilir. Laparoskopik bariyatrik cerrahi uygulanan hastalarda atelektazi yüksek oranda görülmektedir.

Anahtar sözcükler: Akciğer ultrason, atelektazi, bariyatrik cerrahi, obezite, laparoskopi

Introduction

Obesity is a preventable chronic disease with high morbidity and mortality that needs to be treated.[1,2] Treatment options include lifestyle changes, pharmacotherapy, and bariatric surgery.[3] In addition, knowing the physiopathological changes that develop due to obesity facilitates the perioperative patient management of anesthesiologists and enables them to treat possible complications earlier.[4]

Increased fat tissue in the abdomen, diaphragm, and intercostal muscles in obese patients changes the pressure-volume properties of the thorax; reduction in the chest wall, lung compliance, and functional residual capacity provide a basis for the development of atelectasis.[5] Atelectasis is the most common post-operative pulmonary complication.[6] Increased intra-abdominal pressure (IAP) and general anesthesia applied in laparoscopic surgery also increase the frequency of atelectasis.[7] Atelectasis reduces oxygenation, predisposes to infection, may increase the need for intensive care unit and mechanical ventilation, and the length of stay in the hospital; thus, the health-care costs per patient may increase.[8]

Early diagnosis and treatment of atelectasis are essential. Computed tomography (CT) is the gold standard in the diagnosis of atelectasis.[9] However, reluctance in radiation exposure, additional cost, not having suitable CT device for obese patients, and challenges in the transfer of the patients may delay the diagnosis of atelectasis by CT. Therefore, there is a need for more practical and bedside imaging methods that can be used to diagnose atelectasis in obese patients. Lung ultrasound (US) is a non-invasive, reproducible, fast, and inexpensive diagnostic method; used at the bedside to diagnose many lung pathologies.[10,11] The usage of lung US with proper technique may be helpful for early diagnosis in obese patients.[12] However, we have not encountered any study in the literature that uses lung US to diagnose atelectasis in obese patients. Our study aimed to diagnose and reveal the frequency of atelectasis with lung US patients who underwent laparoscopic bariatric surgery.

Methods

Study Design and Setting

The study protocol was approved by the Marmara University Faculty of Medicine Clinical Research Ethics Committee before patient enrollment (09.2017.622). Written informed consent was obtained from all patients for inclusion in the study. Consecutive patients between the ages of 18 and 65, BMI ≥30, and ASA 2-3 who would undergo laparoscopic bariatric surgery were screened for inclusion in our prospective observational study. Exclusion criteria were having uncontrolled acute or chronic pulmonary disease.

Pre-operative Assessment and Perioperative Maintaining

Patients were placed on the operating table in the supine position, and the table was positioned so that the head was up to 30° and the ramp position was provided. For each patient, 12-field lung US was performed before the operation and images were recorded. The back and pressure points of the patients were supported by soft covers. ECG, peripheral oxygen saturation (SpO_2), and non-invasive blood pressure monitoring were routinely performed, and basal values were recorded. Vascular access was established on the forearm with a 22/20/18 Gauge cannula, depending on the vascular structure of the patient. Before general anesthesia induction, all patients were pre-oxygenated with 80% FiO_2 using a face mask. Propofol (2 mg/kg) and remifentanil (1 mcg/kg) doses were administered according to lean body weight (LBW), whereas rocuronium bromide dose (0.6 mg/kg) was administered according to ideal body weight (IBW). Gliderite Rigid

Stylet® (Verathon, Canada) was placed into the endotracheal cuffed tube selected for the patient, and laryngoscopy was performed with GlideScope® AVL (Verathon, Canada). Gastric fluid was aspirated by inserting a nasogastric tube.

Anesthesia was maintained with desflurane inhalation and remifentanil infusion (0.25 mcg/kg/min). Mechanical ventilator settings were initially set in volume-controlled mode; tidal volume 6-8 ml/kg according to IBW, PEEP:5 cmH_2O, FiO_2:40%, P_{max}:40 mmHg, and respiratory rate 12-14/min and optimized according to the anesthesiologist's preference to protect the patient from hypoxia and to prevent hypercarbia.[13] Considering that atelectasis formation is more prominent in patients who developed hypoxia during induction to initiation of positive pressure mechanical ventilation, a recruitment maneuver was performed after intubation, PEEP values (8-14 cmH_2O) were adjusted not to allow reformation of hypoxia. In the pre-operative period, pneumoperitoneum was applied in a way that intra-abdominal pressure remained below 15 cmH_2O. Patients who developed hypoxia during surgery considered having atelectasis, and recruitment maneuver was repeated, and changes in PEEP and FiO_2 values were recorded. Patient's systolic and diastolic blood pressures, mean blood pressure, SpO_2, heart rate, end-tidal carbon dioxide ($EtCO_2$) values, recruitment maneuvers if applied, mechanical ventilator mode, tidal volume, FiO_2, PEEP, P_{max}, P_{plato}, P_{peak}, and compliance values were recorded. Local anesthetic infiltration, intravenous paracetamol (15 mg/kg according to LBW), and dexketoprofen (50 mg) were administered for post-operative analgesia. Nausea and vomiting prophylaxis was provided with intravenous ondansetron (8 mg) and ranitidine (50 mg). At the end of the surgery, remifentanil infusion and inhaled anesthetic agent were discontinued. The patient's trachea was extubated after administering sugammadex, and the dose was calculated according to the total body weight, making sure that muscle strength was achieved. In the 1st post-operative h, 12-field lung US was repeated, and images were recorded.

The Technique of Lung US

Lung US was performed twice for each patient before the operation, and in the 1st h after the operation, images were recorded. Philips® (USA) Sparq model US device and its 2-6 megahertz convex probe or Philips® (USA) HD11xe model US device and its 1-3 megahertz sector probe were used. All lung US assessments were performed by the same anesthesiologist. According to lung US protocol, both hemithorax (front, side, and back areas which are divided into upper and lower zones) were scanned for a total of 12 areas (Figs. 1, 2). After obtaining the "bat sign view" by placing the US

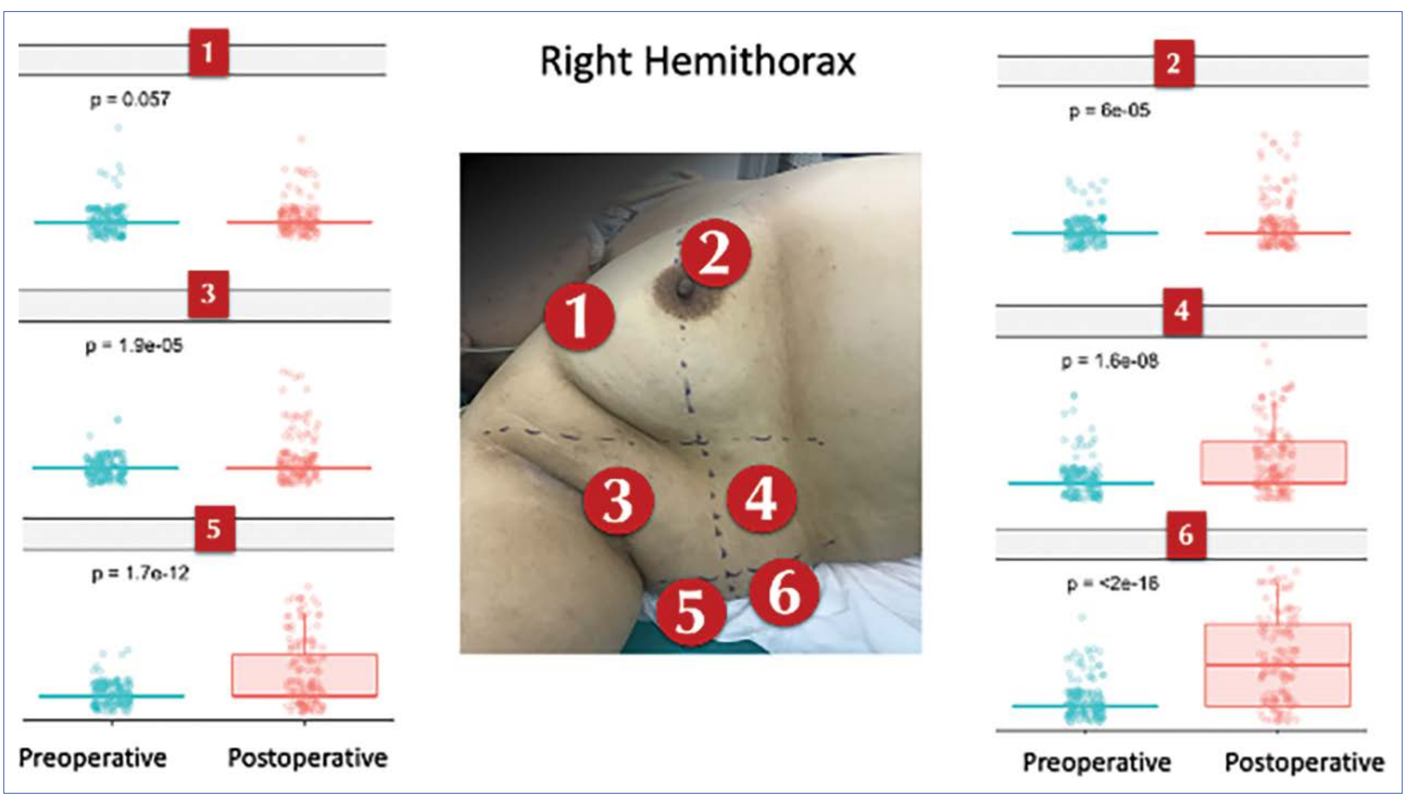


Figure 1. Comparison of pre-operative and post-operative LUS scores according to the right hemithorax imaging areas.

LUS: Lung US scoring system.

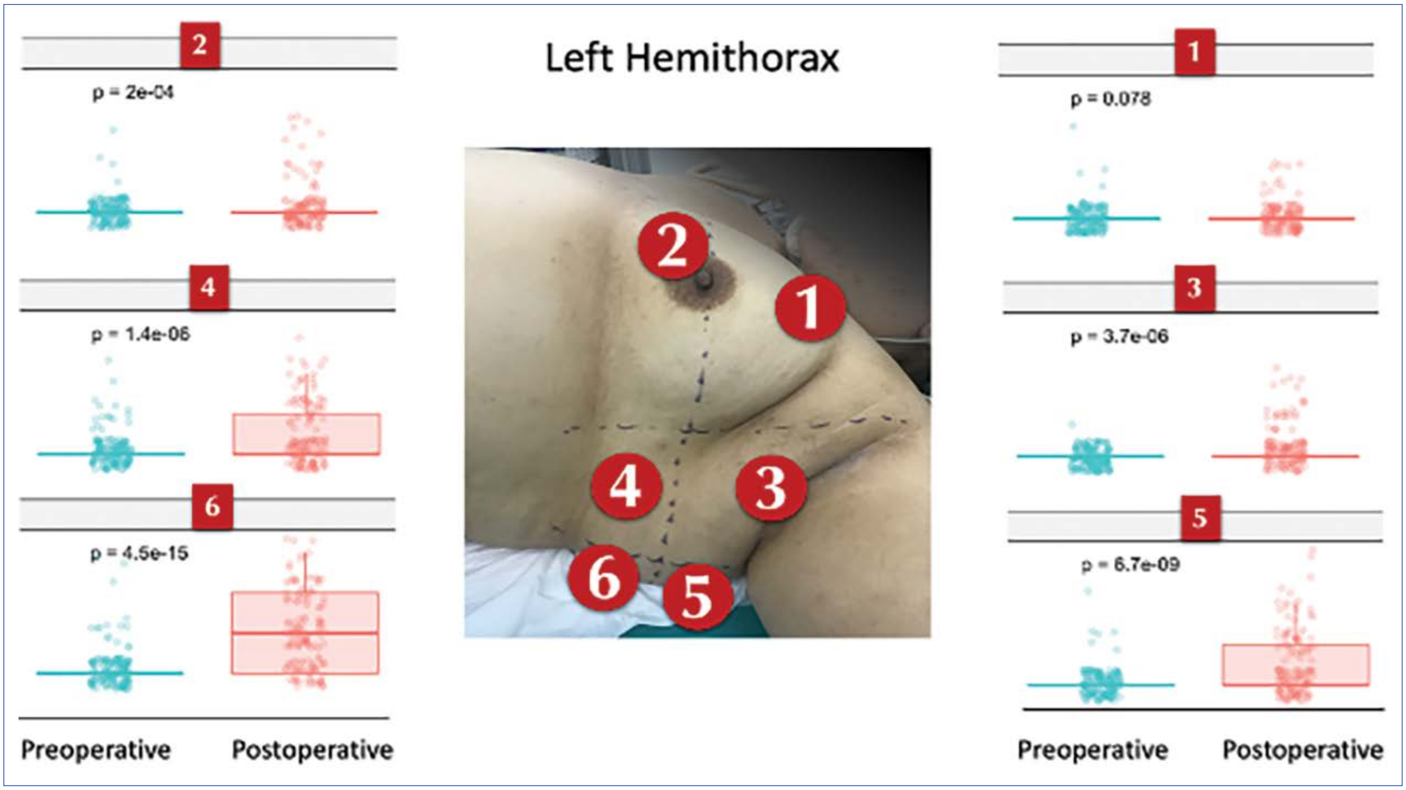


Figure 2. Comparison of pre-operative and post-operative LUS scores according to the left hemithorax imaging areas.

LUS: Lung US scoring system.

probe perpendicular to the ribs, the probe was rotated parallel to the ribs to have a wider lung view. All intercostal spaces in the area under investigation were scanned, and the image with the highest loss of ventilation was recorded. The assessments of the images were done by two experts who were blinded to the patient's information and were experienced in the use of lung US, according to the "Modified lung US scoring system" (LUS) (Table 1).[14]

The score for lack of ventilation was recorded for each area, and the total score was calculated for each patient. Each area was scored from 0 to 3 according to the degree of atelectasis; the total score of the 12 areas was between 0 (no loss of aeration) and 36 (complete loss of aeration).

Sample Size Calculation and Statistical Analysis

The R package program was used for the statistical evaluation (R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/). Descriptive statistical methods (frequency, mean, and standard deviation) and normality analysis (Shapiro-Wilk test) of the test-related parameters of the patients were used and are followed by t-test for normally distributed data in dependent groups and Mann-Whitney U-tests for non-normally distributed data. The significance of time-related differences was investigated using the t-test in dependent groups. Data that met the assumptions of the analysis of variance were analyzed using repeated-measures ANOVA, while data that did not meet the assumptions were analyzed with the Friedman rank-sum test. Pearson's correlation analysis was used for normally distributed data, and Spearman correlation analysis was performed for data that did not show normal distribution to investigate the relationship between pre-operative and post-operative LUS scores and other parameters. The results were evaluated at the 95% confidence interval and the significance at $p<0.05$ level.

Results

Patients' Characteristics and Procedures Performed

The population of our study consists of 225 patients who underwent bariatric surgery between October 2017 and November 2019 by Marmara University Pendik Training and Research Hospital General Surgery Clinic. Of these cases, 150 patients were included in the study. However, seven patients were not added to the statistical analysis due to various reasons (five patients had incomplete/poor quality lung US images and two patients developed surgical complications during the operation). Of the 143 patients included in

Table 1. Modified lung ultrasound scoring system (ultrasound images from our study are used)

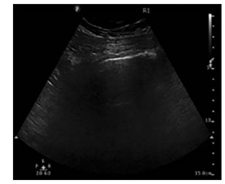
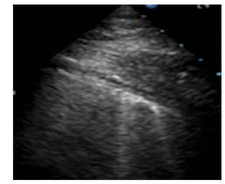
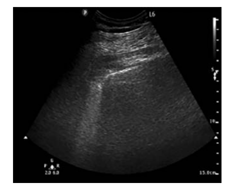
Score	Aeration	Findings	Ultrasound images
0	Normal aeration	0-2 B lines	
1	Small loss of aeration	B lines ≥3 OR 1 or multiple small subpleural consolidations separated by a normal pleural line	
2	Moderate of aeration	Multiple coalescent B lines OR Multiple small subpleural consolidations separated by a thickened or irregular pleural line	
3	Severe loss of aeration	Consolidation OR Small subpleural consolidation of >1×2 cm in diameter	

Table 2. Descriptive statistics of demographic information of the cases included in the study

Characteristics	Mean (SD)	Min.	Q1	Q3	Max.
Bodyweight (kg)	125.55 (20.64)	76	110	137	190
Height (cm)	163.85 (8.29)	141	159	169	184
BMI (kg/m^2)	46.60 (6.90)	31.22	41.35	51.43	66.59
Age (year)	40.24 (10.20)	18	34	48	66
ASA	2.87 (0.34)	2	3	3	3
LOS (day)	4.47 (1.11)	1	4	5	8
Surgery time (min)	111.07 (42.15)	30	80	140	240
Anesthesia time (min)	146.52 (43.48)	65	120	179	300

SD: Standard deviation; Min.: Minimum; Max.: Maximum; Q1: 1st quarter value; Q3: 3rd quarter value; BMI: Body mass index; ASA: American Society of Anesthesiologists; LOS: Length of stay.

the study, 114 were female and 29 were male. Other demographic findings of the patients are shown in Table 2.

The most common comorbidities seen in the patients were diabetes, hypertension, and obstructive sleep apnea. The most frequent bariatric surgery techniques used were "gastric bypass" and "sleeve gastrectomy."

LUS Scores

The sum of the post-operative LUS scores was significantly higher than the sum of the pre-anesthesia scores ($p<0.001$). The median values of pre-operative and post-operative total LUS scores were 0 and 5, respectively, and there was a significant difference between the groups ($W=50.5$, $Z=-9.29$, $p<0.001$, $r=0.78$) (Table 3). LUS scores increased in 116 (81.1%) patients, did not change in 25 (17.5%) patients, and decreased in 2 (1.4%) patients in the post-operative period as compared to the pre-operative period.

In almost all of the cases, an increase in LUS scores was observed in the post-operative lung US evaluation. A small number of cases had high LUS scores even in the pre-operative period. LUS scores increased, especially in the lower lung regions.

Table 3. Descriptive statistics of pre-operative and post-operative LUS scores and Wilcoxon test results

Area	n	Pre-operative Median (IQR)	Post-operative Median (IQR)	r	Z	p
Right 1	143	0 (0-0)	0 (0-0)	0.12	-1.94	0.052
Right 2	143	0 (0-0)	0 (0-0)	0.21	-4.02	<0.001
Right 3	143	0 (0-0)	0 (0-0)	0.30	-4.28	<0.001
Right 4	143	0 (0-0)	0 (0-1)	0.29	-5.66	<0.001
Right 5	143	0 (0-0)	0 (0-1)	0.40	-7.06	<0.001
Right 6	143	0 (0-0)	1 (0-2)	0.56	-8.25	<0.001
Left 1	143	0 (0-0)	0 (0-0)	0.09	-1.81	0.071
Left 2	143	0 (0-0)	0 (0-0)	0.21	-3.73	<0.001
Left 3	143	0 (0-0)	0 (0-0)	0.27	-4.64	<0.001
Left 4	143	0 (0-0)	0 (0-1)	0.38	-4.83	<0.001
Left 5	143	0 (0-0)	0 (0-1)	0.48	-5.80	<0.001
Left 6	143	0 (0-0)	1 (0-2)	0.53	-7.84	<0.001
Total LUS score	143	0 (0-1)	5 (2-8)	0.78	-9.29	<0.001

LUS: Lung US scoring system; IQR: Interquartile range.

Pre- and post-operative LUS scores differed in both hemithorax and in the measured regions. Post-operative LUS scores increased in all areas of the right and left hemithorax, except the anterior upper area (area number 1) as compared to pre-operative measurements. LUS score increases were significant in areas number 4, 5, and 6 in both hemithorax (Figs. 1, 2) (Table 3).

No statistically significant difference was observed between the mean SpO_2 values recorded during the operation (χ^2=6.5098, df=4, p=0.164).

The arithmetic mean of heart rates was statistically significant according to the measurement time variable difference (F=19.82, p<0.001). There was a significant difference in the mean heart rates values measured between the 1st h and post-intubation (p<0.001), pre-operative (p<0.001), and post-operative (p<0.001) periods. Similarly, there was a statistically significant difference in the mean heart rates measured between after pneumoperitoneum and pre-operative (p<0.001), post-intubation (p<0.001), and post-operative (p<0.001) periods. There was no significant difference between other measurement points (p>0.05).

A significant difference was observed between the systolic blood pressure (SBP) values recorded during the operation (χ^2=222.98, df=142, p<0.001). There was a significant difference in measured mean SBP values, which was in favor of the pre-operative period as compared to post-intubation (p<0.001), post-pneumoperitoneum (p<0.001), and the 1st h of surgery (p<0.001). Similarly, there was a significant difference in measured mean SBP values, which was in favor of the post-operative period as compared to post-intubation (p<0.001), post-pneumoperitoneum (p<0.001), and the 1st h of the surgery (p<0.001). There was no difference between other measurement points (p>0.05).

A statistically significant difference was observed between the mean blood pressure (MBP) values recorded during the operation (χ^2=209.34, df=142, p<0.001). There was a significant difference in MBP values which was in favor of the pre-operative period as compared to post-intubation (p<0.001), post-pneumoperitoneum (p<0.001), and the 1st h of surgery (p<0.001) ones. Similarly, there was a statistically significant difference in MBP values, which was in favor of the post-operative period as compared to after intubation (p<0.001), after pneumoperitoneum (p<0.001), and at the 1st h of surgery (p<0.001) periods. There was also a significant difference in favor of post-operative MBP between the pre-operative and post-operative mean values of MBP (p<0.05). There was no significant difference between other measurement points (p>0.05).

A statistically significant difference was observed between the diastolic blood pressure (DBP) values recorded during the operation (χ^2=235.05, df=142, p<0.001). There was a significant difference in mean DBP measures which was in favor of the pre-operative period as compared to post-intubation (p<0.001), post-pneumoperitoneum (p<0.001), and 1st h of surgery (p<0.001). Similarly, there was a statistically significant difference in mean DBP measures which was in favor of the post-operative period as compared to post-intubation (p<0.001), after pneumoperitoneum (p<0.001), and at the 1st h of surgery (p<0.001). There was also a significant difference in favor of post-operative mean DBP values between pre-operative and post-operative periods (p<0.05). There was no significant difference between other measurement points (p>0.05).

Friedman rank-sum test was applied to reveal the change between the mechanical ventilation parameters recorded after intubation during the operation. A statistically significant difference was observed between the FiO_2 values recorded at the measurement points (χ^2=8.1411, df=2, p=0.01707). There was a statistically significant difference in favor of post-intubation FiO_2 values between post-intubation and 1 h after the initiation of the surgery (p<0.05). There was no significant difference between other measurement points (p>0.05).

A statistically significant difference was observed between $EtCO_2$ values (χ^2=310.65, df=142, p<0.001). There was a statistically significant difference in $EtCO_2$ values measured between 1 h after initiation of the operation and after intubation (p<0.001) and after pneumoperitoneum (p<0.001). There was no significant difference between other measurement points (p>0.05).

A statistically significant difference was observed between the measurement points of PEEP values during the operation (χ^2=26.026, df=2, p<0.001). There was a statistically significant difference in the PEEP values measured which was in favor of the post-intubation period as compared to 1 h after initiation of the surgery (p<0.001) and after pneumoperitoneum administration (p<0.001). There was no significant difference between other measurement points (p>0.05).

There was no statistically significant difference between Pplato values (χ^2=5.9225, df=2, p=0.051).

Friedman rank-sum test was applied to reveal the time change in P_{peak} values recorded during the operation in the mechanically ventilated patients. A statistically significant difference was observed between the P_{peak} values recorded at the measurement points (χ^2=27.892, df=2, p<0.001). There was a statistically significant difference in P_{peak} values measured which was in favor of the post-intubation period as compared to 1 h after initiation of the operation (p<0.001) and after pneumoperitoneum administration (p<0.001). There was no significant difference between other measurement points (p>0.05).

A statistically significant difference was observed between the compliance values recorded at the measurement points (χ^2=8.9797, df=2, p=0.011). There was a statistically significant difference in compliance values applied which was in favor of the post-intubation period as compared to 1 h after initiation of the surgery (p<0.05) and after pneumoperitoneum administration (p<0.05). There was no significant difference between other measurement points (p>0.05).

Perioperative recruitment maneuver was performed in 44 patients. Pre-operative and post-operative LUS scores were compared with the existence of recruitment application. According to the Mann-Whitney U-test, there was no significant difference in pre-operative LUS scores between those who received recruitment (median=0, Q1=0, Q3=1) and those who did not (median=0, Q1=0, Q3=1) (U=2167, Z=-0.057, p=0.955). There was also no significant difference in post-operative LUS scores between those who received recruitment (median=5, Q1=2, Q3=8) and those who did not (median=6, Q1=3, Q3=8) (U=3022, Z=-0.641, p=0.521).

To investigate the factors affecting the LUS scores of the patients, we applied correlation analysis between BMI, age, gender, and LUS scores. A weak correlation was found between female gender and pre-operative LUS scores (r=-164, p=0.037). However, we could not see any relationship between post-operative LUS scores.

To show the relationship between perioperative blood gases analysis and LUS scores, we performed correlation analysis between pH, pCO_2, pO_2, and SpO_2, and pre-operative and post-operative LUS scores. A negative correlation was found between the pre-operative LUS score and the pO_2 (r=-0.226, p=0.017) and SpO_2 (r=-0.305, p=0.001) values measured after pneumoperitoneum. A positive correlation was found between post-operative LUS score and post-operative pCO_2 values (r=0.239, p=0.028).

Discussion

During laparoscopic bariatric surgery, patients are at risk of atelectasis due to general anesthesia, pneumoperitoneum, and supine position.[13] In the literature, we did not find any study on the use of lung US in the diagnosis of atelectasis in patients undergoing bariatric surgery. In our study, we showed that lung US could be used in the early diagnosis of atelectasis. As we encounter an increasing number of obese patients, there is a need to develop and learn appropriate diagnostic methods for this patient group.[15] Baltieri et al.[6] revealed the prevalence of atelectasis developing after bariatric surgery performed with laparotomy as 37%. They retrospectively evaluated pre-operative and post-operative chest radiographs of 407 patients without OSAS and asthma in need of CPAP/BPAP and revealed that atelectasis was higher in the lower lung areas and was associated with female gender and increased age. We prospectively and observationally studied 143 patients who underwent laparoscopic bariatric surgery. LUS scores, used as an indicator of the development of atelectasis in the pre-operative and post-operative periods during spontaneous breathing with O_2 support, were increased in 116 (81.1%), did not change in 25 (17.5%), and decreased in 2 (1.4%) patients. Furthermore, we found that atelectasis increased in all areas, except the upper area of the right and left hemithorax, more in the lower lung areas (Figs. 1, 2). We believe that the higher incidence rate in our study compared to Baltieri et al.[6] is due to the difference in imaging techniques.

Lichtenstein et al.,[16] one of the pioneers of the use of US in lung pathologies, showed that bedside US was superior to direct radiography in demonstrating lung consolidation in ARDS patients whose transfer was troublesome from ICU to radiology unit for imaging and that US was also useful in monitoring the lung areas opened by the recruitment maneuver. Recently, Touw et al.[17] reported the rate of pulmonary complications on a post-operative day 0 after major abdominal surgery by lung US as 72.1% and by chest radiography as 36.1%. The difference in the incidence of atelectasis rate between Baltieri et al.[6] and Lichtenstein et al.[16] studies may be due to the high sensitivity and specificity of US than chest radiography. Our study has higher incidence rates than both studies, which may result from several factors. Apart from the different diagnostic tools between the studies, there are also methodological differences in patient selection and the surgical techniques applied. For example, although patients with OSAS and controlled pulmonary diseases were included in our study, they were not included in the study of Baltieri et al.[6] In addition, bariatric surgery was performed by laparoscopic technique in our cases. While pneumoperitoneum increases the risk of intraoperative atelectasis, it has been shown to reduce the occurrence of post-operative pulmonary complications because it causes less post-operative pain.[18] We believe that chest CT and lung US imaging will give more accurate results than chest radiography due to the low sensitivity of the method. Other advantages of using lung US for the diagnosis of atelectasis for the patient include that it is a bedside applicable, repeatable, and easy-to-learn diagnostic tool without radiation exposure risk.

Hedenstierna et al.[19] examined the mechanism of atelectasis that developed in the perioperative period, and they reported the incidence as 90% in patients under anesthesia. This rate is very close to the incidence of atelectasis (81%), we demonstrated in the 1st post-operative h.

It is known that general anesthesia causes atelectasis. There are many studies in the literature about the risk factors and mechanisms of perioperative atelectasis. Among these risk factors, the type and duration of anesthesia and surgery, gender, obesity, shallow breathing due to pain, and underlying neuromuscular and chronic systemic diseases are listed. The fact that our patient population is obese explains the high incidence of atelectasis in our study. However, we did not find a correlation between BMI and atelectasis rates. Similarly, Baltieri et al.[6] could not show the correlation of atelectasis with BMI in their study, and they explained this by the fact that the entire patient population was morbidly obese like our study group. In addition, we did not find a relationship between gender, age, and the frequency of atelectasis. Our study group is not homogeneously distributed in terms of gender; the majority of the cases were women (79.7%). Therefore, commenting on the relationship between gender and atelectasis in our study may be misleading. It would be a correct approach to make this comparison with prospective studies showing an equal distribution in terms of gender. Bariatric surgery is mostly performed in young and middle-aged patients. The mean age of our patients was 40±10. Unlike other studies, the reason that there is no relationship between age and atelectasis in our cases may be due to the age distribution of our patients and the very high incidence of atelectasis.

Although general anesthesia is known to increase the risk of atelectasis, it can also be seen in hospitalized patients before surgery. Eichenberger et al.[20] compared the incidence of post-operative atelectasis with CT in morbidly obese patients who underwent laparoscopic bariatric surgery and non-obese patients who underwent laparoscopic surgery. They demonstrated atelectasis in the pre-operative and post-operative periods in both patient groups. They also found that atelectasis was more common in the morbidly obese group after extubation. Similarly, our patients also had varying degrees of atelectasis in the pre-operative period. In the same study, it was shown that in the non-obese group, atelectasis resolved spontaneously in the first 24 h postoperatively, and the lungs recovered to pre-operative state; but atelectasis did not resolve in the morbidly obese group. In our study, when we compared the pre-operative and post-operative LUS scores, we found that atelectasis increased significantly in the post-operative period and that the post-operative LUS scores of patients with high preoperative LUS scores were also significantly higher. Since we performed the post-operative US evaluation within the 1st h after extubation, we cannot comment on the recovery time of post-operative atelectasis, and whether any other post-operative pulmonary complications developed, this issue can be evaluated with further studies.

We evaluated the variations in peripheral SpO_2, heart rate, and blood pressure values of the patients in the perioperative period. No significant change was observed in peripheral SpO_2 values in the measurement times. This may be due to pre-oxygenation done before induction, adjusting the percentage of FiO_2 to keep SpO_2 values above 92% during mechanical ventilation, and the fact that oxygen was applied to patients with a face mask during spontaneous breathing in the post-operative period. For these reasons, the effect of atelectasis on saturation values may be masked.

Heart rate and systolic, diastolic, and mean blood pressure values were found to be higher in the pre-operative, post-intubation, and post-operative periods as compared to pneumoperitoneum and the 1st h of the operation. In our prospective observational study, we believe that the high heart rate and blood pressure values are due to no premedication which is applied for morbidly obese patients in our clinic, and post-operative opioids are administered when the visual pain scale value is equal to or above 4.

Blood gas evaluations revealed that pO_2 and SpO_2 values decreased simultaneously with the initiation of pneumoperitoneum in patients with high pre-operative LUS scores. We believe with the IAP increase, the atelectasis formation which is already present in these patients is enhanced. Sprung et al.[21] thought that pneumoperitoneum would affect the gas exchange in morbidly obese patients more than normal patients. In their study, they argued that pO_2 was not affected by either pneumoperitoneum or Trendelenburg/reverse Trendelenburg positions in morbidly obese and non-obese patients, but only obesity had an effect on pO_2. However, since the limited number of cases (17 cases), it may be wrong to generalize this assumption. Andersson et al.[22] showed that pneumoperitoneum with a pressure of 11-13 mmHg increased atelectasis in dependent lung areas by an average of 66% in their examination with CT before and after pneumoperitoneum in non-obese patients who underwent laparoscopic cholecystectomy. The same study showed that with pneumoperitoneum, the diaphragm moves to the cephalic direction with an average of 1.9 cm, and the amount of ventilated lung decreases. They stated an improvement in oxygenation, although the ventilated lung areas decreased after pneumoperitoneum. They thought that this was related to the improvement in the V/Q ratio and the reduction in shunt, which they revealed through arterial and pulmonary catheters in another study they performed in laparoscopic surgeries. We could not find any study that performed imaging with pneumoperitoneum in obese patients. Simultaneous lung US imaging with pneumoperitoneum may help to clarify this issue.

Although post-operative LUS scores were increased, clinically significant SaO_2, pO_2, and SpO_2 decreases were not observed. This may be related to analyzing the blood gas samples taken in the post-operative care unit while the patient is under O_2 support. In addition, hypoxemia usually becomes evident after discharge from the post-operative care unit; post-operative atelectasis may present with tachypnea and hypoxia or may be asymptomatic.[23] We found that there was no significant relationship between $EtCO_2$ and pCO_2 values and LUS scores, except in the post-operative period. We think that this is due to changing the intraoperative mechanical ventilator settings to optimize the carbon dioxide value. The positive correlation between LUS scores and the pCO_2 values of the patients in the post-operative period suggests that high pCO_2 values are the result of atelectasis. The negative relationship between post-operative LUS scores and SaO_2 and pO_2 also supports this result. We did not find a significant relationship between HCO_3, BE, lactate values in blood gas analyzes, and LUS scores. We may not have seen the effects of atelectasis on these parameters in the perioperative period since it takes time to see the effect of atelectasis on these parameters.

It has been shown that 10 mmHg PEEP application after recruitment maneuver in obese patients undergoing bariatric surgery reduces the incidence of atelectasis development and improves oxygenation.[13] In our study, SpO_2 values were improved with the titration of PEEP (8-14 mmHg) following the recruitment maneuver in 44 patients who developed hypoxia during surgery. There was no significant difference in post-operative LUS scores between those who received recruitment maneuvers and those who did not. Simultaneous lung US can be used to see the effectiveness of the recruitment maneuver.[24]

The lack of a significant relationship between mechanical ventilator parameters such as minute volume, tidal volume, PEEP, P_{max} and P_{peak}, and LUS scores may be due to the use of a similar mechanical ventilation strategy in all patients. This can be demonstrated by randomized controlled studies investigating the effect of mechanical ventilation on the development of atelectasis. PEEP values applied in the 1st h of the surgery and during pneumoperitoneum were higher than the values applied after intubation. It is the result of the mechanical ventilation strategy applied during surgery to offset the effects of pneumoperitoneum on intrathoracic pressure.

Heart rate and mean blood pressure decreased with pneumoperitoneum. Nguyen et al.[25] observed the opposite in their study investigating the effect of pneumoperitoneum on obese people. In another study conducted in laparoscopic gynecological surgery, pneumoperitoneum had a negative effect on cardiac autonomic functions, and it was stated that a more pronounced effect could be encountered in patients with cardiac pathologies.[26] The cardiac responses we observed in our study may be due to the fact that most of our patients are diabetic with probable autonomic dysfunction.[27]

Our study has some limitations. Since it was an observational study, invasive arterial monitoring was performed after intubation only in necessary cases. Therefore, only these patients intraoperative and post-operative blood gas values and LUS scores could be compared. The diagnosis of atelectasis was made with US, but it could not be compared with post-operative chest X-ray or CT since they are not routinely performed. Since the hemodynamic and respiratory responses due to post-operative atelectasis were examined only in the 1st h after extubation, we could not evaluate the long-term results. Those can be evaluated in further studies.

Conclusion

Lung US is a practical diagnostic method that can be used in the early diagnosis of perioperative lack of aeration and atelectasis in obese patients.

Post-operative atelectasis is seen at a high rate in patients who have undergone laparoscopic bariatric surgery.

Atelectasis can also be seen in the pre-operative period in morbidly obese patients.

A decrease in lung compliance is observed with pneumoperitoneum application in patients who are having laparoscopic bariatric surgery.

Disclosures

Ethics Committee Approval: The study was approved by The Marmara University Faculty of Medicine Clinical Research Ethics Committee (Date: 06/10/2017, No: 09.2017.622).

Informed Consent: Written informed consent was obtained from all patients.

Peer-review: Externally peer-reviewed.

Conflict of Interest: None declared.

Financial Disclosure: The authors declared that this study has received no financial support.

Authorship Contributions: Concept – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Design – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Supervision – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Fundings – None; Materials – None; Data collection &/or processing – D.E., M.K.A.; Analysis and/or interpretation – D.E., M.K.A.; Literature search – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Writing – D.E., M.K.A., G.T.A., P.Ç.D.; Critical review – D.E., M.K.A., G.T.A., P.Ç.D., H.Ö.A.

Etik Kurul Onayı: Çalışma Marmara Üniversitesi Tıp Fakültesi Klinik Araştırmalar Etik Kurulu tarafından onaylandı (Tarih: 06/10/2017, Numara: 09.2017.622).

Hasta Onamı: Hastalardan yazılı onam alınmıştır.

Hakem değerlendirmesi: Dışarıdan hakemli.

Çıkar Çatışması: Çıkar çatışması bulunmamaktadır.

Finansal Destek: Yazarlar bu çalışmanın herhangi bir finansal destek almadığını beyan etmişlerdir.

Yazarlık Katkıları: Fikir – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Tasarım – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Denetmeler – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Kaynaklar – Yok; Malzemeler – Yok; Veri Toplanması ve/veya İşlemesi – D.E., M.K.A.; Analiz ve/veya Yorum – D.E., M.K.A.; Literatür Taraması – D.E., M.K.A., G.T.A., P.Ç.D., E.A.K., H.Ö.A.; Yazıyı Yazan – D.E., M.K.A., G.T.A., P.Ç.D.; Eleştirel İnceleme – D.E., M.K.A., G.T.A., P.Ç.D., H.Ö.A.

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