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Original Article / *Özgün Makale*

Quantitative measurement of air leak in patients with chest drains

Göğüs tüpü bulunan hastalarda hava kaçağının kantitatif ölçümü

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ABSTRACT

Background: This study aims to evaluate a new method that detects peak air leak speed and peak air leak flow, investigate the correlation between the amount of air leak and development of prolonged air leak, and identify patients who are at risk of developing prolonged air leak after lung resection.

Methods: In this prospective trial, the amount of air leak was measured with the assistance of an anemometer connected to the top of a standard underwater drainage system, and a mobile phone with android operating system. Patients who underwent tube thoracostomy for spontaneous pneumothorax were assigned to group 1 (18 males, 1 female; mean age 31.6±10.9 years; range, 18 to 70 years), whereas patients who underwent lung resection for benign or malignant lung diseases were assigned to group 2 (37 males; 16 females; mean age 56.9±15.6 years; range, 18 to 80 years). The receiver operating characteristics analysis was performed for the statistical analysis of the data.

Results: Prolonged air leak was observed in five patients (26.3%) in group 1 and in six patients (11.3%) in group 2. In group 1, first measurement on postoperative day zero could detect prolonged air leak development with 100% sensitivity and 92.9% specificity. Similarly, in group 2, measurements on day zero could detect prolonged air leak development with 100% sensitivity and 87.2% specificity.

Conclusion: Compared to similar products, this newly developed measuring device may be widely used in clinics with its low cost and ease of use. Measured peak air leak flow values can predict patients who may develop prolonged air leak. Patent work for the device is ongoing.

Keywords: Chest tube; lung diseases; pneumothorax.

ÖZ

Amaç: Bu çalışmada tepe hava kaçak hızını ve tepe hava kaçak debisini saptayan yeni bir yöntem değerlendirildi, hava kaçağı miktarı ve uzamış hava kaçağı gelişimi arasındaki ilişki araştırıldı ve akciğer rezeksiyonu sonrası uzamış hava kaçağı gelişimi riski taşıyan hastalar belirlendi.

Çalışma planı: Bu prospektif çalışmada, hava kaçağı miktarı standart bir su altı drenaj sisteminin üstüne bağlı bir anemometre ve android işletim sistemine sahip bir cep telefonu yardımı ile ölçüldü. Spontan pnömotoraks için tüp torakostomi uygulanan hastalar (18 erkek, 1 kadın; ort. yaş 31.6±10.9 yıl; dağılım, 18-70 yıl) grup 1'e, benign veya malign akciğer hastalıkları nedeniyle akciğer rezeksiyonu uygulanan hastalar (37 erkek; 16 kadın; ort. yaş 56.9±15.6 yıl; dağılım, 18-80 yıl) ise grup 2'ye alındı. Verilerin istatistiksel analizi için alıcı işletim karakteristiği analizi uygulandı.

Bulgular: Uzamış hava kaçağı grup 1'de beş hastada (%26.3), grup 2'de altı hastada (%11.3) gözlemlendi. Grup 1'de, ameliyat sonrası sıfırıncı gündeki ilk ölçüm uzamış hava kaçağı gelişimini %100 duyarlılık ve %92.9 özgüllük ile saptayabildi. Benzer şekilde, grup 2'de, ameliyat sonrası sıfırıncı gündeki ölçümler uzamış hava kaçağı gelişimini %100 duyarlılık ve %87.2 özgüllük ile saptayabildi.

Sonuç: Benzer ürünler ile karşılaştırıldığında, yeni geliştirilen bu ölçüm cihazı düşük maliyeti ve kullanım kolaylığı ile kliniklerde yaygın şekilde kullanılabilir. Ölçülen tepe hava kaçak debisi değerleri uzamış hava kaçağı gelişebilecek hastaları öngörebilir. Cihaz için patent çalışmaları devam etmektedir.

Anahtar sözcükler: Göğüs tüpü; akciğer hastalıkları; pnömotoraks.

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While traditional underwater drainage systems (UDS) are able to measure drainage volume of fluids, measurement of air leak depends simply on observation of the bottle.[1,2] Most studies have classified air leaks by observing the air coming from the thorax drain during respiratory maneuvers (such as coughing-taking deep breaths).[3,4] The technical problems encountered during this classification effort have motivated researchers to develop different drainage systems.[3-6] Various instruments, including pressure gauges or flow meters, have been used for the measurement of air leaks.[2,6] Despite these developments, there is no accepted classification system that is able to correlate the amount of air leak with prognosis and establish a quantitative classification.

In this study, we attempted to solve the aforementioned problems by using a simple anemometer. Anemometers were suited to UDS with a simple modification and the amount of air leak is measured quantitatively. In the second stage of study, we tried to predetermine patients who may develop prolonged air leak (PAL). Thus, we questioned the possibility of making the decision for surgery for patients admitted with primary spontaneous pneumothorax (SP), without waiting for the seven day period. Therefore, in this study, we aimed to evaluate a new method that detects peak air leak speed (PALS) and peak air leak flow (PALF), investigate the correlation between the amount of air leak and development of PAL, and identify patients who are at risk of developing PAL after lung resection.

PATIENTS AND METHODS

This prospective study included patients who were followed-up in Ege University Faculty of Medicine, Department of Thoracic Surgery for SP and who underwent lung resection between December 2016 and May 2017. The study protocol was approved by the Ege University Faculty of Medicine Ethics Committee (06.12.2016, Document ID: 246774). A written informed consent was obtained from each patient. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patients were divided into two groups: group 1 consisted of 19 patients (18 males, 1 female; mean age 31.6±10.9 years; range, 18 to 70 years) who underwent tube thoracostomy (TT) for SP. Following TT, all patients were evaluated with chest X-ray. Patients with traumatic or iatrogenic pneumothorax, and those with drain malposition were excluded. Patients with recurrent SP and those who underwent early surgery after TT (before seven days since the date of TT) were also excluded. Group 2 consisted of 53 patients (37 males; 16 females; mean age 56.9±15.6 years; range, 18 to 80 years) who underwent lung resection for benign or malignant lung diseases. Exclusion criteria for group 2 were as follows;

i. Patients who did not undergo parenchymal lung resection (i.e. pleural-pericardial biopsy, enucleation or only bronchial resection),
ii. Mesothelioma patients who underwent lung resection, total decortication, and hyperthermic chemotherapy within the same session,
iii. Patients who underwent pneumonectomy (as their drains were monitored with clamps),
iv. Patients who underwent lung resection for traumatic and resuscitative causes,
v. Patients who underwent revision surgery due to postoperative bleeding,
vi. Patients without air leak after lung resection,
vii. Patients transferred to intensive care unit (ICU) without extubation after surgery (as the level of air leak could vary depending on the settings of the mechanical ventilator).

The amount of drainage, time until drain removal, complications and treatments were recorded for each patient. All chest drains were removed during the deep inspiration phase. Patients who had air leak for seven days or over were accepted as "PAL developed patients" for all groups. Diagnosis of PAL was established by a surgeon blinded towards all PALF values.

All measurements were performed with a digital anemometer (WeatherFlow® Weathermeter, California, USA) (Figure 1). The device is capable of measuring the mean air flow rate and the maximum flow rate. Technical features of the device enable it to connect to mobile phones with android operating systems (Google Inc., Mountain View, California, USA) via Bluetooth (Bluetooth SIG, Inc., Headquarters, Kirkland, USA). The device has been calibrated by the University of Florida at Department of Aerospace Engineering. The device can measure air flow rate within a range of 0.4-55 m/sec with ±0.5% accuracy.

With simple modifications, the digital anemometer was fitted to the air discharge pipe of the drainage bottle (Figure 1). As a result, we created a system which is applicable to standard UDS and do not have any contact with the patient’s fluids. Results were monitored from the mobile phone and recorded in phone memory. In this way, the measurements were transferred to a digital information system.

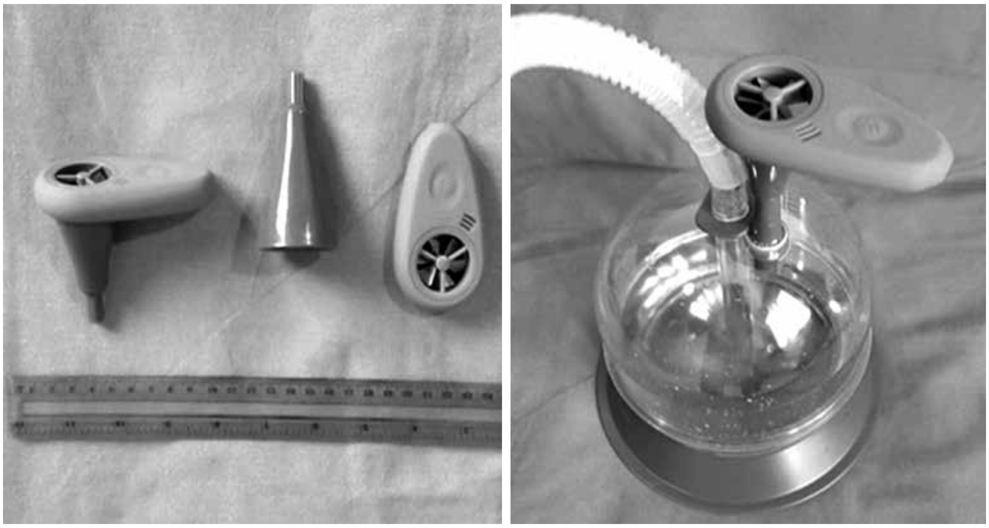

Figure 1. Anemometer used to measure air drainage from underwater drainage system. Device is battery powered and its small size allows mobile use. Anemometer was integrated with chest drain funnel to be suited to underwater drainage system.

Air flow speed measured by the anemometer was converted to flow rate by the following formula: Q=V × A; where Q is flow rate (cm^3/sec), V is velocity (cm/sec), and A is cross-sectional area (cm^2). In summary, PALS values were measured first, and then corresponding PALF values were calculated with the formula.

In group 1, measurements were performed according to standardized measurement sessions, which follow strict regulations, and which were repeated twice daily. In each session, patients were asked to cough vigorously, take deep breaths, and count. During each respiratory maneuver (in each coughing, deep breathing and counting steps), two measurements were performed, and the arithmetic mean of these measurements was calculated to determine PALS. If any of the measurements was beyond the measurement range, a third measurement was performed, and the arithmetic mean of the two highest measurements was calculated. For each PALS value, the corresponding PALF value was calculated with the following formula: “Q=V × A□. During the first measurement on day zero, the highest PALF value was considered as “PALF0”.

Second measurements on day zero were performed as scheduled (same as the first measurement), and were recorded as PALF00. The highest PALF value between morning and evening measurements on postoperative day one was considered as “PALF1”. The same procedure was performed on other days, and values were recorded as “PALF2” and “PALF3”. In sum, two PALF values were determined for day zero, and only one PALF value was determined for other days. Measurements continued until air drainage from the thorax drain was stopped. If air leak continued for seven days or over, measurements were terminated. These patients were either treated with surgical treatment or UDS were replaced with Heimlich valve.

In group 2, the first measurements (PALS0) were performed after the patients were extubated and transferred to ICU, given standard analgesics, evaluated with lung graphy and sufficient wakefulness was detected. Similar to measurements in group 1, patients were asked to cough, take deep breaths and count. Measurements on patients with air leaks from both chest drains were performed from the apical drain, after clamping the basal drain. Afterwards, PALF0 value was calculated for each respiratory maneuver. Second measurements on postoperative day zero were performed approximately four hours after the first measurement. The highest PALF value in this measurement was recorded as PALF00. Subsequent measurements were performed during scheduled times in the morning (07:00-10:00) and evening (17:30-19.00). The highest measurement for each day was considered as the PALF value of the day.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 21.0 software (IBM Corp., Armonk, NY, USA). First, receiver operating characteristic (ROC) curves were generated from PALF values

Table 1. Summary of postoperative measurements in group 1

	First measurement on Day 0 (PALF0)		Second measurement on Day 0 (PALF00)		Day 1 (PALF1)		Day 2 (PALF2)		Day 3 (PALF3)		Day 4 (PALF4)	
	Total	PAL	Total	PAL	Total	PAL	Total	PAL	Total	PAL	Total	PAL
	n	n	n	n	n	n	n	n	n	n	n	n
PALF <212 mL/sec	13	0	13	0	11	0	11	2	4	2	2	2
PALF 212-500 mL/sec	3	2	3	2	3	2	0	0	1	1	2	2
PALF >500 mL/sec	3	3	3	3	3	3	3	3	2	2	1	1

PALF0: First measurement on Day 0; PALF00: Second measurement on Day 0; PALF1: Measurement on Day 1; PALF2: Measurement on Day 2; PALF3: Measurement on Day 3; PALF4: Measurement on Day 4; PALF: Peak air leak flow; Total: Total number of patients; PAL: Prolonged air leak.

(PALF0, PALF00, PALF1 etc.) in group 1 to calculate cut-off values which would indicate PAL development. Statistical significance, sensitivity and specificity values were calculated for each cut-off value. The same procedure was performed for postoperative PALF values in group 2.

RESULTS

In group 1, 14 patients were hospitalized with a diagnosis of primary SP and five with secondary SP. Etiologies of patients with secondary SP included three COPDs, one tuberculosis, and one Langerhans cell histiocytosis. Left-sided pneumothorax was detected in 10 patients (52.63%).

Prolonged air leak was observed in five of 19 patients (26.3%) in group 1. Three of these patients underwent videothoracoscopic wedge resection and patients were discharged without any complication. Histopathological examinations of surgical specimens showed signs of bullous emphysema in two patients, and Langerhans cell histiocytosis in one patient. Active tuberculosis was detected in one patient and one had advanced COPD. Therefore, these patients did not undergo surgery and were discharged with Heimlich valves.

Prolonged air leak was not observed in any of the 13 patients with a PALF0 value <212 mL/sec. Three patients had a PALF0 value between 212-500 mL/sec, and PAL development was observed in two patients. Three patients had a PALF0 value >500 mL/sec, and PAL development was observed in all of these patients. The PALF values on other days and their correlation with PAL were shown in Table 1.

The ROC analysis was performed to determine the prognostic significance of measured PALF values and to calculate significant cut-off values. Receiver operating characteristic curves, putative cut-off values, sensitivity and specificity values based on the cut-off values were recorded (Figure 2).

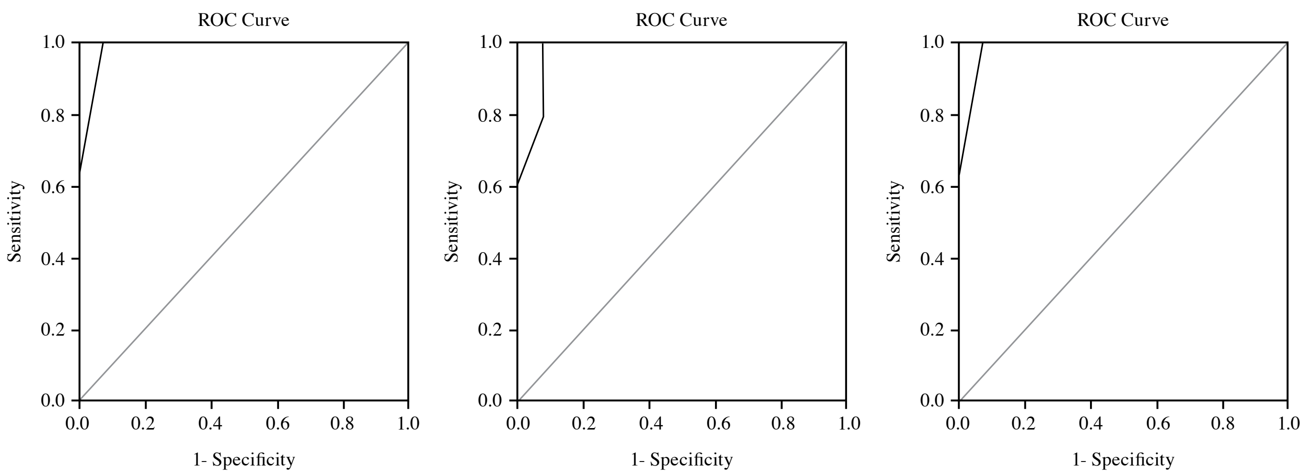

Figure 2. Receiver operating characteristic graphs for group 1.

Table 2. Receiver operating characteristic analysis for different peak air leak flow values in group 1

Measurement time	Cut-off value (mL/sec)	Sensitivity (%)	Specificity (%)
PALF0	265.24	100	92.9
PALF00	238.70	100	92.9
PALF1	265.24	100	91.7
PALF2	371.4	60	100

PALF0: First measurement on Day 0; PALF00: Second measurement on Day 0; PALF1: Measurement on Day 1; PALF2: Measurement on Day 2.

A PALF0 cut-off value of 265.24 mL/sec was able to predict PAL development with 100% sensitivity and 92.9% specificity. When the PALF00 cut-off value was set to 238.7 mL/sec, PAL development could be determined with 100% sensitivity and 92.9% specificity. The procedure was repeated for observed PALF values on other days (e.g. PALF2, PALF3) and the results were recorded. A decrease in the sensitivity

Table 3. Demographic features of patients in group 2

	n	%	Mean±SD
Mean age (year)			56.9±15.6
Gender			
Male	37	69.81	
Female	16	30.19	
Comorbid disease			
Cardiac	20	37.74	
Endocrine	15	28.30	
Chronic obstructive pulmonary disease	10	18.87	
Other	9	16.98	
Previous diagnosis of malignancy			
Yes	22	41.51	
No	31	58.49	
Type of surgery			
Thoracotomy wedge	14	26.42	
Videothoracoscopic wedge	11	20.75	
Right upper lobectomy	9	16.98	
Right lower lobectomy	4	7.55	
Left upper lobectomy	6	11.32	
Left lower lobectomy	6	11.32	
Right upper bilobectomy	1	1.89	
Right lower bilobectomy	2	3.77	
Total number of sublobar resections	25	47.17	
Total number of lobar resections	28	52.83	
Pathological examination result			
Adenocarcinoma	19	35.85	
Squamous cell carcinoma	8	15.09	
Metastatic disease	14	26.42	
Benign disease	8	15.09	
Other malignant disease	4	7.55	
Mean hospitalization time (days)			4.7±2.8

SD: Standard deviation.

Table 4. Summary of postoperative measurements in group 2

	PALF0		PALF00		PALF1		PALF2		PALF3	
	Total	PAL	Total	PAL	Total	PAL	Total	PAL	Total	PAL
	n	n	n	n	n	n	n	n	n	n
PALF <212 mL/sec	40	0	39	0	15	1	12	2	9	2
PALF 212-500 mL/sec	8	1	8	2	5	1	4	1	2	2
PALF >500 mL/sec	5	5	5	4	4	4	3	3	2	2

PALF0: First measurement on Day 0; PALF00: Second measurement on Day 0; PALF1: Measurement on Day 1; PALF2: Measurement on Day 2; PALF3: Measurement on Day 3; PALF: Peak air leak flow; Total: Total number of patients; PAL: P rolonged air leak.

and specificity values was detected on the third and the following days. This was due to the fact that patients whose air drainage stopped and thorax drains were removed were excluded from the statistical analysis, so total sample decreased. In particular, from day four, PAL development was observed in all patients with an air leak. Therefore, we were unable to get a statistically significant result for third and following days. For group 1, the cut-off values obtained from ROC analysis and calculated sensitivity and specificity values were summarized in Table 2.

In group 2, the mean ages of male and female patients were 56.8±16.2 years (range, 18 to 80 years) and 57.1±14.6 years (range, 23 to 72 years), respectively. Patients' demographic features, surgical treatments, and histopathological examination results were summarized in Table 3.

Prolonged air drainage was observed in six patients. Forty patients had a PALF0 value <212 mL/sec, and PAL was not observed in any of these patients. Eight patients had a PALF0 value between 212-500 mL/sec, and PAL was observed

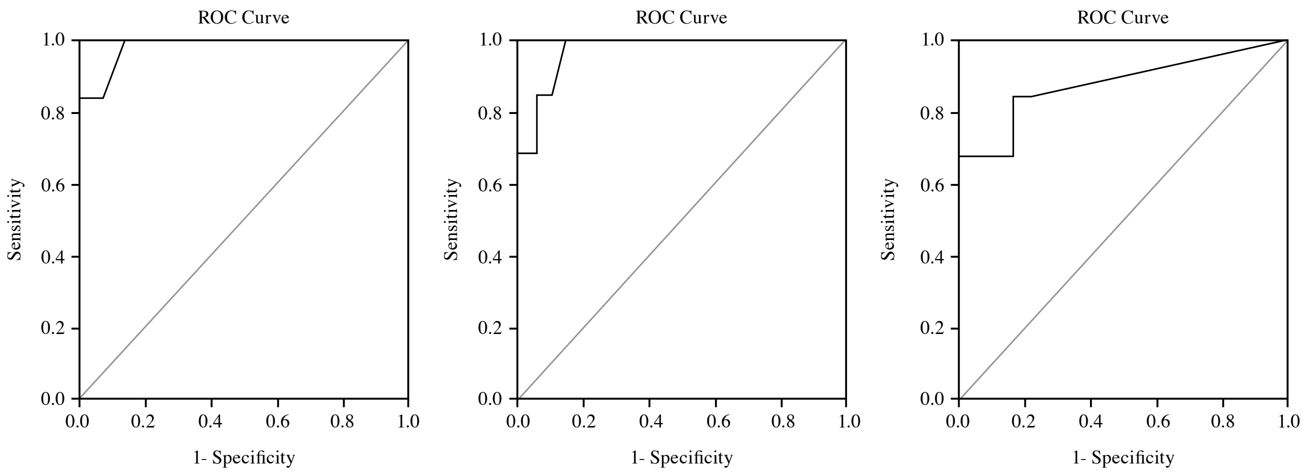

Figure 3. Receiver operating characteristic graphs for group 2.

Table 5. Receiver operating characteristic analysis for peak air leak flow values in group 2

Measurement point	Cut-off value (mL/sec)	Sensitivity (%)	Specificity (%)
PALF0	291.74	100	87.2
PALF00	238.50	100	84.8
PALF1	265.24	83	77.8
PALF2	265.24	66.7	76.9

PALF0: First measurement on Day 0; PALF00: Second measurement on Day 0; PALF1: Measurement on Day 1; PALF2: Measurement on Day 2.

in only one patient. Five patients had a PALF value >500 mL/sec, and PAL was observed in all five patients. Other PALF values and their correlation with PAL were summarized in Table 4.

Subsequently, the ROC analysis was performed for each PALF value. Similar to group 1, the PALF cut-off values and their sensitivity and specificity to predict PAL development were determined (Figure 3). Overall results for patients in group 2 were shown in Table 5.

DISCUSSION

Prolonged air leak is a serious morbidity for patients undergoing TT for SP, as well as patients undergoing lung resection. While inadequate expansion accompanying air leak for longer than two days is considered as "resistant air leak" in some studies,[7] other studies define PAL as air leak lasting for more than five to seven days.[8,9] The fact that PAL is considered as an indication for surgery in patients with SP further increases the importance of PAL.[10,11] Use of digital drainage systems have led to promising attempts towards measurement of the amount of leak but there is no measurement technique that is able to determine PAL development at an early stage with high sensitivity and specificity.[5,12] Previous studies with digital thoracic drainage systems have not utilized measurements such as PALS-PALF as prognostic factors.[12,13-17] Similarly, digital drainage systems that are currently in use have not gained wide use due to high costs. In our study, we used a simple anemometer instead of a digital drainage system, which resulted in significantly reduced costs. The anemometers enabled quantitative measurement of PALS and PAL, and provided a prognostic use for these parameters. Overall, we aimed to detect PAL development at an early stage, in both patients with SP and those who underwent lung resection.

For the measurement of the PAF value as a prognostic factor, we were inspired by the peak expiratory flow meters (PEF-meter) that are used for evaluating treatment response in patients with asthma. It is known that PEF-meters can be used by asthma patients without requiring help, and they offer a cheap, effective, and easy measurement method. Peak expiratory flow meters measure the air flow during strong expiration.[18-20] High PEF values are generally considered as an indicator of good response to treatment.[18,19] Similarly, the use of PALF values to predict PAL development is a logical approach. Air leaks are known to decline over time, and eventually cease. In case of patients with massive air leaks, it is reasonable to hypothesize that the air leak will decrease rather slowly and it will take a long time to cease. A second hypothesis is that air leaks with high flow rate may indicate large lung damage that will not end without an intervention. In our study, massive air leaks were directly clarified with increased PALF values. We obtained two PALF values for postoperative day zero, and one PALF value on the subsequent days. These quantitative data offered an opportunity for a statistical comparison, and a possibility to calculate a cut-off value. The ROC analyses for group 1 revealed that particularly PALF0, PALF00, and PALF1 values can determine PAL development with high specificity and sensitivity (>90%).

The results in group 2 were similar to group 1. The PALF0 cut-off value of 291.74 mL/sec could detect PAL development with 100% sensitivity and 87.2% specificity. The PALF00 could detect PAL development with 100% sensitivity and 84.8% specificity, whereas PALF1 could detect PAL development with 83% sensitivity and 77.8% specificity. The decreasing trend in sensitivity and specificity values are likely to result from the reduction in total number of patients, as patients were excluded from further analysis after removal of drains.

Based on the results of this study, we believe that measurements on patients with SP after TT on days zero, one, and two would enable early detection of PAL, and will guide the decisions for surgery. Based on the results in the first two days, the decision for surgery can be established without having to wait for a period of five to seven days. By using these results, it may be possible to prevent unnecessary hospitalization of patients during the preoperative period.

Detection of PAL during early postoperative period for patients in group 2 may ensure that interventions towards minimizing air leak can be performed relatively soon.

The digital drainage systems used to measure air leak, such as Thopaz (Medela AG, Lättichstrasse, Baar, Switzerland) or Airfix (TEUP's Ltd., Deutschlandsberg, Austria), etc. have not been widely used in our country due to their high costs. They can be used only on one patient at a time, and each device requires use of special drainage bottles.[13] In this regard, both the device and the special drainage bottles that should be used increase the cost. In our study, we used a simple anemometer to measure air leakage. The changes made to the anemometers to ensure that they are compatible with the UDS did not result in any additional cost. All in all, the entire system costed 600 Turkish liras (US$125). Compared to other systems with similar functions (which cost around US$15,000), our system is clearly far more favorable in terms of its high benefit-to-cost ratio.

The major limitation of this study is related to the technical features of the anemometer. In some studies in the literature, different types of anemometers have been used for medical measurement, and results have been compared to flow-meters.[21] Compared to digital drainage systems, the anemometer used in our study has lower sensitivity. We attempted to overcome this technical limitation to a certain extent, by using PALS-PALF values instead of continuous measurements. Other limitations include the single-center nature of the study, and very small sample size. We attempted to overcome both limitations by obtaining sufficient numbers of measurements and using appropriate statistical methods.

In conclusion, this pioneering study provided a new and practical technique for quantitative measurement of air leaks, and described new and important prognostic parameters, such as peak air leak speed and peak air leak flow. Patent work for the device is ongoing.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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