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Duration of air leak is reduced after awake nonresectional lung volume reduction surgery☆

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Abstract

Objective: Prolonged air leak occurs frequently after lung volume reduction surgery (LVRS) and can negatively affect both morbidity and hospital stay. We hypothesised that awake nonresectional LVRS could reduce the duration of air leak in emphysema patients. **Methods:** This analysis included 66 patients undergoing awake, unilateral plication of the most emphysematous lung regions under sole epidural anaesthesia. Primary outcome measure was the rate of prolonged (>7 days) air leak; secondary outcome measures included the mean duration of air leak, hospital stay and early discharges ($\leq$4 days). All results were retrospectively compared with those of a similar control group undergoing resectional LVRS under general anaesthesia. **Results:** Intergroup comparisons showed that demographics and baseline data were well matched. Prolonged air leak occurred in 12 patients (18%) in the awake group versus 27 patients (40%) in the control group ($p = 0.007$) with a mean duration of 5.2 ± 6.5 days versus 7.9 ± 7.6 days ($p < 0.0002$). Mean hospital stay was significantly shorter in the awake group (6.3 ± 2.8 days vs 9.2 ± 5.6 days, $p < 0.0001$). At univariate analysis, resectional LVRS ($p = 0.007$), higher severity of emphysema ($p < 0.0001$) and lower diffusion capacity for carbon monoxide ($p = 0.0001$) correlated with occurrence of prolonged air leak; however, logistic regression indicated high severity of emphysema as the most important factor predicting prolonged air leak (odds ratio = 4.85, $p < 0.0001$). At 6 months, dyspnoea index, FEV1 and 6 min walking test improved significantly in both study groups. **Conclusions:** In this study, awake nonresectional LVRS was associated with a lower rate of prolonged air leak and a shorter hospital stay than the standard resectional technique.

Keywords: Emphysema; LVRS; Air leak; VATS; Complication; Awake thoracic surgery

1. Introduction

Lung volume reduction surgery (LVRS) is aimed at achieving safe, effective and durable palliation of dyspnoea with improvement of lung function and quality of life in selected patients with severe emphysema. Randomised studies have demonstrated the efficacy of resectional LVRS in patients with predominant upper lobe distribution of disease, although persistent air leak still represents a major cause of morbidity, long hospitalisation and high costs [1—5].

Several methods have been proposed in an attempt to limit the occurrence of air leak after LVRS including staple line buttress [6—9], use of biological sealant [7], adjunctive operative methods [10,11], and development of nonresectional surgical techniques [12—16].

Recently, DeCamp and co-workers [5] have shown that in the National Emphysema Treatment Trial (NETT), air leak occurred in 90% of the patients irrespective of the surgical approach, staple line buttressing, and intraoperative adjunctive procedures. Yet, this analysis showed that low diffusion capacity for carbon monoxide, important pleural adhesions, Caucasian ethnicity, and low forced expiratory volume in 1 s (FEV1) were all associated with the development of air leak.

We reasoned that in resectional LVRS, causes of air leak could theoretically include resection of lung tissue with pleural discontinuation, deep suturing of the lung tissue, and creation of a rigid continuous suture line resulting in an uneven distribution of lung expansion forces [12,17].

In an attempt to overcome these theoretical concerns, we have developed a nonresectional LVRS technique in awake patients that respects the basic concepts of the resectional procedure but entails thoracoscopic plication of emphysematous lung regions performed through sole epidural anaesthesia [12].

The aim of this study is to assess perioperative results of this surgical technique and to make a retrospective comparison with a group of patients undergoing standard resectional LVRS.

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2. Materials and methods

This analysis included 66 patients who underwent awake, unilateral introflexing plication of the most emphysematous lung regions under sole epidural anaesthesia between January 2001 and March 2008. Primary outcome measure was the rate of prolonged (>7 days) air leak; secondary outcome measures were, mean duration of air leak, hospital stay and the rate of early discharges ($\leq$4 days).

The study was set as a retrospective analysis of a prospective database in which all preoperative clinical and radiological data as well as intraoperative and postoperative findings have been stored according to a standardised protocol since January 2000. Results achieved in the awake group were retrospectively compared with those of a similar control group including the last 66 patients undergoing resectional LVRS under general anaesthesia during this time span. All patients gave written informed consent for the procedure and the Tor Vergata ethical committee approved the study. Eligibility criteria for LVRS were the same for both groups, and have been already described in detail [12,18,19]. Briefly, they included the finding of severe emphysema with radiologic evidence of distinct heterogeneity of disease associated with severe disability despite maximised medical care, post-bronchodilator forced expiratory volume in 1 s (FEV1) less than 40% predicted, and residual volume (RV) more than 180% predicted. Exclusion criteria included prevailing bullous disease with nearly normal underlying lung tissue.

Contraindications for awake LVRS regarded radiologic evidence of extensive pleural adhesions with pleural scarring and calcifications and/or a contraindication for thoracic epidural anaesthesia including patient's refusal or noncompliance, unfavourable anatomy, previous surgery of the cervical or upper thoracic spine, compromised coagulation (thromboplastin time <80%, prothrombin time >40 s, or platelets <100/nl) or bleeding disorder.

3. Preoperative workup

Preoperative workup included assessment of static lung volumes by body plethysmography, of diffusing capacity for carbon monoxide by the single breath technique, post-bronchodilator pulmonary function tests, 6 min walking test (SMWT) and modified Medical Research Council dyspnoea scoring. Radiologic study included estimation of emphysema severity (ES, range from 12 to 48) graded according to a previously described visual scoring classification based on high-resolution computed tomography findings [19]. Serum α-1-antitrypsine deficiency was assessed by nephelometric assay in all patients.

3.1. Anaesthesia and surgical technique

The objective of thoracic epidural anaesthesia was to achieve somatosensory and motor block at the T1 to T8 level while preserving diaphragmatic motion. The thoracic epidural catheter was inserted at T4 level. In the operating room, patients received a continuous infusion of ropivacaine 0.5% and sufentanil 1.66 μg/ml into the epidural space at a rate of 5 ml/h, starting about 20 min prior to surgery. During this time, the patient was placed in lateral decubitus position with the hemithorax targeted for operation in a dependent position to facilitate gravity distribution of the anaesthetics. A warm–cold discrimination test was used to assess the quality of anaesthesia. If necessary, additional local injection of anaesthetics (2–5 ml of mixed ropivacaine 0.5% plus bupivacaine 2%) was used to reinforce analgesia at the trocars' sites. Immediately before starting the surgical procedure, the patient's lateral position was changed placing upward the side targeted for surgery. Intraoperatively, patients breathed O_2 through a Venturi mask to keep oxygen saturation above 90%. During wound closure, the anaesthetic regimen was changed to ropivacaine 0.16% and sufentanil 1 μg/ml at 2–5 ml/h.

Patients undergoing resectional LVRS through general anaesthesia received a thoracic epidural catheter inserted between T5 and T8 and a continuous infusion of ropivacaine 0.5%. General anaesthesia was induced with intravenous propofol (1.5–2 mg/kg), fentanyl (1γ/kg) and vecuronium (0.1 mg/kg). Anaesthesia was maintained on the basis of a target controlled infusion administration with a target value of 4 mcg/ml of propofol. A left-sided double-lumen tube was used for one-lung ventilation, and ventilation was set at a tidal volume of 8–10 ml/kg and a peak airway pressure not exceeding 25 cm H_2O.

In all instances the operation was carried out through a videothoracoscopic approach and by a four-flexible-trocars' access.

In the awake group, the most emphysematous target areas were visualised and introflexed with a cotton swab while redundant lung edges were gently grasped by two ring forceps. Subsequently, a 45 mm, 'no knife' endostapler (Ethicon Endosurgery, Pomezia, Italy) was fired on the plicated lung region starting at the apex of the upper lobe and continuing to apply two other cartridges in the ventral and dorsal side of the targeted area to perform a linear, interrupted suture line [12,18]. In the control group, staple resection of target areas was performed excising a reversed U-shaped single strip of emphysematous lung tissue to reduce the upper lobe of about 50%.

No suture line buttress was used in either group while at the end of the procedure two chest tubes were always inserted. All the operations were performed by the same two surgeons (TCM, EP).

3.2. Drainage management

Management of chest tubes was standardised. Chest drainages were placed waterseal whereas mild suction (−10 cm H_2O) was employed whenever pneumothorax exceeded 1/3 of the pleural space at postoperative chest roentgenogram and/or gross subcutaneous emphysema developed. Criteria for tubes' removal included no air leak following 2 h of tube clamping and serous fluid loss <200 ml/24 h. Patients with minimal residual air leak were discharged with a Heimlich valve if they were clinically stable and had the possibility to reach our institution within about 30 min in case of any unexpected problem. Patients with large air leak not resolving within 15 days were scheduled for reoperation.

One week after chest tube removal, patients underwent outpatient follow-up which included physical examination, spirometry and blood gases assay. A chest roentgenogram was performed 30 days after the operation. Patients complaining of exacerbating dyspnoea despite apparently normal roentgenogram underwent a computed tomography to rule out the presence of occult loculated pneumothorax. Follow-up visits with complete functional assessment including blood gases, 6 min walking test and spirometry with plethysmography were carried out postoperatively, every 6 months.

3.3. Statistical method

Due to the non-normal distribution of some data, the nonparametric Wilcoxon signed rank and the Mann—Whitney tests were used for paired and unpaired data, respectively. Frequencies were compared with the two-tailed Fisher's exact test. Air-leak duration was recorded until removal of the last chest tube irrespective of the presence of a Heimlich valve.

The nonparametric time-to-event Kaplan—Meyer method was used to analyse air leak duration and differences between curves were tested by the Cox—Mantel method.

Correlation between air leak duration and continuous variables were assessed with Spearman's correlation coefficients. Variables that showed a significant relationship with air leak occurrence at univariate analysis were included in a multivariate, forward stepwise, logistic regression analysis to identify the most important nondependent factor. In this analysis, continuous variables were dichotomised taking medians as cut-off points. A p value of less than 0.05 was considered statistically significant.

4. Results

4.1. Baseline and perioperative findings

Demographics and baseline data are illustrated in Table 1. The number of patients included in each group was identical and baseline data were well matched. All patients were former heavy smokers while no patient had homozygous α-1-antitrypsin deficiency. In all instances there was evidence of severe, nonbullous, upper-lobe predominant emphysema at the high-resolution computed tomography.

Awake versus control group patients' comorbidity included non-insulin dependent diabetes mellitus (five patient vs six patients, respectively), chronic cardiac failure (five patients vs four patients, respectively), mild renal failure (one patient in each group) and HBV-related hepatic failure with hypoalbuminaemia (one patient in the awake group).

Pleural adhesions were found in 15 patients in the awake group versus 17 patients in the control group. Conversion to thoracotomy due to adhesions was necessary in one patient in each group. Both thoracotomies were performed under general anaesthesia.

Mean operative time was 35 ± 13 min (median 30, QR: 27—35 min) in the awake group and 52 ± 10 min (median 51, QR: 45—55 min) in the control group ($p < 0.0001$). Oxygenation remained satisfactory throughout the procedure in both groups while mean end-operative arterial carbon dioxide tension ($PaCO_2$) was significantly higher in the awake group (53.2 ± 8 mmHg [median 55, QR: 49—60] vs 42.2 ± 4 mmHg [median 41, QR: 39—45], $p < 0.0001$). In one instance, perioperative rise in $PaCO_2$ up to 83 mmHg was not tolerated by the patient and conversion to general anaesthesia was necessary. Another cause of conversion to general anaesthesia was the development of panic attacks, which occurred in two awake patients.

4.2. Air leak analysis

Postoperative air leak occurred in 54 patients (81%) in the awake group and in 58 patients (88%) in the control group ($p = 0.46$). Amongst these, air leak developed early (within

Table 1
Demographics and preoperative data in the study groups.

Variable	Awake group*	Mean ± SD	Control group*	Mean ± SD	p value
Age (year)	65 [55—68]	63 ± 7	65 [61—68]	64 ± 6	0.6
Gender (male/female)	58/8	—	59/7	—	1.0
Smoking habit (pack-years)	35 [26—46]	38 ± 12	40 [35—46]	40 ± 9	0.3
Emphysema severity (score)	26 [25—27]	26 ± 3	26 [25—28]	26.5 ± 3	0.15
Pleural adhesions (y/n)	15/51	—	17/49	—	0.8
Oxygen use (y/n)	23/43	—	25/43	—	0.8
Steroid use (oral/inhaled)	24/36	—	23/40	—	0.7
Concomitant morbidity (y/n)	12/54	—	11/55	—	0.8
RV (l)	5.0 [4.8—5.3]	5.0 ± 0.4	5.1 [4.9—5.5]	5.0 ± 0.5	0.8
RV % predicted	218 [216—218]	216 ± 5	215 [210—218]	209 ± 10	0.8
RV/TLC ratio	0.66 [0.65—0.68]	0.66 ± 0.02	0.67 [0.66—0.69]	0.67 ± 0.02	0.1
DLCO % predicted	39 [33—45]	40 ± 7	36 [33—44]	39 ± 6	0.3
Dyspnoea (MMRC)	3 [3—3]	3.1 ± 0.5	3 [3—3]	3.1 ± 0.4	0.7
SMWT (m)	380 [290—410]	370 ± 76	392 [280—420]	373 ± 45	0.7
PaO_2 (mmHg)	69 [63—72]	70 ± 6	68 [65—70]	69 ± 5	0.1
$PaCO_2$ (mmHg)	39 [38—42]	39 ± 2	40 [39—42]	40 ± 4	0.2
FEV1 (l)	0.88 [0.83—0.93]	0.8 ± 0.1	0.89 [0.82—0.96]	0.8 ± 0.1	0.2
FEV1% predicted	29 [26—30]	28 ± 4	29 [27—30]	28 ± 3	0.8
FVC (l)	2.5 [2.2—2.6]	2.4 ± 0.3	2.4 [2.1—2.6]	2.3 ± 0.3	0.2
FVC % predicted	67 [61—73]	67 ± 10	68 [64—73]	68 ± 7	0.8
Body mass index (kg/m^2)	24 [22—25]	23.6 ± 2.0	24 [23—25]	23.9 ± 2.03	0.4

DLCO: diffusion capacity for carbon monoxide; FEV1: forced expiratory volume at 1 s; FVC: forced vital capacity; MMRC: modified medical research council scale; RV: residual volume; TLC: total lung capacity; SMWT: 6-min walking test.

* Average data indicated as median [QR].

24 h) in 48 versus 46 patients, respectively ($p = 0.2$), whereas it occurred later in 6 versus 12 patients, respectively ($p = 0.2$). There was no difference between study groups as far as need of suction at the chest tube due to pneumothorax and/or massive subcutaneous emphysema was concerned (5 vs 13 patients, respectively, $p = 0.07$).

Mean duration of air leak was 5.2 ± 6.5 days (median 4.5, QR 2—6 days) in the awake group and 7.9 ± 7.6 days in the control group (median 6, QR 5—10 days) ($p < 0.0002$). In addition, in the awake group there was a significantly higher rate of patients who were free from air leak within the first 4 postoperative days (21 patients vs 8 patients, $p = 0.01$, Fig. 1). Yet, a significantly higher rate of prolonged air leak occurred in patients undergoing resectional LVRS under general anaesthesia (27 patients vs 12 patients in the awake group, $p = 0.007$, Fig. 1). Time-related analysis of air leak according to the Kaplan—Meier method is illustrated in Fig. 2, which shows the significantly better behaviour of air leak duration in the awake group.

Overall, at univariate analysis, higher severity of emphysema ($r = 0.36$, $p < 0.0001$) and lower diffusion capacity for carbon monoxide (DLCO % predicted) ($r = -0.33$, $p = 0.0001$) correlated with occurrence of prolonged air leak. However, multivariate logistic regression analysis indicated a high severity of emphysema as the most important factor predicting risk of prolonged air leak (odds ratio = 4.85, CI = 2.77—9.09, Wald test = 28.99, $p < 0.0001$). Intergroup difference in air leak duration according to the emphysema severity score is expressed in Fig. 3.

4.3. Early outcome

In the awake group no patient needed intubation immediately after the procedure whereas one patient needed delayed intubation at postoperative day 12 due to acute lung injury (ALI) and respiratory failure. He eventually died in the intensive care unit 38 days after the operation. In the control group, four patients remained intubated after the procedure in the ICU for 2, 5, 8 and 24 h, respectively. In the same group, another patient who needed delayed reintubation due to ALI and respiratory failure at day 3, eventually died 67 days after the operation. Both patients who died postoperatively had developed massive air leak.

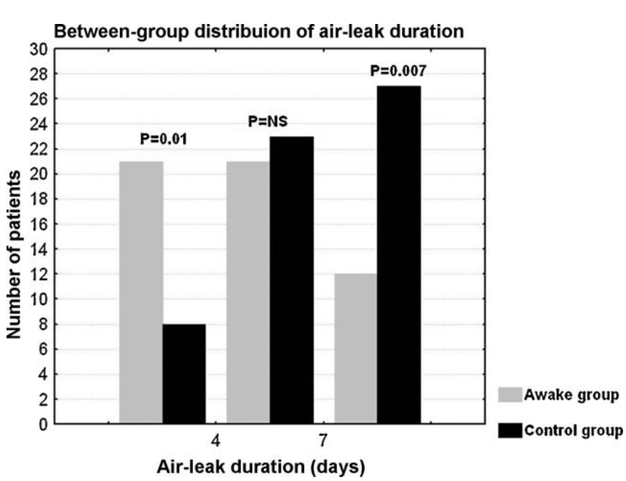

Fig. 1. Behaviour of air leak duration amongst the study groups.

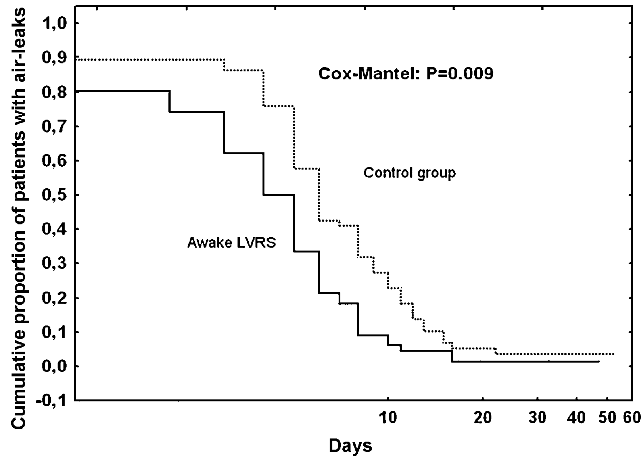

Fig. 2. Kaplan—Meier analysis of air leak duration in awake patients versus control group. Time-axis is given in a logarithmic scale for better graphing.

Other non-fatal complications occurred in 7 patients in the awake group (11%) versus 12 patients (18%) in the control group ($p = 0.1$); they were, atrial fibrillation (2 vs 3, respectively), urinary retention requiring catheterisation (2 vs 3, respectively); transient hypotension (2 in each group); pneumonia (1 vs 2, respectively); atelectasis (2 in the control group), and ALI (1 in the control group). One patient had more than one complication (pneumonia plus ALI).

Hospital stay averaged 6.3 ± 2.8 days in the awake group (median 6 days; QR 5—7 days) and 9.2 ± 5.6 days (median 7 days; QR 5—11 days) in the control group ($p < 0.0001$). An early discharge was possible in 12 patients (18%) in the awake group and in 4 patients (6%) in the control group ($p = 0.06$). Furthermore, in the control group, there was a greater number of patients who remained hospitalised for more than 7 days (30 patients vs 14 patients, $p = 0.01$). Discharges with Heimlich valve were carried out in nine patients in the awake group versus seven patients in the control group ($p = 0.7$).

One patient in the awake group and two patients in the control group were re-admitted due to loculated pneumothorax and unexpected persistence of an air leak. All these patients underwent initial chest tube drainage whereas

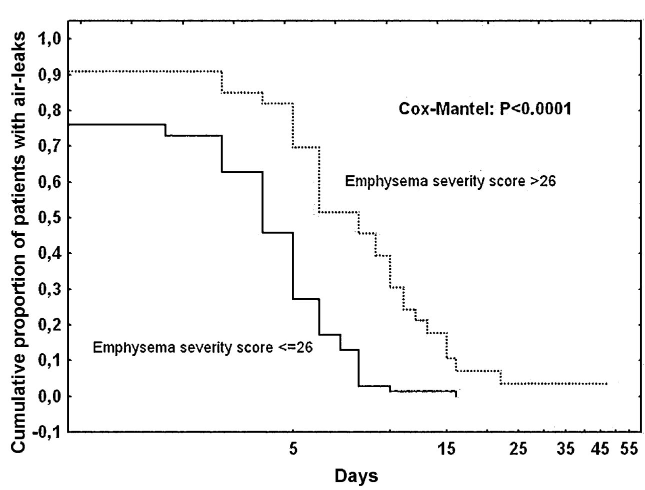

Fig. 3. Kaplan—Meier analysis of air leak duration according to emphysema severity score. Time-axis is given in a logarithmic scale for better graphing.

Table 2
Postoperative results at 6 months.

Variable	Awake group*	Mean ± SD	Control group*	Mean ± SD	p value
Δ FEV1 (l)	0.32 [0.26–0.34]	0.29 ± 0.09	0.30 [0.26–0.32]	0.28 ± 0.07	0.2
Δ FVC (l)	0.37 [0.30–0.50]	0.36 ± 0.16	0.36 [0.30–0.50]	0.33 ± 0.21	0.2
Δ RV (l)	−0.59 [−0.60/−0.50]	−0.54 ± 0.10	−0.52 [−0.55/−0.50]	−0.52 ± 0.12	0.1
Δ RV/TLC	−0.15 [−0.13–0.16]	−0.15 ± 0.02	−0.14 [−0.13/0.15]	−0.13 ± 0.33	0.2
Δ Dyspnoea (MMRC)	−1 [0–1]	−0.7 ± 0.6	−1 [0–1]	−0.4 ± 0.6	0.1
Δ SMWT	140 [120–155]	149 ± 38	145 [130–150]	153 ± 23	0.2

FEV1: forced expiratory volume at 1 s; FVC: forced vital capacity; MMRC: modified medical research council scale; RV: residual volume; SMWT: 6 min walk test; TLC: total lung capacity.
* Average data indicated as median [QR].

reoperation was carried out in two patients only (control group).

4.4. Clinical outcome

At the 6-month follow-up, significant clinical improvements occurred in both study groups with no intergroup differences (Table 2). No patient was lost to follow-up.

5. Discussion

Lung volume reduction surgery has considerably evolved since 1959 when Brantigan and Kress [20] performed manual nonanatomical lung resection or plication of emphysematous lung regions through thoracotomy. The first significant step ahead came several decades later from Cooper and co-workers [21] who first proposed a bilateral, buttressed, staple, resectional LVRS technique, performed through a median sternotomy approach. Subsequent technical advances included the use of unilateral or bilateral thoracoscopic approaches and the development of nonresectional techniques (Table 3). However, despite satisfactory results being reported with these techniques, air leak continues to be the most common complication of LVRS, and it can persist even 1 month after the operation in almost 12% of treated patients [5]. Moreover, even though air leak does not seem to be associated with operative mortality [5], it can promote other complications including gross subcutaneous emphysema, atelectasis, lung infection and even respiratory failure.

The most striking result of our study is that following awake nonresectional LVRS, mean duration of air leak and occurrence of prolonged air leak were both significantly reduced in comparison with results from the control group. These findings eventually reflected in a shorter hospital stay in the same group. Theoretical explanations of these results include avoidance of any discontinuation of visceral pleura and of deep suturing in the lung as well as elimination of the single, continuous, staple line crossing the outward side of the upper lung lobe, that are all features of resectional LVRS.

Our results are in agreement with those of other investigators, who observed a remarkable reduction of prolonged air leak using different plication techniques [12,15]. In particular, Swanson and co-workers [14] employed a thoracoscopic nonresectional technique re-elaborated from that proposed by Crosa-Dorado and co-workers in 1992 [15]. With this LVRS technique entailing small multiple peripheral staple lung plications, the authors reported a satisfactory 10% rate of prolonged air leak. Other attempts of reducing the incidence of postoperative air leak include the surgical techniques proposed by Iwasaki and co-workers [13], Busetto and co-workers [10], and Mink and co-workers [16]. All these techniques have peculiar characteristics and differ from our own technique (Table 3).

In our study, multivariate analysis indicated a higher degree of radiologic emphysema severity score to represent the best predictor of prolonged air leak. This finding seems in accordance with recent NETT data [5] indicating that prolonged air leak was more common in patients with low DLCO that is also an indicator of higher severity of emphysema in LVRS candidates.

Some investigators advocated [6–9] use of exogenous buttressing material along the parenchymal line of resection. Cooper and co-workers [21] found prolonged air leaks to occur in 46% of their 150 patients undergoing bilateral resectional LVRS, with bovine pericardium buttress and pleural tenting used as adjunctive sealant methods. Stammberger and co-workers [7] in a three-centre randomised study comparing bovine pericardium buttress versus no buttress found a significant reduction in air leak in the buttressed group but no intergroup difference in hospital

Table 3
Characteristics of the main surgical techniques of LVRS.

Author	Surgical technique	Suture characteristics			
		Deepness	Type	Buttress	Staple firings
Cooper and co-workers [6,21]	Resection	Deep	Single continuous	Pericardium	Multiple
Swanson and co-workers [14]	Rolled plication	Intermediate	Multiple interrupted	Visceral pleura	Multiple
Iwasaki and co-workers [13]	Plication	Deep	Single continuous	Visceral pleura	Multiple
Mink and co-workers [16][a]	Compression	Deep	Two U stitches	Silicon sleeve	No
Buesetto and co-workers [10]	Extrapleural LVRS	Deep	Continuous	Parietal pleura	Multiple
Mineo and co-workers [12]	Introflexing plication	Peripheral	Single interrupted	Bullous tissue + visceral pleura	Three

[a] Experimental model.

stay. Hazerligg and co-workers [9] demonstrated a slight reduction of air leak duration and hospital stay in patients receiving buttressed LVRS, but no advantages in hospitalisation costs. Conversely, DeCamp and co-workers [5] found no difference in air leak duration with different buttressing material including bovine pericardium, polytetrafluoroethylene, or fibrin glue, although in this series, 26 patients only underwent nonbuttressed LVRS. Overall, these results suggest that, despite some potential advantage of using buttressing material, there is still no confirmation of the real cost-effectiveness of this choice.

It is worth noting that in some patients, air leak is absent or minimal at the completion of the procedure but dramatically deteriorates a few hours later. In addition, we have observed at reoperations for intractable air leak that lung tears mostly develop in proximity of the suture line, which is usually airtight. These features suggest that it is not within the suture line that air leak usually develops but rather somewhere in its proximity, probably due to the increased rigidity of the reduced lung surface. This finding seems in agreement with the theory proposed by West [17] who hypothesised that localisation of lung diseases such as pneumothorax and even progression of the emphysema could be addressed to the increased mechanical stress induced on the upper part of the lung during ventilation. This mechanism has also been advocated as a possible cause of giant bulla formation after LVRS [22]. In a similar manner, it might be that in the early postoperative period, mechanical stress on the lung surface is even increased either due to the incomplete lung expansion and to an uneven distribution of expanding forces on the lung surface where the suture line creates a more rigid and albeit fragile lung region. This model could also explain why placing drainages on waterseal has proven more effective than suction in resolving postoperative air leaks [23].

This difference in stressing strains, which can be negligible whenever the underlying lung is relatively well preserved but can become critical in presence of a severely emphysematous residual lung tissue. Moreover, even if minimal air leak due to staple pinholes is probably unavoidable with current LVRS techniques, we believe that our nonresectional surgical technique with peripheral interrupted suturing along a single ideal line could create a more flexible sutured lung that might fill better and more promptly the pleural cavity thus leading to a rapid cessation of any air leak in many instances [12,18]. Although these theoretical explanations cannot be confirmed by our current study, they might justify the reduced mean duration of air leak that has been observed in the awake group.

As far as clinical outcome is concerned, we had already reported comparative clinical results of awake nonresectional and nonawake resectional LVRS [18] showing similar magnitude and duration of clinical benefit at 6 months and for up to 2 years. These findings suggest similar mechanisms of action and stability of improvements over time and contradict the theoretical risk of an early disruption of the staple lines.

Data from the current analysis corroborate our previous findings indicating that satisfactory clinical benefit can be achieved by either resectional and awake nonresectional LVRS, although the latter procedure can be associated with a smoother postoperative course.

In both our study groups, there was a 1.5% mortality rate, which was associated with the development of an ALI syndrome. Although this serious complication usually occurs following anatomic resections, it has been reported even after nonanatomical lung resection, especially in patients with advanced lung disease and low DLCO [24]. General anaesthesia with one-lung ventilation seems to play a role in development of ALI due to oxidative stress-mediated damage deriving from exclusion and subsequent reventilation of the lung as well as to fluid overload [25]. The aforementioned findings may explain the development of early onset ALI in two patients who underwent resectional LVRS in our series. The presence of massive air leaks with a collapsed lung could have worsened the clinical scenario in these patients whereas it could have acted as a 'triggering' factor in the patient undergoing awake-nonresectional LVRS [25].

5.1. Limitations

Limitations include the retrospective design of our study and the impossibility to identify procedure-related factors that contributed to reduce air leak occurrence in the awake group. In fact, study groups differed in two technical aspects including type of anaesthesia and type of surgical technique that might both have influenced early outcome. However, it is likely that avoidance of general anaesthesia had a negligible impact on air leak that is mainly influenced by other factors such as the surgical technique and the condition of the underlying lung tissue as also our current results suggest. Furthermore, although patients were not randomly assigned to each treatment group, preoperative therapy, inclusion criteria, clinical—radiological work-up as well as criteria for discharge were the same in both study groups. Yet, all patients were operated on by the same two surgeons (TCM, EP).

5.2. Conclusions

In this study, a reduced rate of prolonged air leak and shorter hospital stay occurred following awake nonresectional LVRS in comparison with results achieved by the resectional technique performed with general anaesthesia. Hopefully, results deriving from a randomised study will provide more useful answers on this particular topic.

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Appendix A. Conference discussion

Dr P. Van Schil (*Antwerp, Belgium*): When you compare the control group with the study group, you changed two variables: the first was general versus awake anaesthesia, and the second was the specific technique. What is the contribution of the change in technique to the postoperative air leak?

Secondly, your control group is a retrospective group, so there could be a selection bias. Did you apply the same selection criteria? Why did you change your specific technique?

Dr Tacconi: Your first question is have we evaluated separately the kind of anaesthesia and the surgical procedure?

Dr R. Cerfolio (*Birmingham, Alabama, USA*): Yes, yes, that's right.

Dr Van Schil: You have two variables. What is the contribution of each variable to the postoperative air leak?

Dr Tacconi: I have two variables, but one group underwent the awake procedure and the nonresectional technique.

Dr Cerfolio: That's his question. What if you had given people a general anaesthetic and then just done a nonresection with a stapler, put them to sleep but then just used a stapler and not resect them, how do you know they wouldn't have done just as well?

Dr Tacconi: Now, at the moment, we usually perform the nonresectional technique even in patients who are scheduled for general anaesthesia. It's our own technique. We no longer perform resectional lung volume reduction surgery now.

Dr C. Choong (*Cambridge, United Kingdom*): As we know, the National Emphysema Treatment Trial has shown a definite survival and symptomatic benefit for highly selected patients. However, we are also well aware that the chest physicians are reluctant to refer patients to us due to the morbidity and mortality which they perceive relating to lung volume reduction surgery, and therefore your important work which is associated with a marked decrease in complications and mortality is very commendable.

In terms of the plication technique, it clearly is very different from the resection technique which is the conventional technique, and then your second improvement is doing it awake rather than with mechanical ventilation. Similar to the first discussant, do you think that plication plays a more important part in comparison to general anaesthesia? Most of our patients who undergo LVRS have an early extubation in the operating theatre, and therefore mechanical ventilation, barotrauma and volume-trauma is minimised in the early postoperative period.

The second question is, in general anaesthetic patients, we utilise a double-lumen endotracheal tube, so we have single lung ventilation which provides good exposure for the LVRS. In your awake patient, obviously you are not able to use double-lung ventilation and isolate the lung at all, and, therefore, how do you deal with the exposure required to do the LVRS?

Dr Tacconi: The first question, we don't know actually if the avoidance of general anaesthesia and mechanical ventilation or the nonresectional technique is more important. We observed a reduction in air leaks and we are studying what could be the more important factor in this result.

The second question, of course the space into the pleural cavity you can obtain without lung exclusion is less. Anyway, we usually can perform the procedure without particular difficulty. If necessary, a paddle retractor can be used to increase the space. Of course, the awake lung volume reduction surgery requires training. It is somewhat more difficult than the standard procedures, but usually the space within the pleural cavity is enough to work with.

Dr D. Wood (*Seattle, Washington, USA*): I have two brief questions.

Was your control group a bilateral procedure or a unilateral procedure?

Dr Tacconi: Unilateral.

Dr Wood: I'm confused about why you are using unilateral procedures when actually the literature gives pretty strong evidence of the benefit of a bilateral procedure over a unilateral procedure and would seem to be a limitation of your study.

The other question that I have is, almost all surgeons who have experience with lung volume reduction surgery note that air leaks do not occur from the area of resected lung. It occurs from areas adjacent to staple lines. The staple lines exist by either technique. What do you postulate is the difference, then, in why you are seeing less air leaks since it doesn't appear to be from the resection area anyway?

Dr Cerfolio: Do you understand his question?

Dr Tacconi: I don't understand his question. I'm sorry.

Dr Cerfolio: The air leaks usually don't come from where you do the stapling.

Dr Tacconi: Okay. Yes.

Dr Cerfolio: So why does your technique have less air leaks?

Dr Tacconi: Okay. We hypothesise a series of mechanisms. Of course, there is the avoidance of cutting of visceral pleura, but we believe that the most important factor is the strain of lung re-expansion. There is less tension on the sutures lines, so the areas of surrounding lung are preserved from excessive strain. This is our opinion, of course.

Dr Cerfolio: We know in general surgery that if you staple the bowel, within 6 months or 9 months it reopens. I would invite you to study your patients longer, because I'm afraid that at a year or a year and a half, those staple lines may reopen and that lung may re-expand. So you need longer follow-up.