A comparative study of two- versus one-lung ventilation for needlescopic bleb resection

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ABSTRACT: This prospective study was conducted to evaluate the feasibility of two-lung (TL) ventilation with low tidal volume anaesthesia compared with one-lung (OL) ventilation for needlescopic bleb resection.

Patients with spontaneous pneumothorax that underwent bleb resection with a 2-mm thoracoscope were enrolled. During the operation, the tidal volume was set at 4.0 mL·kg⁻¹ in the TL group and 8.0 mL·kg⁻¹ in the OL group; the respiration rate was set at 23 and 12 breaths·min⁻¹, respectively, at the same inspiratory oxygen fraction (50%).

A total of 108 patients (55 patients in the TL group and 53 in the OL group) were included in this study. Airway pressure was significantly lower in the TL group (mean ± SD 8.0 ± 3.3 versus 24.0 ± 3.9 mmHg in the OL group; $p < 0.001$). The time from endotracheal intubation to the incision was 17.1 ± 4.0 min in the TL group and 35.3 ± 7.6 min in the OL group, which was significantly different ($p < 0.001$). However, the operation time was not different in comparisons between the two groups. Therefore, the total anaesthesia time was significantly longer in the OL group (77.9 ± 21.6 versus 64.9 ± 14.7 min in the TL group; $p = 0.002$).

Needlescopic bleb resection using TL ventilation anaesthesia with low tidal volume was technically feasible, cost-effective and time-saving compared with OL ventilation anaesthesia.

KEYWORDS: Anaesthesia, pneumothorax, ventilation, video-assisted thoracoscopic surgery

The surgical strategy used for the treatment of a spontaneous pneumothorax is resection of the blebs and bullae, and obliteration of the pleural space by pleurectomy or pleural abrasion, alone or in combination [1]. The use of video-assisted thoracoscopic surgery (VATS) has become widespread, and the traditional open thoracotomy has been replaced with VATS due to its minimal invasiveness and associated low morbidity [2]. As thoracoscopic surgical techniques continue to improve, the size of the thoracoscope has gradually decreased. Recently, a 2-mm thoracoscope (a needlescope) and accompanying instruments have been introduced for bullectomy [3]. Since September 2004, we have performed needlescope surgery in all patients that required a lung biopsy [4]. On the basis of this experience, the needlescopic approach to bleb resection for a spontaneous pneumothorax was launched in March 2005 at our hospital (Korea University Guro Hospital, Seoul, Korea).

One-lung (OL) ventilation is a commonly used technique that facilitates surgical visualisation

during thoracic surgical procedures. In particular, during VATS, OL ventilation may play a pivotal role in the successful completion of a planned procedure [5]. However, it has the disadvantages of causing hypoxaemia and tracheobronchial trauma [6]. In addition to these complications, it may add additional time and cost to the procedure due to the need to confirm the proper position of the tube by fibre-optic bronchoscopy [7]. Recently, CERFOLIO *et al.* [8] suggested that low tidal ventilation without OL ventilation is relatively easy to perform in simple VATS procedures, such as pleural biopsies and talc pleurodesis. Since April 2007, we have used two-lung (TL) ventilation with low tidal volume ventilation anaesthesia for 5-mm thoracoscopic bleb resection in patients with a spontaneous pneumothorax, and have previously reported on its technical safety and feasibility [9].

The goal of this study was to compare the safety and feasibility of TL ventilation plus low tidal volume anaesthesia with OL ventilation for needlescopic bleb resection of a spontaneous pneumothorax.

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Received:

April 13 2010

Accepted after revision:

July 23 2010

First published online:

Aug 06 2010

METHODS

Patient population

A consecutive series of 110 patients with primary spontaneous pneumothorax underwent needlescopic bleb resection from April 2007 to May 2008 at the Korea University Guro Hospital. After approval by the Ethics Committee of the Korea University Guro Hospital, written informed consent was obtained from all patients in accordance with the Declaration of Helsinki. All patients were initially managed with chest tube placement; a chest computed tomography (CT) was performed prior to surgery. Surgery was indicated if the first episode of pneumothorax was complicated, if blebs or bullae were observed on the chest CT or in cases with recurrent pneumothorax. Complicated pneumothorax refers to a persistent air leak, haemothorax, or failure of the lung to re-expand, bilaterally, and tension pneumothorax. The patients without blebs or bullae on the chest CT, with their first pneumothorax, and patients with a secondary spontaneous pneumothorax were excluded from this study. In addition, if patients refused the operation, or if moderate-to-severe pleural adhesions were found on the chest radiogram or chest CT, the patient was excluded. The subjects were assigned to one of the two procedure arms (55 subjects each), one-by-one according to the order of hospital admission.

Anaesthetic techniques

Soon after general anaesthesia was induced, the radial artery was cannulated for intermittent arterial blood gas analysis. In the TL group, the patients were intubated with a single-lumen endotracheal tube (SHERIDAN/CF[®] Tracheal Tubes; Hudson RCI, Durham, NC, USA) and ventilated with a tidal volume of 4 mL·kg⁻¹ and a respiratory rate of 23 breaths·min⁻¹ at an inspiratory oxygen fraction (F_{I,O_2}) of 0.5. In the OL group, the patients were intubated with a double-lumen endotracheal tube (Broncho-cathTM; Mallinckrodt Medical, Athlone, Ireland) for separate lung ventilation, and ventilated with a tidal volume of 8 mL·kg⁻¹ and a respiratory rate of 12 breaths·min⁻¹ at an F_{I,O_2} of 0.5 from start to finish. In the OL group, a bronchoscopic examination was performed to confirm the optimal position of the double-lumen endotracheal tube. To avoid hypoxia and airway barotrauma, the anaesthetist controlled the ventilator settings during low tidal volume ventilation or OL ventilation; when the arterial oxygen saturation measured by pulse oximetry (Sp,O_2) was too low (<90%) or when the airway peak pressure was too high (>25 mmHg), the F_{I,O_2} was increased or the tidal volume was reduced. During the surgery, arterial blood gas analysis was performed at 10 min after establishing low tidal volume settings in the TL group and the OL ventilation settings in the OL group. The airway pressure, end-tidal carbon dioxide and oxygen saturation were recorded. In addition, the time from intubation to the incision, operation time and total time for anaesthesia were measured.

Operative techniques

The patients were placed in the lateral decubitus position. Initially, a 2-mm thoracoscope (needlescope; KARL-STORZ GmbH & Co, Tuttlingen, Germany) was introduced into the thoracic cavity *via* an 11.5-mm port at the sixth or seventh intercostal space on the anterior axillary line (previous closed thoracostomy site) to examine whether there were any dense

adhesions, blebs or bullae. If there were moderate-to-severe pleural adhesions in the thoracic cavity, TL ventilation was converted to OL ventilation, or the needlescopic procedure was abandoned. In the cases where the needlescopic procedure was continued, a 2-mm needlescopic port at the fifth or sixth intercostal space along the midaxillary line and another 2-mm port for the minisite endograsp (Auto Suture; Covidien, Norwalk, CT, USA) at the fifth or sixth intercostal space along the posterior axillary line were made. When there were loose or moderate pleural adhesions, a 5-mm thoracoscope was used that provided better visualisation; it was introduced through an 11.5-mm port. Then, the pleural adhesions were dissected with a 2-mm minisite endograsp or minisite minishers (Auto Suture) through the two 2-mm ports. The bleb resections were performed using one or two endostaplers *via* an 11.5-mm port used for securing the pulmonary margins; the resected blebs were removed from the 11.5-mm port (fig. 1). Mechanical and chemical pleurodesis, with iodine-soaked cotton, were performed at the apical area of the visceral and parietal pleurae through an 11.5-mm port. Upon completion of the operation, a 28-French chest tube was inserted through the 11.5-mm port.

Statistics

Distribution of the two groups was analysed using the Chi-squared test, and continuous outcomes with the independent t-test or Mann-Whitney U-test depending on the distribution of data. The sample size was determined by using the statistical software program PASS 2008 (NCSS, Kaysville, UT, USA). A p-value of <0.05 was considered statistically significant. All the other statistical analysis was carried out using the statistical software SPSS for Windows, release 12.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

There was no case where TL ventilation was converted to OL ventilation, or the needlescopic procedure was abandoned, with the exception of two patients in the OL group. In these two cases, which were excluded from the study, needlescopic

FIGURE 1. Intraoperative needlescopic image of a bleb resection.

TABLE 1 Indications for surgery in patients with primary spontaneous pneumothorax

	Patients	
	TL group	OL group
Subjects n	55	53
First episode		
Bleb on CT	21 (38.2)	22 (41.5)
Prolonged air leak	7 (12.7)	6 (11.3)
Tension	5 (9.1)	4 (7.5)
Non re-expansion	3 (5.5)	5 (9.4)
Bilaterality	2 (3.6)	2 (3.8)
Recurrence		
Ipsilateral	12 (21.8)	10 (18.9)
Contralateral	5 (9.1)	4 (7.5)

Data are presented as n (%), unless otherwise stated. TL: two-lung; OL: one-lung; CT: computed tomography.

surgery was converted to 5-mm thoracoscopic surgery due to the presence of moderate pleural adhesions. A total of 108 patients were treated for primary spontaneous pneumothorax during the study period. 55 and 53 patients were included in the TL and the OL groups, respectively. The patient age (mean $\pm$ SD 23.4 ± 10.0 yrs in the TL group and 27.4 ± 14.8 yrs in the OL group; $p=0.128$) and sex (males:females 52:3 in the TL group and 46:6 in the OL group; $p=0.176$) were not significantly different between the two study groups.

The most common indications for the needlescopic bleb resection were primary spontaneous pneumothorax with a visible bleb on the chest CT or a recurrent pneumothorax on the same side (table 1). The distribution of the surgical

indications was not significantly different between the two groups ($p=0.474$).

During bleb resection, although the tidal volume and respiratory rate were significantly different between the two groups, the minute ventilation was not significantly different (table 2). There was no need to decrease the tidal volume more in order to obtain an optimal working field in the TL group. pH, carbon dioxide tension, oxygen tension, arterial oxygen saturation and Sp,O_2 were compared between the two groups and were significantly different; however, these differences had no negative impact on the pulmonary status of the patients. In particular, the airway pressure was significantly lower in the TL group than in the OL group (8.0 ± 3.3 mmHg in the TL group and 24.0 ± 3.9 mmHg in the OL group; $p<0.001$); this suggests less airway damage in the TL group. The time from endotracheal intubation to the incision was 17.1 ± 4.0 min in the TL group and 35.3 ± 7.6 min in the OL group; these differences were significant ($p<0.001$) (table 3). However, the operation time was not different in the comparisons between the two groups. Therefore, the total anaesthesia time was significantly longer in the OL group (64.9 ± 14.7 min in the TL group and 77.9 ± 21.6 min in the OL group; $p=0.002$).

The thoracoscopic bleb resection with pleurodesis was performed successfully in all patients. The number of endostaplers used was not significantly different in comparisons between the two groups (table 3). Two patients in the TL group and three in the OL group had air leakage until the third post-operative day, but the chest tube could be withdrawn by the fifth or sixth post-operative day after surgery by managing this complication with talcum pleurodesis. There were no wound infections, early recurrences or readmissions. The chest tube indwelling duration and length of stay were not significantly different in the comparisons between the two groups. During the follow-up period (15.9 ± 3.5 months, range 5–22 months), there was no recurrence on the side that underwent surgery.

TABLE 2 Ventilator settings and arterial blood gas analysis

	TL group	OL group	p-value
Tidal volume mL	240.5 ± 35.9	498.8 ± 79.0	<0.001
Minute ventilation mL	5.2 ± 1.1	5.4 ± 1.1	0.461
Respiratory rate breaths·min⁻¹	22.7 ± 1.9	12.6 ± 1.9	<0.001
Maximum airway pressure mmHg	8.0 ± 3.3	24.0 ± 3.9	<0.001
pH	7.40 ± 0.04	7.43 ± 0.04	<0.001
P_{CO}₂ mmHg	41.2 ± 4.5	43.3 ± 3.7	0.020
P_O₂ mmHg	235.1 ± 45.2	108.1 ± 27.5	<0.001
Sa_O₂ %	99.8 ± 0.6	97.8 ± 1.6	<0.001
End-tidal CO₂ mmHg	35.7 ± 5.9	34.6 ± 4.1	0.305
Sp_O₂ %	99.6 ± 0.7	97.5 ± 1.640	<0.001

Data are presented as mean $\pm$ SD, unless otherwise stated. TL: two-lung; OL: one-lung; P_{CO}₂: carbon dioxide tension; P_O₂: oxygen tension; Sa_O₂: arterial oxygen tension; CO₂: carbon dioxide; Sp_O₂: arterial oxygen saturation measured by pulse oximetry.

DISCUSSION

The minimal invasiveness of VATS has changed the treatment strategy for primary spontaneous pneumothorax. SAWADA, *et al.* [10] recommended VATS not only for patients with recurrence or prolonged air leakage, but also for the first pneumothorax episode in patients with bullae on the chest CT. MARGOLIS *et al.* [11] suggested that VATS may be an effective first-line treatment for primary spontaneous pneumothorax in young adult patients regardless of the chest CT findings. In our hospital, the indications for VATS, for the first episode of a primary spontaneous pneumothorax, are similar to those reported by SAWADA [10]. For the first episode in patients where blebs or bullae are not detected by CT, a conservative approach is the first-line treatment. However, first episodes with blebs or bullae noted on the CT are treated by VATS.

Needlescopic surgery, using instruments with a diameter of <3 mm, has been used mainly in cases requiring a cholecystectomy [12] and, sporadically, for urological surgery [13]. For thoracic procedures, it has been used for diagnostic thoracoscopy [14], laser ablation or thoracic sympathectomy for palmar hyperhidrosis [15]. Recently, this technique has been used for lung biopsy procedures for diffuse pulmonary disease

TABLE 3 Procedure time and operative results

	TL group	OL group	p-value
Time from anaesthesia induction to incision min	17.1±4.0	35.3±7.6	<0.001
Operation time min	31.5±14.2	31.7±19.3	0.956
Total anaesthesia time min	64.9±14.7	77.9±21.6	0.002
Endostapler used n	2.1±0.7	1.9±0.8	0.434
Chest tube indwelling duration days	3.4±1.3	3.7±1.3	0.270
Length of stay days	4.4±1.3	4.7±1.3	0.195

Data are presented as mean ± sd, unless otherwise stated. TL: two-lung; OL: one-lung.

[16] and bullectomy for patients with a spontaneous pneumothorax [3, 17]. Recently, we reported the first needlescopic resection of a small pulmonary nodule [4].

Compared with conventional thoracoscopic surgery, needlescopy has safety concerns, including poor imaging and difficulty with fine motor control [3]; the 11.5-mm chest tube wound is probably the major cause of post-operative discomfort and scarring, even with downsizing of the other two ports. However, it is clear that needlescopic surgery leaves minimal scarring at the other two ports. In addition, especially with narrow posterior interspaces, smaller cameras and instruments that apply less torque probably improve the wound healing effects of intercostal nerve injuries [18]. In addition, as technology advances, low-profile cameras will probably capture high-definition images with less light and supplemental luminescence delivered through separate needle holes; moreover, instruments that angle will also reduce leverage-related rib trauma [18]. We previously reported that there was no significant difference in the operation time,

duration of indwelling chest tube and pain according to the size of the thoracoscope [19]. In addition, needlescopic surgery provided an accurate pathological diagnosis for patients with interstitial lung disease and indeterminate pulmonary nodules when compared with the open procedure [4]. Therefore, bleb resection using the needlescope for spontaneous pneumothorax was initiated at our centre.

OL ventilation is almost always used for VATS. It is usually safe and it provides superb visualisation and an excellent working field for procedures involving the pleura, lung and mediastinum, after the appropriate collapse of the lung [8]. However, OL ventilation requires additional time and cost. The cost of a single-lumen tube and placing of the tube is \$50, compared with the \$375 cost of placing a double-lumen endotracheal tube, in the USA [8]. At our hospital, the price is higher for the double-lumen endotracheal tube (US \$98) and Univent (US \$179) compared with the single-lumen tube (US \$3.37). A bronchoscopic examination is mandatory to confirm the positioning of the endotracheal tube for OL ventilation; this

FIGURE 2. Operative field for the a) two-lung ventilation with low tidal volume and b) one-lung ventilation during needlescopic bleb resection for primary spontaneous pneumothorax.

adds additional time [8]. The complications, high cost and increased time for OL ventilation add significant burdens to what is an otherwise very short and simple procedure. Because $8 \text{ mL}\cdot\text{kg}^{-1}$ is the lowest tidal volume that is recommended during OL ventilation in most anaesthesiology textbooks, we chose the ventilator setting of $8 \text{ mL}\cdot\text{kg}^{-1}$ tidal volume (based on the ideal body weight) in OL ventilation, as long as patients had no problem with gas exchange or airway pressure. However, there have been several studies that have demonstrated acute lung injury after using large tidal volumes and that lung protective ventilation strategies are associated with small tidal volumes [20]. Therefore, reduction of the tidal volume during OL ventilation is planned for our next study.

CERFOLIO *et al.* [8] reported that an adequate working field with low tidal volumes could be obtained while both lungs were ventilated during VATS for pleural biopsies and talc pleurodesis. On occasion, we would use TL ventilation during VATS for primary spontaneous pneumothorax during a OL ventilation procedure to find an air leak, collapsed bleb or bullae. At first, we partially clamped the bronchial lumen of the double-lumen endotracheal tube on the side undergoing surgery, with normally set tidal volumes to continue ventilating the lung undergoing surgery. Partial clamping resulted in a substantial decrease in the tidal volume delivered to the operative lung and provided a better working field than the complete TL ventilation. After several cases with no problems, we placed the double-lumen endotracheal tube, but inflated both lungs and used a low tidal volume. Next, we started to place a single-lumen tube in all cases during VATS for a primary spontaneous pneumothorax [1]. During the present study, we prepared the wire-guided endobronchial blocker for OL ventilation in case we failed to obtain adequate surgical visualisation with low tidal volumes under TL ventilation. Under bronchoscopic guidance, the wire-guided endobronchial blocker can be inserted through the endotracheal tube with the patient in any position, even the lateral position. This procedure can be performed within 10 min at our hospital.

The results of a previous study showed that a tidal volume of $4 \text{ mL}\cdot\text{kg}^{-1}$ was sufficient to obtain an adequate surgical field (fig. 2); this tidal volume maintained optimal pulmonary function without hypoxia or hypercapnia. CERFOLIO *et al.* [8] routinely decreased the tidal volume to 150 to 250 mL in their study. Although these differences had no negative impact on the pulmonary status of the patients, the airway pressure was significantly lower in the TL group than in the OL group; this suggests that airway damage might be reduced in the TL group.

The most important benefit of this anesthetic procedure was that the total anaesthesia time was reduced by decreasing the time from intubation to the incision, because bronchoscopic examination was not needed. As a matter of fact, the time for verifying double-lumen tube placement is an institutional variable. In experienced hands, it takes a few minutes to confirm the proper position of the double-lumen tube. However, because our centre is a teaching hospital, the anaesthetist often must teach their trainee how to perform OL ventilation. This is a major cause of increase of the total anaesthesia time. In addition, the bleb resection using the needlescope for the TL ventilation did not require more

surgical time compared to surgery using a 5-mm thoracoscope, as reported previously [9].

Awake VATS has been tried under local anaesthesia and sedation or thoracic epidural anaesthesia in spontaneous pneumothorax [21, 22]. This procedure has several potential advantages, including avoidance of airway trauma associated with endotracheal intubation, general anaesthesia, and OL ventilation [23]. In addition, it is associated with minimal hospitalisation and cost-saving treatment [24]. Therefore, awake VATS may be considered to be a more ideal surgery than our procedure, although there was concern that operating on a ventilating lung would render surgical manoeuvres more difficult because of the lung movements and the lack of a sufficient operating space [24].

Some investigators have reported thoracoscopic talc pleurodesis without bullectomy as an initial treatment for recurrent or persistent air leak in patients with spontaneous pneumothorax and small blebs ($<2 \text{ cm}$) [21, 25, 26]. This procedure could be performed *via* a single-port medical thoracoscopy under local anaesthesia with sedation, and had a good success rate in long-term follow-up. In that study, small blebs/bullae $<2 \text{ cm}$ (Vanderschueren's classification type III or less) were found in 28 (25.9%) out of 108 patients that could be candidates for thoracoscopic talc pleurodesis as an alternative treatment.

The results of this study suggest that needlescopic surgery using TL ventilation with low tidal volume was safe and effective, and could provide an alternative option for a relatively short and simple procedure, such as bleb resection for spontaneous pneumothorax. In conclusion, needlescopic bleb resection using TL ventilation anaesthesia with low tidal volume was safe, technically feasible, cost-effective and time-saving compared with TL ventilation anaesthesia.

STATEMENT OF INTEREST

None declared.

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