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Double lumen tube location predicts tube malposition and hypoxaemia during one lung ventilation

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Background. Poor positioning of an endobronchial double lumen tube (DLT) could affect oxygenation during one lung ventilation (OLV). We set out to relate DLT position to hypoxaemia and DLT misplacement during OLV.

Methods. We recruited 152 ASA physical status I–II patients about to have elective thoracic surgery. The trachea was intubated with a left-sided DLT. Tube position was assessed by fibre-optic scope and correction was made after patient positioning and during OLV. If Pa_{O_2} was less than 10.7 kPa, the DLT position was checked and then PEEP, continuous positive airway pressure (CPAP), oxygen insufflation, or two lung ventilation (TLV) were tried.

Results. The DLT was found to be misplaced in 49 patients (32%) after patient positioning, and in 38 patients (25%) during OLV. PEEP to the dependent lung, CPAP or apneic oxygen insufflation to the non-dependent lung, or brief periods of TLV, were applied in 46 patients (30%). Patients who had DLT malposition after placing the patient in the lateral position had a greater incidence of DLT malposition during OLV (59 *vs* 9%) and also required each intervention more frequently (57 *vs* 10%). Patients with DLT malposition during OLV also required interventions more often (84 *vs* 12%).

Conclusions. Patients who have DLT malposition after placing the patient in the lateral position had more DLT malposition during OLV and hypoxaemia during OLV.

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Between 9 and 28% of patients undergoing one lung ventilation (OLV) during thoracic surgery develop severe arterial hypoxaemia (Pa_{O_2} less than 10.7–8.0 kPa).[1–4] Perioperative predictive factors for hypoxaemia have been investigated,[1 3–5] but factors that predict severe arterial hypoxaemia have not been found. Endobronchial double lumen tubes (DLTs) are usually used for lung separation, and DLT placement is usually easy. However, DLT malposition and displacement can occur easily after blind intubation and moving the patient into the lateral position.[2 4 6 7] Correction of DLT malposition and suctioning of blood or secretion are frequently required during surgery.[2 4 6 8 9] Given these considerations, we considered that problems with DLT position could cause severe arterial hypoxaemia, more than other factors such as preoperative condition or intraoperative gas exchange.

Most DLTs are specifically designed to fit the anatomy of the trachea, bronchial carina, and main bronchus according to Robertshaw's suggestion.[10] Guidelines are available to choose a properly sized DLT.[11 12] Nevertheless, significant malposition of a DLT can occur after a patient is moved, and some degree of DLT movement is unavoidable.[6 7] DLT displacement may indicate poor matching with the anatomy of the patient's airway. In such patients who develop significant malposition of the DLT after patient movement, there may also be more problems with DLT use and more hypoxaemia during OLV compared with other patients, even if the DLT position is corrected by fibre-optic bronchoscopy after the patient has been moved into the lateral position. We studied whether DLT malposition after placing the patient in the lateral position is related to hypoxaemia and frequent DLT malposition during OLV.

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Methods

After institutional approval and informed consent, 152 ASA physical status I–II patients undergoing elective thoracic surgical procedures in the lateral position were enrolled. We excluded patients with less than 70% predicted forced expiratory volume in 1 s (FEV1), less than 80% predicted forced vital capacity, or a Pa_{O_2} less than 9.3 kPa while breathing air. If patients had a previous thoracotomy, those who have a repeat operation on the same side were included. In addition, patients who were judged to need a right side DLT were excluded because we considered DLT malposition would be more likely[13] although recent clinical evidence has shown that this is not the case.[14] We included patients given vasodilators.

All patients were pre-medicated with roxatidine (H2 blocker) 75 mg orally 2 h preoperatively. Before induction of anaesthesia, an epidural catheter was inserted at the 6–7th, 7–8th, or 8–9th thoracic interspace. General anaesthesia was induced with propofol 1.5–2.5 mg kg^{-1}, fentanyl 1–2 μg kg^{-1}, and vecuronium 0.15 mg kg^{-1}. Anaesthesia was maintained with oxygen 100%, propofol 3–5 mg kg^{-1} h^{-1}, and an epidural bolus injection of 6–10 ml of lidocaine 1% followed by a continuous infusion of 4–8 ml h^{-1}. Routine monitoring included an ECG, a non-invasive arterial pressure cuff, pulse oximetry, and capnogram. Blood gas samples were analysed with a commercial blood gas analyzer (Bayer 860, Bayer Diagnostic Manufacturing Ltd, Bury St Edmunds, UK). To obtain continuous arterial blood gas values, pressure measurements, and intermittent blood samples, we used a continuous arterial blood gas monitoring system (Paratrend 7^{TN}, Diametrics Medical Limited, High Wycombe, UK). A 20-gauge intravascular catheter was inserted into the radial artery. The intravascular sensor, calibrated with gases in a tonometer, was advanced through the arterial catheter into the radial artery to a length of 15 cm. Systolic arterial pressure was maintained within 20% of the preoperative value by controlling doses of anaesthetics, and giving ephedrine or nicardipine as necessary to treat changes in arterial pressure.

We managed DLTs in the way described by Klein.[6] The trachea and bronchus were intubated with a left-sided DLT (Bronchocath; Mallinckrodt, Argyle, NY, USA). The size of DLT was chosen according to Brodsky,[11] but could be changed to meet the following criteria: a small air leak detectable with the endobronchial cuff deflated and no leaks when inflated with a maximum of 3 ml air. Immediately after blind insertion, the correct position was confirmed by ausculation and fibre-optic bronchoscopy. The position was checked and corrected by fibre-optic bronchoscopy once again after positioning the patient for thoracotomy (lateral position). The criteria for correct DLT position were defined as follows: an unobstructed view into the left upper and lower lobe bronchus through the endobronchial lumen with the bronchial cuff immediately below the carina and just visible in the main left bronchus through the tracheal lumen.[15] We defined malposition if the tube had to be moved (in or out) by more than 1.0 cm to correct its position. The DLT was taped securely in place after each fibre-optic bronchoscopic confirmation.

A Siemens servo 900 C ventilator (Siemens Life Support Systems, Solna, Sweden) was used for controlled ventilation of the lungs. A pressure-controlled mode was used. The inspiration/expiration ratio was set 1:1.9 (25% inspiration and 10% pause). For two lung ventilation (TLV), the inspiratory pressure was set at 14 cm H_2O and the ventilatory frequency was adjusted to maintain Pa_{CO_2} at around 5.3 kPa (40 mm Hg). Inspiratory and expiratory tidal volumes (ITV and ETV) were monitored. OLV was started just before the pleura was opened. After the endobronchial cuff was inflated, the corresponding part of the DLT was opened to the atmosphere and suctioned through a fibre-optic scope to facilitate lung collapse. The inspiratory pressure was then adjusted to 20 cm H_2O. During OLV, lung isolation was assessed by surgeons using the following grade: 1=excellent, 2=acceptable, 3=difficult to perform surgery. The first assessment was done after the pleura was opened and the lung could be seen. OLV was stopped just after the pleura was closed. The lung on the side of the surgery was suctioned and inflated sufficiently and then the endobronchial cuff was deflated. TLV was re-started with the same initial ventilation settings.

A Pa_{O_2} value less than 10.7 kPa (80 mm Hg) was defined as hypoxaemia.[4] Hypoxaemia during OLV was treated by the following strategies. First, 5 cm H_2O of PEEP was applied to the dependent lung. Secondly, 5 cm H_2O of continuous positive airway pressure (CPAP) (for thoracotomy) or 5 litre min^{-1} of apnoeic oxygen insufflation (for video-assisted thoracoscopic procedures) was applied to the non-dependent lung. Thirdly, brief periods of TLV were used. Each time these interventions were performed, bronchoscopy was done to allow correction of the tube position, the tube was sucked out, and arterial blood gases (ABGs), ITV and ETV were measured. Then, lung isolation was reassessed by the surgeons. The following measurements were collected at initial DLT placement under TLV (supine position), just before the end of OLV (lateral position), and after surgery under TLV (supine position): ABGs, ITV, ETV, and bronchoscopic assessment for DLT position. However, more frequent measurements were made in patients who required interventions for hypoxaemia during OLV, with sets of data measured just before the application of each intervention.

Statistical analysis

The study population size was determined as follows. Assuming DLT malposition after patient positioning would occur in 30% of patients and severe hypoxaemia would occur in 10% of patients during OLV, we assumed that those who had malposition after patient positioning would be twice as likely to show to hypoxaemia during OLV.

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Using the formula for normal theory and assuming a type I error protection of 0.05 and a power of 0.90, 152 patients were required for this study.

Analysis was done using descriptive statistics. Data for continuous variables are expressed as mean (SD) with range (minimum – maximum values). Hypothesis testing was done using the χ^2 test or Fisher's exact test accompanied with the relative risk (RR) and its 95% confidence interval (CI). To assess lung isolation, the Mann–Whitney test or Wilcoxon signed-ranks test was used. In regard to changes of Pa_{O_2}, ITV, and ETV among the subgroups, to facilitate statistical analysis, the several values recorded for each patient during OLV were averaged to yield a single number. They were compared using analysis of variance (ANOVA) for repeated measures followed by Scheffe's test. To compare other values among the subgroups, ANOVA was used. Results were considered significant at $P<0.05$.

Table 1 Patient characteristics and pulmonary function values (*n*=151). VATs=video-assisted thoracoscopic surgery

	Mean (SD)	Range
Age (yr)	59 (13)	19–79
Gender (M/F)	92/59	
Height (cm)	160 (8)	140–183
Weight (kg)	58 (8)	39–83
Smoking (Brinkman Index: cigarettes/day yr)	451 (617)	0–2400
Operative side (R/L)	73/78	
Thoracotomy/VATs	97/54	
Previous thoracotomy (Yes/No)	7/144	
Pa_{O_2} on air (kPa)	10.9 (1.1)	9.3–13.3
Pa_{CO_2} on air (kPa)	5.5 (0.5)	4.3–6.4
FEV1 (% predicted)	78.34 (8.6)	70–113.9
FVC (% predicted)	100.69 (15.9)	80–145.6
Surgical procedure	Number of patients (*n*=151)	
Wedge resection	36	
Segmentectomy	5	
Lobectomy	97	
Pneumonectomy	9	
Lung biopsy	4	

Results

One patient was excluded because calibration of the Paratrend 7^{TN} sensor was not carried out properly. Patient characteristics and pulmonary function data are shown in Table 1. The tube sizes used were 32F (*n*=3), 35F (*n*=52), 37F (*n*=61), 39F (*n*=35). After patient positioning, DLT malposition was detected broncoscopically in 49 patients (32%).

As shown in Table 2, treatment for hypoxaemia was needed in 46 patients (30%), and DLT malposition was found in 38 patients during OLV (25%). Forty-nine (32%) patients had DLT malposition and 29 (19%) developed DLT malposition during OLV with hypoxaemia during OLV in 28 (18.5%). Thus, 59% of patients with DLT malposition after lateral positioning developed DLT malposition again during OLV and 97% of these patients experienced hypoxaemia during OLV. Table 3 shows RR, 95% CI, and *P* values provided by χ^2-test. Patients who had DLT malposition at initial assessment also required each step of intervention more frequently. This group was more likely to contain patients with a previous history of thoracotomy. Patients with DLT malposition during OLV also required more frequent intervention to treat hypoxaemia.

Intraoperative changes of Pa_{O_2}, ITV, and ETV are shown in Figure 1. The subgroups that required interventions showed lower values of Pa_{O_2} during OLV. However, Pa_{O_2} did not differ between the subgroups after ending OLV. Values of ITV and ETV in the subgroup that required the final treatment (TLV) were less compared with those patients who required no intervention or only PEEP.

Figure 2 shows distributions of lung isolation score. The subgroup that required no intervention provided the most acceptable operative fields. Interventions were associated with a worse operative field. Successful interventions provided better operative fields than unsuccessful interventions.

Preoperative vasodilators (*n*=21) and intraoperative use of vasoactive agents (ephedrine *n*=18, nicardipine *n*=6) did not affect the incidence of hypoxaemia or need for interventions during OLV (statistical results not shown). For most of these patients, vasoactive agents were used

Table 2 Number of patients receiving each intervention, incidence of DLT malposition and minimum Pa_{O_2} during OLV. DLT malposition after patient positioning was detected in 49 patients after initial placement in the supine position with fibre-optic bronchoscopy. DLT malposition during OLV was detected in 38 patients even after initial confirmation and correction of placement in the lateral position with fibre-optic bronchoscopy

	Number of patients (*n*=151; 100%)	DLT malposition detected during OLV (*n*=38; 25%)	DLT mal position after patient positioning (*n*=49; 32%)	Minimum Pa_{O_2} during OLV (kPa)
No intervention	105 (70%)	8/105 (7.6%)	21/105 (20%)	29.7 (12.7) (11.2–56.9)
First intervention (PEEP)	46 (30%)	30/46 (65%)	28/46 (61%)	10.6 (0.7) (8.3–10.9)
Second intervention (CPAP or insufflation)	25 (17%)	19/25 (76%)	15/25 (60%)	9.5 (0.9) (7.6–10.7)
Third intervention (Brief TLVs)	11 (7%)	9/11 (82%)	7/11 (64%)	8.0 (0.9) (6.4–1.0)

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Table 3 Relative risk (RR), 95% confidence intervals (95% CI), and *P* values (χ^2 test) between DLT malposition or previous history of thoracotomy and each intervention. DLT position after patient positioning was assessed to see whether DLT malposition could occur after initial placement in the supine position with fibre-optic bronchoscopy. DLT position during OLV was assessed to see whether DLT malposition could occur even after initial confirmation and correction of placement in the lateral position with fibre-optic bronchoscopy when hypoxaemia developed. VATs=video-assisted thoracoscopic surgery

	DLT malposition after patient positioning (*n*=49)	**DLT acceptable position after patient positioning (*n*=102)**	**RR**	**95% CI**	***P***
PEEP (*n*=46)	28	18	3.04	1.95–4.76	<0.05
CPAP or insufflation (*n*=25)	15	10	2.22	1.45–3.42	<0.01
Brief TLVs (*n*=11)	7	4	2.12	1.27–3.54	<0.05
DLT malposition during OLV (*n*=38)	29	9	4.31	2.79–6.66	<0.01
Previous thoracotomy (*n*=7)	5	2	2.34	1.38–3.97	<0.05
	DLT malposition during OLV (*n*=38)	**DLT acceptable position during OLV (*n*=113)**	**RR**	**95% CI**	***P***
PEEP (*n*=46)	32	14	12.2	5.47–27.1	<0.01
CPAP or insufflation (*n*=25)	19	6	5.04	3.15–8.06	<0.01
Brief TLVs (*n*=11)	8	3	3.39	2.10–5.49	<0.01
Previous thoracotomy (*n*=7)	4	3	2.42	1.20–4.90	0.07
	Previous history of thoracotomy (*n*=7)	**No previous history of thoracotomy or VATs (*n*=144)**	**RR**	**95% CI**	***P***
PEEP (*n*=46)	4	42	3.04	0.71–13.1	0.12
CPAP or insufflation (*n*=25)	4	21	6.72	1.60–28.2	<0.01
Brief TLVs (*n*=11)	3	8	9.55	2.44–37.4	<0.01

before starting OLV. Seven patients had a previous thoracotomy. They needed more frequent intervention during OLV (except PEEP, P=0.12) and showed more DLT malposition after patient positioning (P<0.05) but not during OLV (P=0.07). Comparisons of other preoperative data (including pulmonary function test and operative side) in relation to requirement of intervention, DLT malposition, or previous thoracotomy, did not provide important information (data not shown).

Discussion

We found that patients with malposition of a DLT after placing in the lateral position had more hypoxaemia during OLV, and persistent DLT malposition during OLV, even after correction of the DLT position with fibre-optic bronchoscopy. This suggests that hypoxaemia during OLV might, at least partially, be caused by DLT malposition during OLV and that we might be able to predict the patients who could develop these problems. In addition, patients who had a previous thoracotomy also had more hypoxaemia during OLV and DLT malposition.

Hypoxaemia is a major concern during OLV. This problem appears to consist of two main parts. One is based on changes in lung function during OLV. The other is based on the smaller margin of safety of positioning for DLTs. Several researchers have tried to discover good predictors for arterial oxygenation during OLV, mainly studying pulmonary pathophysiology.[1 3–5] However, despite their efforts we have no good predictors. Others have studied DLT placement intensively;[2 4 6 7–9] but the small margin of safety in the DLT placement has not been related to arterial oxygenation during OLV. We suggest that this small safety margin has more effect on hypoxaemia during OLV than pulmonary pathophysiology because DLT malposition accounts for poor ventilation and hypoxaemia during OLV.

Some factors may predispose to DLT malposition and hypoxaemia during OLV. Factors such as the surgical procedures, movement of the mediastium by gravity, and compression by abdominal contents might change the relationship between the DLT and the patient's tracheobronchial anatomy. Those who did not show DLT malposition during OLV were probably tolerant to these intraoperative factors, and those who develop DLT malposition after patient positioning are more susceptible to such intraoperative factors.

Oxygenation during OLV is affected by several factors.[16 17] DLT malposition will have an important influence on hypoxaemia if it happens. The position of the DLT is usually checked first when hypoxaemia is detected during OLV. We found that DLT malposition can happen repeatedly. Patients with hypoxaemia (9–28% of all patients) may involve patients with persistent DLT malposition. Hurford and colleagues[2] reported 7–30% of patients required DLT position readjustment during OLV. Klein and colleagues[6] also reported that 13 and 13.5% of patients required position readjustment or suctioning blood or secretions with the aid of a fibre-optic scope. Campos and co-workers detected DLT malposition, despite initial adjustment using fibre-optic bronchoscopy, in 12.5–25% of patients during OLV although it did not happen repeatedly.[8 9] Taking these

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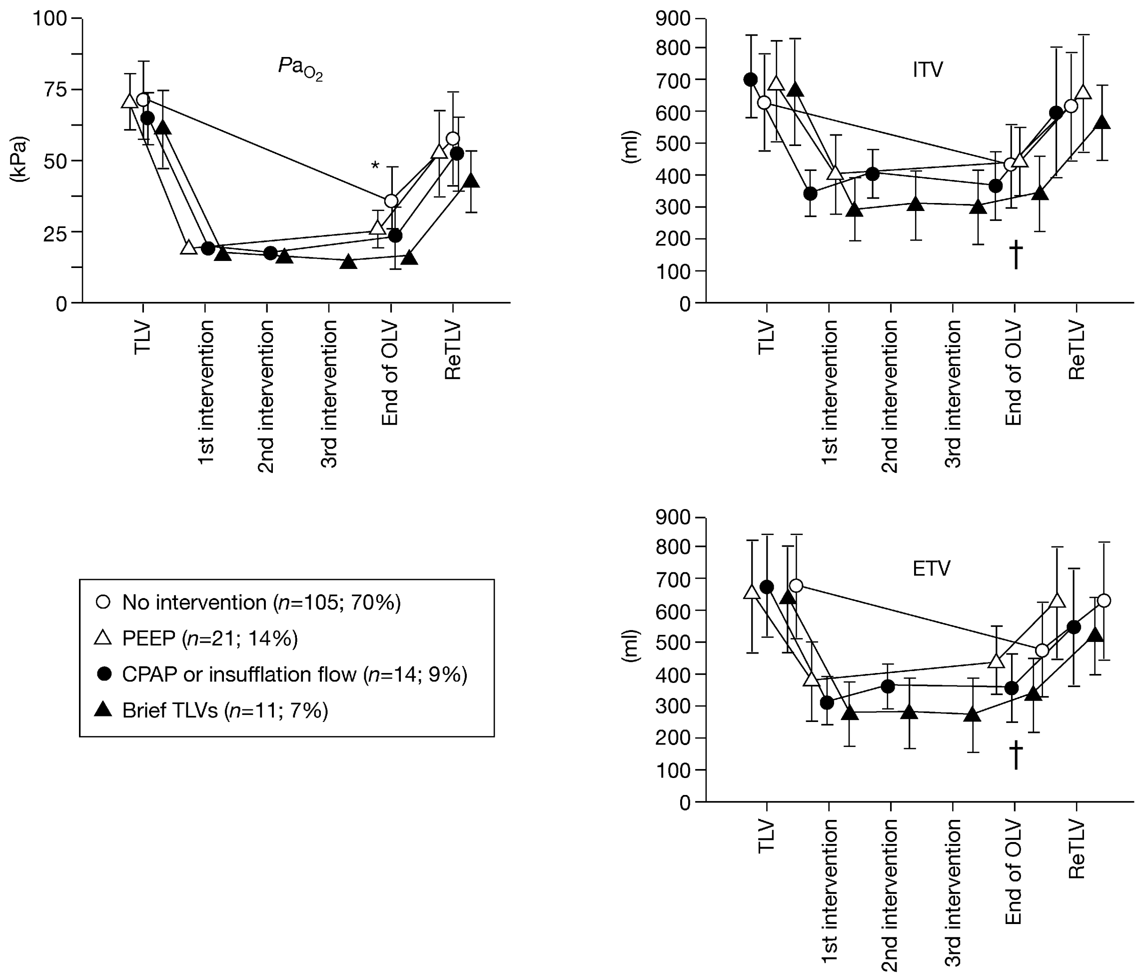

Fig 1 Changes in Pa_{O_2}, ITV, and ETV in the subgroups The data are mean (SD). Open circles: no intervention during OLV. Open triangle: only PEEP to the dependent lung during OLV. Solid circle: additional CPAP or insufflation to the independent lung during OLV. Solid triangle: brief TLV during OLV. TLV=at initial DLT placement with TLV. 1st intervention=just before application of PEEP to the dependent lung. 2nd intervention=just before application of CPAP or apnoeic oxygen insufflation to the independent lung. 3rd intervention=just before application of 1st brief TLV. The end of OLV=just before the end of OLV. ReTLV after all surgical procedure under TLV. *$P<0.05$ the subgroups, which required intervention *vs* the subgroup, which required no intervention during OLV. †$P<0.05$ final intervention *vs* no intervention or only PEEP during OLV.

results with ours, DLT position is probably one of the main factors for hypoxaemia during OLV.

There are two ways to treat hypoxaemia during OLV. One is to apply CPAP or oxygen insufflation to the non-dependent lung.[18–20] The other is to apply PEEP to the dependent lung to reduce atelectasis.[4 21] In this study, we applied PEEP first according to Lewis.[4] If Pa_{O_2} decreased further, we applied brief TLV.[4 20] We found that patients whose oxygenation improved had a better lung isolation score than those patients in whom oxygenation did not improve although each intervention *per se* made conditions of the operative field progressively worse. These interventions, which exert an effect by airway pressure or flow, may support the airway and reduce the misfit between the DLT and the airway. On the other hand, this anatomical misfit may persist in the unsuccessful interventions, which then worsened the operative conditions. Support for this comes from ITVs and ETVs during OLV. The patients who required more interventions and correction of DLT placement had smaller ITVs and ETVs. This could mean that these patients developed ventilation failure during OLV, caused by persistent DLT malposition, at least partially because of the misfit between the DLT and the patient's lungs. Patients with a previous thoracotomy were at risk. They had almost normal preoperative chest X-ray films, but probably had intrathoracic adhesions. This could distort lung structure and enhance the misfit between the DLT and the lung.

We defined DLT malposition in this study as a 1.0 cm deviation from optimal position. We set this value to provide a simple quantitative measure. The average margin of safety in positioning is 19 mm for a left-sided Mallinckrodt tube.[13] However, some consider only 0.5 cm of deviation from an optimal placement could be danger-

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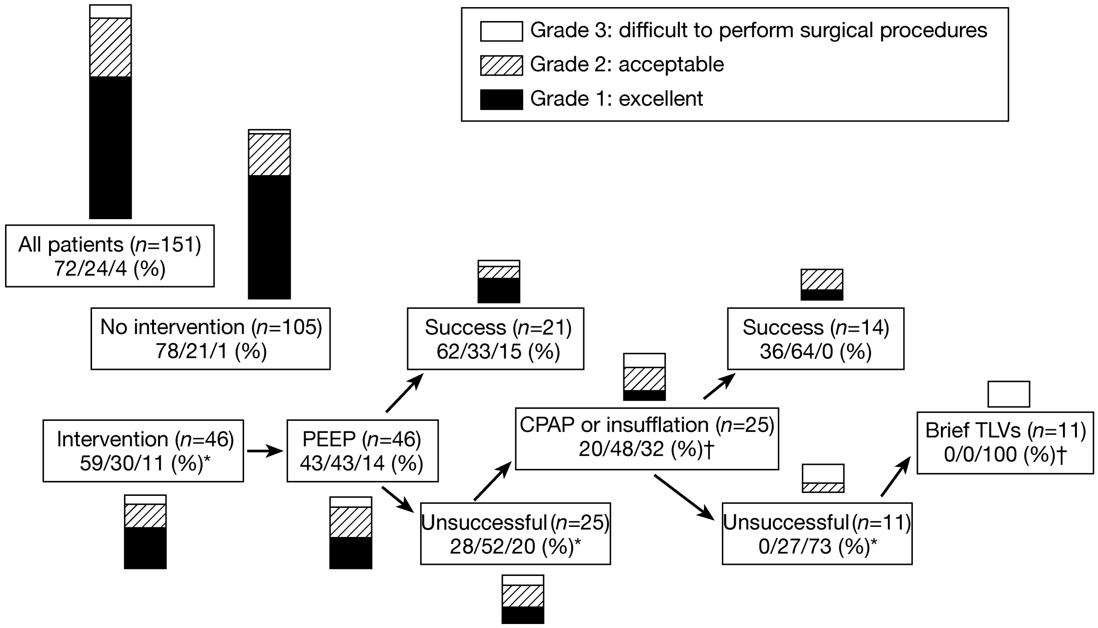

Fig 2 Number of patients for each subgroup and population percentage of lung isolation score (score 1/2/3). Lung isolation score: 1=excellent, 2=acceptable, 3=difficult to perform surgical procedure. *$P<0.05$ *vs* the subgroup that did not require interventions for hypoxemia. †$P<0.05$ *vs* before application of the intervention.

ous.[6] The Japanese patients we studied are smaller compared with patients in other studies (Table 1), and 1.0 cm deviation could be critical for them, so we decided to use 1.0 cm as a cut-off value. In fact, all patients with DLT malposition in this study met the bronchoscopic criteria for DLT malposition of Campos and colleagues.[9] How can we stop DLTs becoming misplaced? We have no solution so far, but we could try an alternative method for OLV. Univent[R] tubes, which are single-lumen tubes with enclosed bronchial blockers, can be easier to insert and have less risks than DLTs.[22–25] However, the frequency of malposition for the Univent[R] can be greater than for the DLT.[8] Therefore, frequent fibre-optic assessment of tube position seems necessary although further studies are needed.

In this study we used pressure-controlled ventilation, which is not standard practice.[26] With volume-controlled ventilation, we could have had different results. With pressure-controlled ventilation, tidal volume decreases during OLV, as it did in this study (Fig. 1). Any airway narrowing from DLT malposition will increase resistance and reduce tidal volume further. The reduced tidal volume could allow atelectasis in the dependent lung and lead to hypoxia during OLV. Consequently, DLT malposition could be a more frequent cause of hypoxia during OLV if pressure-controlled ventilation were used. Our conclusions may be only applicable for pressure-controlled ventilation. Studies with volume-controlled ventilation might be needed to address this concern.

In conclusion, we showed that patients with DLT malposition after being placed in the lateral position were more likely to have misplacement of the DLT during OLV and develop hypoxaemia, even if the DLT position had been corrected with fibre-optic bronchoscopy. In addition, patients who have had a previous thoracotomy are at increased-risk of developing hypoxaemia during OLV because of DLT malposition.

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