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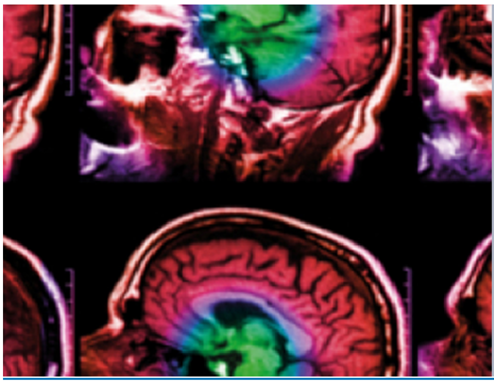

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A randomised trial evaluating mask ventilation using electrical impedance tomography during anesthetic induction: one-handed technique versus two-handed technique

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Keywords: mask ventilation, one-handed technique, two-handed technique, pulmonary ventilation distribution, electrical impedance tomography

Abstract

Objective. Mask positive-pressure ventilation could lead to lung ventilation inhomogeneity, potentially inducing lung function impairments, when compared with spontaneous breathing. Lung ventilation inhomogeneity can be monitored by chest electrical impedance tomography (EIT), which could increase our understanding of mask ventilation-derived respiratory mechanics. We hypothesized that the two-handed mask holding ventilation technique resulted in better lung ventilation, reflected by respiratory mechanics, when compared with the one-handed mask holding technique. *Approach.* Elective surgical patients with healthy lungs were randomly assigned to receive either one-handed mask holding (one-handed group) or two-handed mask holding (two-handed group) ventilation. Mask ventilation was performed by certified registered anesthesiologists, during which the patients were mechanically ventilated using the pressure-controlled mode. EIT was used to assess respiratory mechanics, including ventilation distribution, global and regional respiratory system compliance (C_{RS}), expiratory tidal volume (TVe) and minute ventilation volume. Hemodynamic parameters and the PaO_2-FiO_2 ratio were also recorded. *Main results.* Eighty adult patients were included in this study. Compared with spontaneous ventilation, mask positive-pressure ventilation caused lung ventilation inhomogeneity with both one-handed(global inhomogeneity index: 0.40 ± 0.07 versus 0.50 ± 0.15; $P < 0.001$) and two-handed mask holding (0.40 ± 0.08 versus 0.50 ± 0.13; $P < 0.001$). There were no differences in the global inhomogeneity index ($P = 0.948$) between the one-handed and two-handed mask holding. Compared with the one-handed mask holding, the two-handed mask holding was associated with higher TVe (552.6 ± 184.2 ml versus 672.9 ± 156.6 ml, $P = 0.002$) and higher global C_{RS} (46.5 ± 16.4 ml/cmH_2O versus 53.5 ± 14.5 ml/cmH_2O, $P = 0.049$). No difference in PaO_2-FiO_2 ratio was found between both holding techniques ($P = 0.743$). *Significance.* The two-handed mask holding technique could not improve the inhomogeneity of lung ventilation when monitored by EIT during mask ventilation although it obtained larger expiratory tidal volumes than the one-handed mask holding technique.

Abbreviations

ASA	American Society of Anesthesiologists
BMI	body mass index

C_{RS}	respiratory system compliance
EIT	electrical impedance tomography
GI	global inhomogeneity index
PBW	predicted body weight, for men = 50 + 0.9 [height (cm): 152.4], and for women = 45.5 + 0.9 [height (cm): 152.4]
ROI	regional lungs of interest
RVD_{SD}	regional ventilation delays standard deviation
TVe	expiratory tidal volume
ΔEELV	changes in end-expiratory lung volume

Introduction

Mask ventilation, an essential skill for practitioners engaged in airway management (Lim and Nielsen 2016), has been shown to cause regional distributions of ventilation shifts towards ventral lung areas in the supine position (Ukere *et al* 2016, Lumb *et al* 2020), leading to lung ventilation inhomogeneity (Ukere *et al* 2016). This impairs carbon dioxide removal and oxygen uptake (Rothen *et al* 1998, Lumb *et al* 2020). Therefore, it is necessary to improve the inhomogeneity of lung ventilation when using mask ventilation in several clinical scenarios in order to improve oxygenation, for instance, for obesity patients. However, the reasons for lung ventilation inhomogeneity during mask ventilation remains elusive, and methods to improve this remain to be investigated.

Global measures such as oxygenation or respiratory system mechanics are traditionally used to evaluate the effects of mask ventilation (Joffe *et al* 2010, Fei *et al* 2017, Itagaki *et al* 2017). Misleading information may be produced by 'averaging' opposite pathological phenomena in different lung units (Frerichs *et al* 2017). This underlines the need for regional lung monitoring. Conventional radiological methods such as chest radiography, computed tomography, and magnetic resonance imaging, generate static information on the structural changes of the pulmonary tissue. However, these methods are not practical for evaluating the dynamic changes of mask ventilation, especially in the operating room. Electrical impedance tomography (EIT), as a noninvasive, nonradiological medical imaging method (Frerichs *et al* 2017), can be used for bedside monitoring of the lung, both globally and regionally, even under dynamic lung ventilation. Lung impedance changes are highly correlated to the global volume changes measured at the airway opening (Ngo *et al* 2017, Zhao *et al* 2017). Recent clinical studies (Zhao *et al* 2019, Lumb *et al* 2020, Zhang *et al* 2020, Bayford *et al* 2022) imply the potential of EIT to assess the heterogeneous behavior of regional lung tissue from various conditions, including mask ventilation (Lumb *et al* 2020). The heterogeneity estimation provided by EIT includes not only spatial but also the temporal distribution of lung function measures (e.g. Lasarow *et al* 2021).

Despite the knowledge that the two-handed mask holding technique is superior to the one-handed mask holding technique for providing higher tidal volume (Joffe *et al* 2010, Fei *et al* 2017), the influence of these two mask ventilation techniques on regional ventilation mechanics remains unknown. Understanding the ventilation-derived respiratory mechanics via EIT monitoring may be helpful in improving our mask ventilation performance. The aim of the present study was to determine the effects of the two mask holding ventilation techniques on global and regional lung ventilation during anesthetic induction. We hypothesized that two-handed mask holding ventilation improves the lung ventilation inhomogeneity monitored by EIT. The primary outcome was the global inhomogeneity index (GI). The secondary outcomes were other respiratory metrics including centre of ventilation, regional ventilation delays standard deviation (RVD_{SD}), expiratory tidal volume (TVe) and the PaO_2-FiO_2 ratio.

Methods

Ethics approval

This clinical trial was a single center, randomized clinical study performed in Fudan university Shanghai Cancer Center and approved by the Ethics Committee (IRB2010225-10). This study was registered on ClinicalTrial.gov (NCT04617665) and written informed consents were obtained from all participating patients before enrollment. An investigator assessed patients for eligibility the day before surgery.

Inclusion and exclusion criteria

From November to December 2020, adult patients with American Society of Anesthesiologists (ASA) physical status I-II scheduled for elective surgery under general anesthesia were screened for this study. The exclusion

Figure 1. One-handed and two-handed mask holding ventilation techniques. (a) One-handed mask holding technique. (b) Two-handed mask holding technique. For the one-handed technique, only one hand can be used to achieve the face mask seal. The left thumb and index finger form a 'C,' providing anterior pressure over the mask, while the third, fourth, and fifth fingers form an 'E' to lift the jaw. For the two-handed technique, the provider's thumb and thenar eminence of each hand are held parallel, adjacent to the mask connector, and depress each side of the mask. The second through fifth digits wrap around and elevate the mandible to draw it anteriorly into the mask, establishing both a jaw-thrust and chin-lift maneuver when appropriate.

criteria included: (i) acute and chronic respiratory disorders, including chronic obstructive pulmonary disease (COPD) and asthma; (ii) a history of lung surgery; (iii) high risk of reflux and aspiration; (iv) requirement of awake intubation; (v) facial and thoracic deformities; (vi) implants in the body, such as cardiac pacemakers, and (vii) pregnancy.

Study procedure

After entering the operating room, patients were placed in the supine position with the head in a neutral position on a pillow and elevated 10 cm. The baseline clinical characteristics of patients were collected by a nurse, including age, gender, height, weight, body mass index (BMI) and ASA physical status. Additionally, airway assessments such as Mallampati scores, thyromental distance, mouth opening, lack of dentition, presence of beard, history of sleep apnea, upper lip bite test and laryngoscope grade were also recorded.

Standard monitoring protocols were applied, including ECG, pulse oximetry, and capnography, and an arterial line was established for invasive arterial pressure monitoring and arterial blood gas analysis. Preoxygenation, via a suitable plastic mask (PAIM, AM0031 (5316), Congren Medical Device Co., LTD, Xiamen, China) placed over the bridge of the nose and chin to achieve an air-tight seal, was performed before anaesthetic induction with a flow rate of 6 l min^{-1} of 100% O_2 for three minutes under spontaneous breathing. Then anesthetic induction was conducted with intravenous target control infusion propofol (Marsh mode) 4 $\mu g\ ml^{-1}$ (Thomson *et al* 2014), sufentanil 0.3 $\mu g\ kg^{-1}$, and rocuronium 0.6 mg kg^{-1}. After the patient's loss of consciousness, spontaneous breathing disappeared gradually. Twenty seconds after the injection of rocuronium, mechanical ventilation was delivered by the anaesthetic machine in pressure control mode (Fei *et al* 2017). The ventilation parameters were set as respiratory frequency = 15 bpm, inspiratory-to-expiratory time ratio = 1:2, peak inspiratory pressure = 15 cmH_2O, and positive end-expiratory pressure (PEEP) = 0 cmH_2O. The operators performing mask ventilation were certified registered anesthesiologists (figure 1). To achieve an air-tight seal, the face mask leak was checked through the monitoring of the ventilation pressure and capnography waveform. Endotracheal intubation was performed ninety seconds after rocuronium administration. Throughout the whole procedure, further airway management was initiated if oxygen saturation was $\leqslant$90% during mask ventilation, or for safety reasons based on the judgment of study team. Those patients with unexpected difficult mask ventilation would be excluded from the study.

The whole procedure of anaesthetic induction, including the dynamical parameters (e.g. TV, respiratory rate) showed in the anaesthesia monitor and machine, was recorded by a video recorder for data revisiting and further analysis. Only the person who conducted the statistical analysis was blinded to the randomization. The revisited parameters included TVe (the average TVe value of the last five breaths during mask ventilation), minute ventilation volume (value immediately before intubation), driving pressure, heart rates (immediately before induction and intubation), and systolic blood pressure (immediately before induction and intubation). The globe respiratory system compliances (C_{RS}) were calculated as TVe/driving pressure. Immediately before anaesthetic induction and endotracheal intubation, arterial blood gas analysis (GEM3500; Instrumentation Laboratory, USA) was performed twice.

EIT monitoring and analysis

The global and regional lung ventilation were continuously monitored and recorded by EIT (PulmoVista500, Draeger Medical, Luebeck, Germany). In the present study, an EIT electrode belt, which carries 16 electrodes with a width of 40 mm, was placed around the thorax in the fifth intercostal space, and a reference electrode was placed on the right thorax (Spinelli *et al* 2019). Customized software was used to quantitatively analyze the offline EIT data. During mask ventilation, results were derived from the mean of all the breaths occurring in the 1 min before intubation (Lumb *et al* 2020). The following variables were calculated (Frerichs *et al* 2017): GI, centre of ventilation, RVD_{SD}, compliance win and loss of mask ventilation compared with spontaneous lung ventilation. Changes in end-expiratory lung volume between mask ventilation and spontaneous lung ventilation were analyzed by calculating the differences between the minimum (end-expiratory) values of tidal volume relative impedance change (Hinz *et al* 2003, Zick *et al* 2013). The EIT image was divided into quadrants (four regions of interest, ROIs) . Regional C_{RS} was determined as ((fraction of ROI) $\times$ TVe)/driving pressure.

Randomization

The patients were randomly divided into two groups: the one-handed mask holding ventilation group (one-handed group) and the two-handed mask holding ventilation group (two-handed group) immediately after the EIT electrode belt was placed. Randomization was accomplished using the series of envelopes method (Itagaki *et al* 2017). 80 envelopes each contained a sheet of paper with one of 80 sequential numbers written on it, ensuring that 40 participants were allocated to the one-handed group and another 40 to the two-handed group. The operators participating in the study were blinded to the group assignment until the induction of general anesthesia, when the envelopes were opened.

Statistical analyses

As GI was reported to be 0.43 ± 0.04 during bag-mask ventilation (Lumb *et al* 2020), we assumed that there was a 0.025 difference between one-handed mask holding ventilation and two-handed mask holding ventilation, and the variance was 0.04. And with a statistical power of 80%, a two-sided α significance level of 0.05, a sample size of 40 patients in each group would be enrolled. Considering a dropout rate of 30%, a total of 114 patients would be enrolled at least.

Continuous variables were presented as mean $\pm$ standard deviation, or median with the interquartile range depending on the normality of the distribution. Categorical variables were presented as numbers and proportions. Binary variables were analyzed using a chi-square test or a Fisher's exact test. Quantitative variables between the groups were analyzed using Student's *t* test or the Mann–Whitney U test. The primary outcome GI was analyzed by an unpaired *t* test. Statistical significance was defined as $P < 0.05$, and all *P* values were two-sided. The clinical data were analyzed using SPSS 19.0 (SPSS, Inc., Chicago, IL, USA).

Results

A total of 119 consecutive patients were screened in the study period. 39 patients were excluded due to various causes (figure 2). All patients were successfully intubated at the first attempt. There were no anaesthesia-related adverse events in either group. The data of 80 patients were included in the final analysis, in which 40 patients were allocated to the one-handed group and 40 patients to the two-handed group. Their clinical characteristics are listed in table 1.

As compared with spontaneous ventilation, mask positive-pressure ventilation during anaesthetic induction caused significant lung ventilation inhomogeneity, both with one-handed (GI: 0.40 ± 0.07 versus 0.50 ± 0.15; $P < 0.001$) and two-handed mask holding (0.40 ± 0.08 versus 0.50 ± 0.13; $P < 0.001$) (figure 3). However, there were no differences in GI ($P = 0.948$, table 2) between the one-handed and two-handed mask holding, as well as the parameter centre of ventilation ($P = 0.438$, table 2). There were no significant differences in the ventilation distribution of the four ROIs ($P > 0.05$, table 2) between both holding techniques. In contrast, compared with the one-handed mask holding technique, the two-handed mask holding technique decreased the RVD_{SD} ($P = 0.032$, table 2).

Compared with the one-handed mask holding technique, the two-handed mask holding technique was associated with higher TVe (552.6 ± 184.2 ml versus 672.9 ± 156.6 ml, $P = 0.002$, table 3), minute ventilation volume (8.2 ± 2.9 l min^{-1} versus 9.8 ± 2.3 l min^{-1}, $P = 0.010$, table 3) and global C_{RS} (46.5 ± 16.4 ml/cmH_2O versus 53.5 ± 14.5 ml/cmH_2O, $P = 0.049$) (table 2). However, there were no significant differences in regional C_{RS} between both holding techniques ($P > 0.05$, table 2).

Though a higher TVe was associated with two-handed mask holding ventilation, the heart rates, systolic pressure, and PaO_2-FiO_2 ratio were compatible between the two holding techniques during anaesthetic induction (table 3).

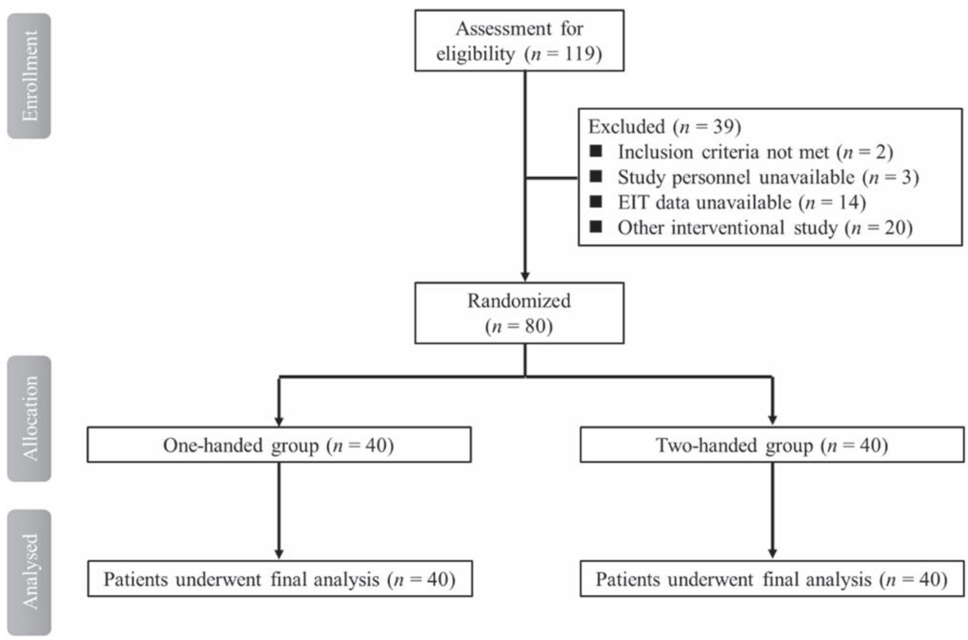

Figure 2. Flowchart of subject enrollment. EIT: electrical impedance tomography.

Table 1. Baseline characteristics of the patients.

	One-handed group (n = 40)	Two-handed group (n = 40)	P value
Age (years)	56.3 (19–76)	55.4 (28–83)	0.812
Gender (male/female)	19/21	22/18	0.655
ASA status (I/II)	10/30	14/26	0.465
Weight (kg)	66.1 ± 12.1	66.7 ± 12.4	0.846
Height (cm)	164.3 ± 7.3	165.6 ± 7.0	0.403
BMI ($kg.m^{-2}$)	24.4 ± 3.3	24.2 ± 3.5	0.829
PBW (kg)	58.3 ± 8.2	59.9 ± 8.0	0.395
Mouth opening (cm)	4.4 ± 1.1	4.5 ± 0.8	0.857
Thyromental distance (cm)	7.1 ± 1.2	7.0 ± 1.4	0.913
Missing teeth (absent/present)	30/10	30/10	1.000
Beard (absent/present)	36/4	37/3	1.000
Snoring history (absent/present)	18/22	14/26	0.494
Bite the upper lip test (I/II/III)	25/13/2	30/9/1	0.469
Mallampati grade (I/II/III)	14/17/9	17/17/6	0.641
Laryngoscope grade (I/II/III)	21/16/3	23/17/0	0.210
Spontaneous lung ventilation			
GI	0.40 ± 0.07	0.40 ± 0.08	0.917
Centre of ventilation (%)	45.9 ± 4.5	45.6 ± 5.6	0.773
RVD_{SD}	7.0 (6.0–8.75)	7.0 (6.0–9.0)	0.583
Ventilation of regional lung of interest (proportion, %)			
ROI 1 (%)	29.4 ± 6.0	28.7 ± 7.7	0.640
ROI 2 (%)	24.8 ± 5.8	25.2 ± 7.4	0.777
ROI 3 (%)	24.3 ± 6.2	24.0 ± 8.2	0.854
ROI 4 (%)	18.1 ± 4.8	18.6 ± 5.2	0.623
Basic hemodynamics			
Heart rate (bmp)	77.4 ± 13.4	72.3 ± 12.2	0.082
Systolic pressure (mmHg)	163.1 ± 26.7	154.2 ± 23.4	0.118
Basic arterial blood gas			
PaO_2-FiO_2 ratio	425.3 ± 58.3	414.7 ± 46.9	0.371

Data are presented as mean ± SD or median (range) unless otherwise noted. ASA = American Society of Anesthesiologists; BMI = body mass index; PBW = predicted body weight, for men = 50 + 0.9 [height (cm): 152.4], and for women = 45.5 + 0.9 [Height (cm): 152.4]. GI = global inhomogeneity index; RVD_{SD} = regional ventilation delays standard deviation; ROI = regional of interest.

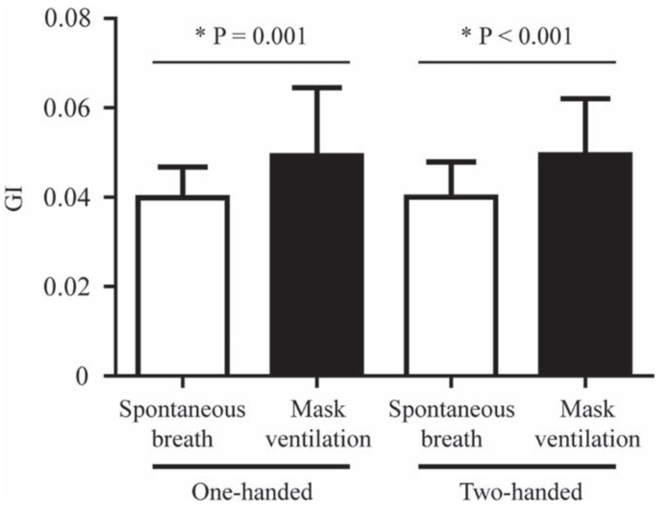

Figure 3. GI values affected by mask positive-pressure ventilation. GI: global inhomogeneity index. * Compared with spontaneous breath.

Table 2. Parameters of regional ventilation distribution of one-handed mask holding ventilation versus two-handed mask holding ventilation.

	One-handed group ($n = 40$)	Two-handed group ($n = 40$)	P value
GI	0.50 ± 0.15	0.50 ± 0.13	0.948
Centre of ventilation (%)	39.7 ± 5.0	38.8 ± 4.6	0.438
RVD_{SD}	5.5 (4.0–7.0)	4.0 (3.0–5.0)	0.032
Global C_{RS} (ml/cmH_2O)	46.5 ± 16.4	53.5 ± 14.5	0.049
△EELV (rel. △Z)	−300.5 ± 1388.1	−114.3 ± 1445.0	0.558
Ventilation of regional lung of interest (proportion, %)			
ROI 1 (%)	36.6 ± 6.7	36.4 ± 6.6	0.893
ROI 2 (%)	33.3 ± 5.4	33.9 ± 8.7	0.736
ROI 3 (%)	14.3 ± 4.4	14.2 ± 4.7	0.922
ROI 4 (%)	12.1 ± 4.0	12.2 ± 3.6	0.931
ROI C_{RS} (ml/cmH_2O)			
ROI 1	16.8 ± 6.8	19.0 ± 4.5	0.102
ROI 2	15.4 ± 6.2	18.0 ± 7.4	0.099
ROI 3	6.9 ± 3.8	8.0 ± 3.6	0.173
ROI 4	5.7 ± 2.9	6.7 ± 3.1	0.142
Compliance win (%)	43.0 (24.0–54.8)	44.5 (20.0–75.8)	0.202
Compliance loss (%)	20.2 ± 14.7	20.1 ± 17.2	0.972

Data are presented as mean ± SD or median (range) unless otherwise noted. GI: global inhomogeneity index; RVD_{SD}: regional ventilation delays standard deviation; ROI: region of interest.

Table 3. The expiratory tidal volume, minute ventilation volume, hemodynamic, and ABG analysis: one-handed mask holding ventilation versus two-handed mask holding ventilation.

	One-handed group ($n = 40$)	Two-handed group ($n = 40$)	*P* values
TVe (ml)	552.6 ± 184.2	672.9 ± 156.6	0.002
Minute ventilation volume (l min^{-1})	8.2 ± 2.9	9.8 ± 2.3	0.010
Hemodynamic			
Heart rate (bmp)	64.5 ± 9.7	63.9 ± 10.1	0.779
Systolic pressure (mmHg)	121.0 ± 21.4	125.0 ± 22.4	0.409
Arterial blood gas			
PaO_2-FiO_2 ratio	390.3 ± 92.0	383.1 ± 104.1	0.743

Data are presented as mean ± SD. TVe: expiratory tidal volume.

Discussion

Our study examined regional ventilation with two mask-holding ventilation techniques during anesthetic induction in lung-healthy surgical patients. The protocol was designed to reflect clinical decision-making for anesthesiologists regarding the choice of one-handed or two-handed mask holding ventilation for healthy lungs. The EIT method confirmed that mask positive-pressure ventilation causes ventilation redistribution, but the two-handed mask holding technique could not improve lung ventilation inhomogeneity compared to the one-handed mask holding technique. However, two-handed mask holding ventilation provided higher TVe and global C_{RS}.

Lung ventilation inhomogeneity during anesthesia was mainly caused by the ventilation ventral shift. In the present study, we found that ventilation was redistributed towards ventral regions regardless of which of the mask holding ventilation techniques (one-handed or two-handed) was applied. This finding was in accordance with other studies during intermitted positive-pressure ventilation (Lagier *et al* 2020, Lumb *et al* 2020). The reasons for this ventral shift of ventilation may include: anesthesia (Radke *et al* 2012, Bordes *et al* 2016), neuromuscular blockade, positive pressure ventilation, or any artificial airway used to facilitate ventilation (Lumb *et al* 2020). Based on the centre of ventilation between the two techniques, we found that such a ventral shift in lung-healthy patients may not be associated with mask ventilation holding techniques.

As expected, the present study showed that two-handed mask holding ventilation provided higher TVe and minute ventilation volume than one-handed mask holding ventilation. In an animal study led by Zick G *et al* (Zick *et al* 2013), EIT examinations were performed in 10 anesthetized pigs with normal lungs ventilated at 5 and 10 ml kg^{-1} body weight TV and 5 cmH_2O PEEP. Increasing TV from 5 to 10 ml kg^{-1} body weight led to a small but significant redistribution of ventilation in favor of the dependent lung regions. The geometrical centre of ventilation moved slightly but significantly towards dependent regions. We suspected that such redistribution via increasing TV might indicate rather tidal recruitment/derecruitment. Therefore, RVD_{SD} was calculated to assess the level of tidal recruitment/derecruitment in our study. The two-handed mask holding technique provided higher TVe when compared with the one-handed mask holding technique. However, the extra TVe was not enough to improve ventilation distribution. In fact, the lower RVD_{SD} in the two-handed mask holding technique might suggest that the extra TVe provided by the two-handed mask holding technique might have no adverse effects. The zero PEEP setting in our study may also contribute to the negative result, because an adequate PEEP level improves ventilation in the dorsal lung regions (Sinclair *et al* 2010, Lagier *et al* 2020).

Our findings of increased global C_{RS} and TVe in the two-handed group were in accordance with the fact that with identical mechanical properties, an increase in ventilated volume leads to an increase in compliance. In the regional C_{RS} analysis, though there were no statistical differences, all the absolute values of four ROI C_{RS} were bigger in the two-handed group than in the one-handed group. These results indicated that there was elevated C_{RS} in both ventral and dorsal regions. When compared with one-handed mask holding ventilation, two-handed mask holding ventilation did not cause hyperventilation in ventral regions because of the increased C_{RS}. It had been found that hyperventilation could be inferred from decreased C_{RS} using different TV (Zick *et al* 2013). The studies demonstrated that high TV with PEEP was associated with increased regional C_{RS} in the dependent lung regions and decreased regional C_{RS} in the nondependent lung regions (Zhao *et al* 2021).

In our daily practice, a harness, such as four headbands, was usually used to hold the mask to achieve an air-tight seal in noninvasive positive-pressure ventilation. The harness fixes the mask tightly onto the patient's face. However, with the harness holding the mask there is no chin-lift and head-tilt maneuver, while this can be performed by the two-handed technique (Joffe *et al* 2010). This maneuver is demonstrated to move the epiglottis away from the posterior pharyngeal wall, which can decrease the upper airway's resistance. So, the two-handed technique may be associated with better ventilation results when compared with a harness holding mask, especially for obese patients with a difficult airway. It would be interesting to carry out a study comparing the use of a harness with the two-handed technique for mask ventilation.

There are several limitations in this study. Around 12% of the screened patients were excluded from the analysis because of EIT data unavailability. The poor EIT signal quality occurred in some very nervous patients with irregular deep breathing during spontaneous breathing before anesthetic induction. Large changes in chest dimensions caused by deep inspiration may decrease the data quality (Schullcke *et al* 2016) and cause instability in electrode–skin contact. To minimize this effect on data collection, we tried to calm down enrolled patients through communications with them and then started the EIT data recording. To get better skin contact, we used conductive gel between the elastic belt electrodes and skin for patients with bad electrode-skin contact. The study was only performed in the operating room for anesthetized patients; whether the results are applicable to another scenario would need to be validated further. Furthermore, there were few obese patients in our study. Since obesity is a well-known contributing factor to difficult mask ventilation (Leoni *et al* 2014, Moon *et al* 2019), the regional distribution of lung ventilation during mask ventilation may be different in obese patients when compared with nonobese ones. The performances of the two techniques on the regional distribution of lung ventilation in obese patients remains to be determined.

Conclusion

In conclusion, compared with the one-handed mask holding technique, larger TVe values were presented using the two-handed mask holding technique. However, lung ventilation inhomogeneity could not be improved by using the two-handed mask holding technique during mask ventilation.

Acknowledgments

The authors would like to thank colleagues for their assistance in carrying out the study, by performing the specified mask ventilation technique on patients.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

GLL and ZY carried out the trial procedures, analysed the data and drafted the manuscript. YY and PC performed the randomisation, assisted with the trial procedures, and prepared the manuscript. ZZ gave statistical advice and significantly revised the manuscript. ZJ and YL conceived of the study, and participated in its design and coordination and helped to revise the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This trial was approved by the Fudan University Shanghai Cancer Center Ethics Committee (IRB2010225-10), and written informed consents were obtained from all participating patients before enrollment. All methods were performed in accordance with the relevant guidelines and regulations.

Competing interests

Zhanqi Zhao receives a consulting fee from Dräger Medical. Other authors declare that they have no competing interests.

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