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Effect of Positive End-Expiratory Pressure on Overlap Between Internal Jugular Vein and Carotid Artery in Mechanically Ventilated Patients with Laryngeal Mask Airway (LMA) Insertion – A Prospective Randomized Trial

Authors' Contribution:
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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: In the present study, we aimed to determine the effect of different positive end-expiratory pressure (PEEP) levels on the cross-sectional area (CSA) of the right internal jugular vein (RIJV) and the overlap index between the RIJV and the right common carotid artery (RCCA) in mechanically ventilated patients with laryngeal mask airway (LMA) insertion.

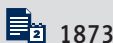
Material/Methods: A total of 60 patients who were scheduled for elective surgery under general anesthesia with LMA insertion were enrolled. After LMA insertion, the image of RIJV and RCCA were taken after applying 4 different PEEPs in a random order: 0 (P0), 5 (P5), 10 (P10), and 15 (P15) cm H₂O. The CSA, transverse and anteroposterior (AP) diameters of the RIJV, and the overlap index were measured.

Results: Compared to group P0, the overlap indexes of P10 ($P=0.0032$) and P15 ($P<0.001$) were significantly increased, but without a significant trend toward further increases in group P15. PEEP at 10 and 15 cm H₂O increased CSA, transverse and AP diameter of the RIJV in comparison to group P0 (all $P<0.001$). There was a statistically significant increase in CSA of the RIJV in P15 compared with P10 by 12.2% ($P<0.001$), but did not reach the relevant cut-off value ($\Delta\text{CSA} \geq 15\%$).

Conclusions: The application of PEEP at 10 cm and 15 cm H₂O in patients receiving mechanical ventilation with LMA insertion significantly increases the size of the RIJV. However, the overlap index between the RIJV and the RCCA increased as well.

MeSH Keywords: Carotid Artery, Common • Jugular Veins • Laryngeal Masks • Positive-Pressure Respiratio

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Background

The laryngeal mask airway (LMA) is frequently used as an effective and safe airway adjunct in general anesthesia [1,2]. In clinical practice, a situation arises occasionally where internal jugular vein (IJV) catheterization after LMA insertion is required [3,4]. However, the anatomical relationship between the IJV and the common carotid artery (CCA) changes significantly in patients after LMA insertion [4,5], that is, the degree of overlap between the IJV and CCA increases [5]. This finding means that there is a lower rate of successful IJV cannulation and a higher risk of CCA puncture after LMA insertion [5,6].

Previous research demonstrated that the use of positive end-expiratory pressure (PEEP) increased the cross-sectional area (CSA) of the IJV [7]. Similarly, Marcus et al. showed the level at which PEEP is effective and suggested that additional PEEP at 10 cm H₂O enhanced the beneficial effect of the Trendelenburg positioning on the CSA of the IJV [8]. However, the changes to the CSA of the IJV induced by PEEP may affect the degree of overlap between IJV and CCA, thus it is critical to investigate both the degree of overlap and changes in IJV size. In this study, we aimed to determine the effect of different PEEP levels on the CSA of the right IJV (RIJV) and the overlap index between the RIJV and the right CCA (RCCA), as measured by ultrasound, in mechanically ventilated patients with LMA insertion.

Material and Methods

Patients

This study was a prospective randomized clinical trial approved by the Ningbo No. 2 Hospital Institutional Review Board and Ethics Committee (PJ-NBEY-KY-2018-002-01) and registered prior to patient enrollment at chictr.org.cn (ChiCTR-TRC-14004871, principal investigator: Bo Lu, Date of registration: May 18, 2014). After obtaining written informed consent, 60 patients with American Society of Anesthesiologists (ASA) physical status I and II aged 20–65 years, who were scheduled for elective surgery under general anesthesia with LMA insertion were enrolled in our study. Exclusion criteria included previous neck trauma or surgery, preexisting lung disease, severe hypotension (>180/110 mmHg), extreme obesity (body mass index >35 kg/m²), stenosis or plaques of the carotis, thrombosis of the IJV, and predicted or confirmed presence of a difficult airway.

General management

Anesthesia was induced with sufentanil (0.2 µg/kg), propofol (2 mg/kg) and rocuronium (0.3 mg/kg) and was maintained with sevoflurane (2%). We selected the appropriate size LMA

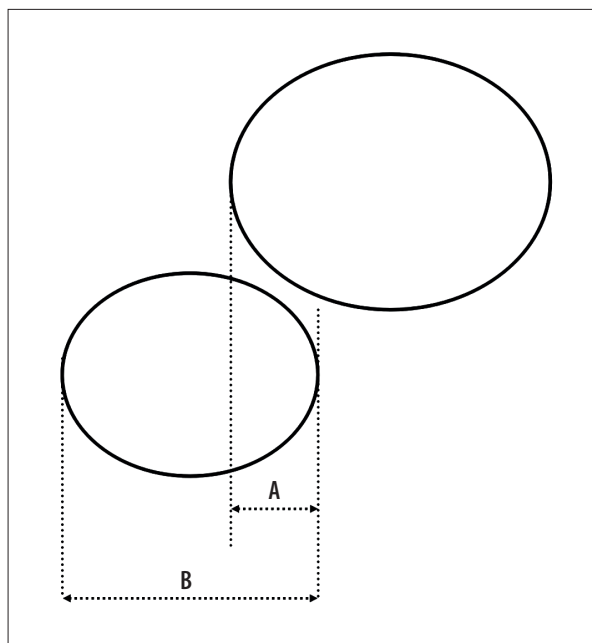


Figure 1. Overlap index is indicated. Overlap index=[overlap (cm)/CCA diameter (cm)] ×100%. A) Overlap of common carotid artery (CCA) and internal jugular vein (IJV); B) CCA diameter.

(LMA Supreme™, Singapore) based on the patient's weight (3#: 30–50 kg; 4#: 50–70 kg; 5#: >70 kg); the cuff pressure was controlled between 40–50 mmHg by adjust cuff volume. After LMA insertion, mechanical ventilation was conducted with a tidal volume of 8 mL/kg, a respiration rate of 12 breathes per minute and an I: E ratio of 1: 2. Optimal positioning of the LMA was defined by fiberoptic bronchoscopy (Olympus, Japan) if the placement of the tip was behind the arytenoids and visibility of the epiglottis was without folding or obstructing airway and visibility of the vocal cords.

Data collection

The patients were placed to a supine position and the head was rotated to the left 20°. Using a standardized technique, a 5- to 13-MHz linear array probe (Mindray Medical, Shenzhen, China) was applied perpendicularly to the skin with minimal pressure at the cricoid cartilage level to obtain an adequate sonographic image of the right IJV and CCA. While keeping the probe in the same position, the images of RIJV and RCCA were taken at the end of expiration after applying four different PEEPs in a random order: 0 (P0), 5 (P5), 10 (P10), and 15 (P15) cm H₂O. The CSA, transverse and anteroposterior (AP) diameters of the RIJV, and the overlap index between the RIJV and RCCA were measured after 1 minute of treatment at each PEEP. The formula used to calculate overlap index is as follows (Figure 1): IJV overlap (cm)/CCA horizontal diameter (cm) ×100% [5]. All measurements were determined

Table 1. Overlap index between RCCA and RIJV measurements.

PEEP (cm H ₂ O)	RCCA diameter (cm)	Overlap index [% (% increase)]
0	0.68±0.08 (0.66–0.70)	76.80±20.03 (71.62–81.97)
5	0.67±0.07 (0.65–0.69)	78.37±21.26 (72.87–83.86)
10	0.69±0.07 (0.68–0.71)	91.10±26.13 ^b (84.35–97.85) (18.6%)
15	0.70±0.07 (0.68–0.72)	96.21±25.36 ^c (89.66–102.80) (25.3%, 5.6%)

Values were presented as mean ± standard deviation (95% confidence interval). The percent increase of P10 is based on P0; The percent increase of P15 is based on P0 and P10, respectively. PEEP – positive end-expiratory pressure; RCCA – right common carotid artery; RIJV – right internal jugular vein; ^b *P*<0.01, ^c *P*<0.001 vs. PEEP 0 cm H₂O.

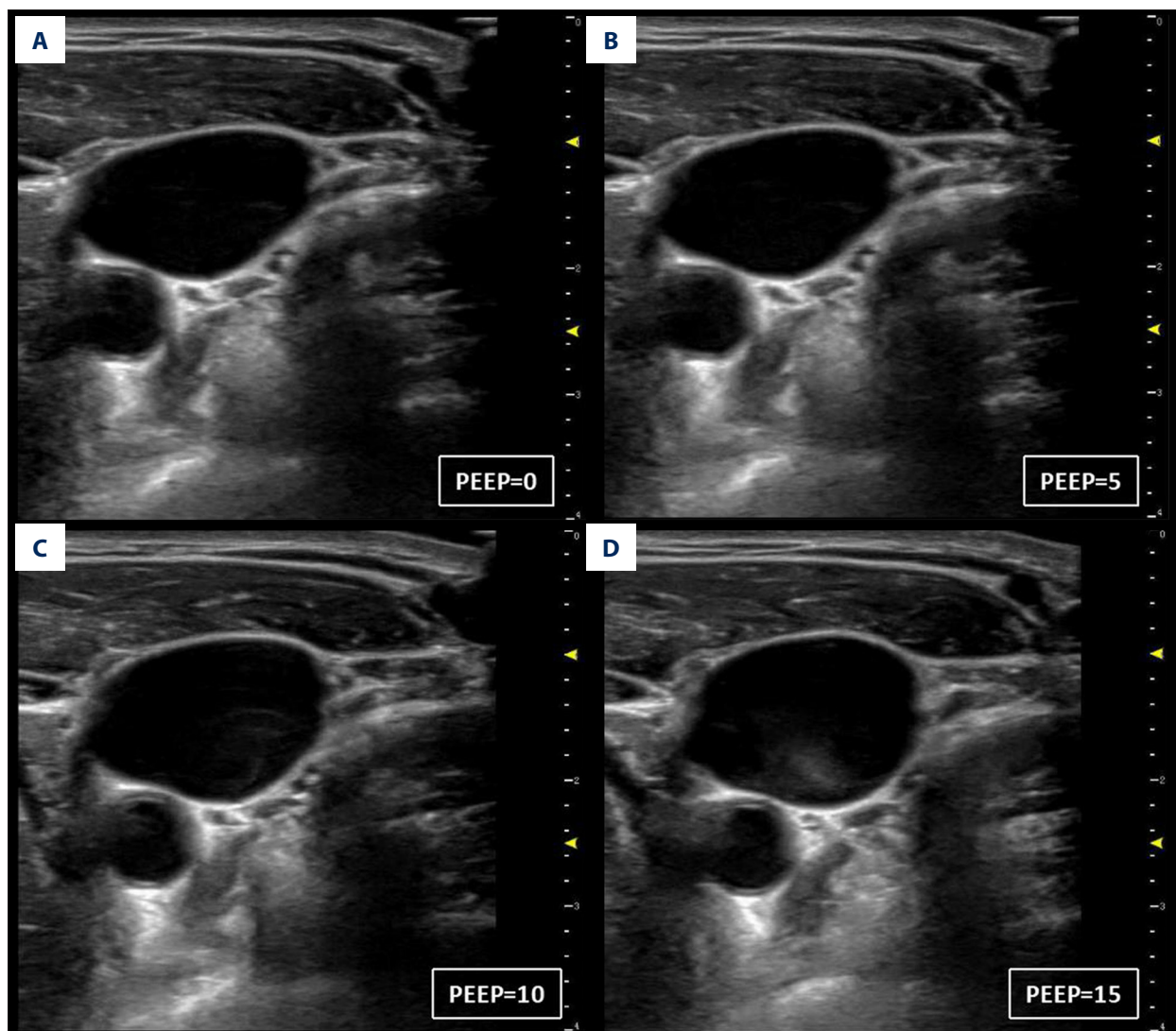


Figure 2. Ultrasonographic images of the internal jugular vein and the common carotid artery with the application of positive end-expiratory pressure (PEEP) at (A) 0 cm H₂O, (B) 5 cm H₂O, (C) 10 cm H₂O, and (D) 15 cm H₂O.

Table 2. Right IJV Measurements.

PEEP (cm H ₂ O)	CSA [cm ² (% increase)]	Transverse diameter [cm (% increase)]	AP diameter [cm (% increase)]
0	1.36±0.55 (1.22–1.50)	1.31±0.33 (1.23–1.40)	1.12±0.20 (1.07–1.17)
5	1.48±0.53 (1.34–1.61)	1.41±0.36 (1.32–1.51)	1.24±0.23 (1.18–1.29)
10	1.80±0.54 [#] (1.66–1.94) (32.3%)	1.61±0.49 ^b (1.48–1.74) (22.9%)	1.33±0.30 ^c (1.25–1.41) (18.8%)
15	2.02±0.58 ^c (1.87–2.17) (48.5%, 12.2%)	1.74±0.53 ^c (1.60–1.87) (32.8%, 8.1%)	1.46±0.32 ^c (1.38–1.54) (30.4%, 9.8%)

Values were presented as mean±standard deviation (95% confidence interval). The percent increase of P10 is based on P0; The percent increase of P15 is based on P0 and P10, respectively. PEEP – positive end-expiratory pressure; CSA – cross-sectional area; IJV – internal jugular vein; AP – anteroposterior. ^b *P*<0.01, ^c *P*<0.001 vs. PEEP 0 cm H₂O. [#] *P*<0.001 vs. PEEP 15 cm H₂O.

Table 3. Hemodynamic Variation with Application of PEEP.

PEEP (cm H ₂ O)	Mean arterial pressure (mmHg)	Heart rate (beats/min)
0	73.35±9.73 (70.84–75.86)	72.23±12.53 (69.00–75.47)
5	74.05±12.42 (70.84–77.26)	71.95±13.25 (68.53–75.37)
10	69.68±11.07 (66.82–72.54)	73.40±13.67 (69.87–76.93)
15	67.58±12.58 ^a (64.33–70.83)	75.02±13.01 (71.66–78.38)

Values were presented as mean ± standard deviation (95% confidence interval). PEEP – positive end-expiratory pressure; ^a *P*<0.05 vs PEEP 0 cm H₂O.

using the planimetry software provided by Mindray. A 15% difference in the CSA, transverse and AP diameters of the RIJV, overlap index was considered to be a relevant change. The same investigator (XJ A) obtained and stored all images to achieve consistency in measurements.

The hemodynamic variables, including arterial blood pressure and heart rate (HR), were monitored every minute during the study. Atropine (0.5 mg) was injected to treat bradycardia, defined as a decrease in the HR less than 45 beat per minute. Phenylephrine (100 µg) was given when the mean arterial blood pressure decreased 20% below the baseline value.

The primary outcome was the overlap index between RIJV and RCCA. The secondary outcome was CSA, and transverse and AP diameters of the RIJV at different PEEPs. In a pilot study, the overlap index of patients with LMA insertion was (0.76±0.20) ×100%, and 52 patients were required to detect a 15% difference in the overlap index at a significant *P*=0.05 and a power of 80%. Considering a 15% dropout rate, a sample size of 65 patients were aimed to be enrolled.

Statistical analysis

Repeated-measures analysis of variance (ANOVA) was used to analyze all variables, followed by a Bonferroni post hoc analysis for multiple comparisons. If the variables did not pass the Kolmogorov Smirnov test and Mauchly test, normal assumptions for repeated-measure ANOVA were applied after applying the additional q-q plot and Greenhouse-Geisser correction. A Bonferroni-corrected *P* value of <0.0125 was considered to be statistically significant for the comparisons (P0 versus P5, P10, and P15; P10 versus P15; 0.05/4=0.0125). Finally, statistical analysis was performed using SPSS 20.0 software (IBM Corporations, Chicago, IL, USA).

Results

Study population characteristics

Ultrasonographic images suitable for analysis were obtained from all patients (38 male patients and 22 female patients; 46.1±6.8 years of age; ASA I/II: 23/37; height, 166.3±7.2 cm; weight, 62.4±12.2 kg; body mass index, 22.7±5.1 kg·m⁻²). None of the patients were excluded.

Ultrasonic measurement of overlap index between RIJV and RCCA

The diameter of the RCCA did not change among the 4 treatment groups ($F=2.06$, $P=0.1071$). Compared to group P0, the overlap indexes of P10 and P15 were significantly increased by 18.6% and 25.3%, respectively (P10 versus P0, $P=0.0032$; P15 versus P0, $P<0.001$, Table 1, Figure 2), but without a significant trend toward further increases in PEEP up to 15 cm H₂O (P10 versus P15, $P=0.9001$).

Ultrasonic measurement of CSA, transverse and the AP diameter of the RIJV

PEEP at 10 cm and 15 cm H₂O increased CSA, transverse and AP diameter of the RIJV in comparison to PEEP at 0 cm H₂O (P10 versus P0, by 32.3%, 22.9%, and 18.8%; P15 versus P0, by 48.5%, 32.8%, and 30.4%; all $P<0.001$; Table 2, Figure 2). There was a statistically significant increase in CSA of the RIJV in P15 compared with P10 by 12.2% ($P<0.001$), but did not reach the relevant cutoff value ($\Delta\text{CSA} \geq 15\%$). Additionally, no significant trend toward further increases was seen in the transverse (P10 versus P15, by 8.1%, $P=0.4532$) and AP diameter (P10 versus P15, by 9.8%, $P=0.0676$) with increases in PEEP up to 15 cm H₂O.

Hemodynamic variation

There was no statistic difference in HR among the 4 treatment groups ($F=0.65$, $P=0.5867$, Table 3). Compared to P10, the MAP of P15 decreased by 7.9% ($P=0.0301$). None of the patients were given atropine or phenylephrine.

Discussion

Our results demonstrate that the overlap index between the RIJV and RCCA increased when PEEP of 10 cm and 15 cm H₂O was applied in patients receiving mechanical ventilation with LMA insertion. Notably, application of PEEP at 10 cm and 15 cm H₂O also increased the size (CSA, transverse and AP diameter) of the RIJV.

Hollenbeck et al. showed that the application of PEEP at 10 cm H₂O increased the CSA of the IJV by 41% in anesthetized tracheal-intubated patients [7]. In patients under mechanical ventilation with LMA insertion, our study suggests that PEEP 10 cm and 15 cm H₂O can also increase the CSA, transverse and AP diameter of the IJV. Furthermore, when PEEP increased to 15 cm H₂O, the CSA, transverse and AP diameter did not increase further. This accompanied a decrease in MAP by 7.9% compared with P0. Although, all patients did not need intervention with vasoactive drugs, this does not imply that the application of PEEP in 15 cm H₂O is safe for critically ill patients.

This finding suggests that a PEEP of 10 cm H₂O may better balance the increase in IJV size and maintenance of hemodynamic stability; a conclusion consistent with previous studies that PEEP gave the largest CSA at 12 cm H₂O [9].

CCA injury is a serious complication of IJV catheterization [10,11]. Following the insertion of LMA, the anatomy and positional relationship between the IJV and CCA changes in a manner that increase both the difficulty of IJV puncture and the risk of accidentally puncturing the CCA [3–5]. Our study found that an increase in PEEP from 0 cm to 15 cm H₂O was accompanied by an increase in the overlap index from 76.8% to 96.2% and in some patients the CCA was completely covered by the IJV. We speculate that this was due to the increase of CSA and transverse diameter, which causes the CCA to be covered by more IJV. On the one hand, an increase IJV size may be beneficial to improve the success rate of puncture and reduce the risk of accidentally puncturing the CCA; on the other hand, the increase in overlap index may increase the risk of CCA injury. These conflicting eventualities suggest that clinical practitioners must weigh the advantages and disadvantages of apply PEEP cautiously before proceeding with IJV puncture procedures.

There are several limitations to this study. First, only ASA I or II status patients were studied, therefore the effect of PEEP on elderly or critically ill patients was not examined. Second, actual catheterization was not performed so the success rate of IJV catheterization and the incidence of complications could not be determined with respect to PEEP levels. Third, all of the outcome variables were measured with patients in the horizontal position. Previous studies have reported that Trendelenburg position can increase CSA of the IJV as well [8,12]. If Trendelenburg position was applied in this study, the results of the overlap index may have been different. Fourth, in the present study, the investigator was aware of PEEP levels applied, the non-blinded character could have led to bias. Fifth, high levels of PEEP might also influence the overlap index by changed expansion of the lungs leading to the alteration of the ultrasound plane. Finally, ultrasound images were obtained only at the level of cricoid cartilage but not at the high and low levels of the neck. However, the primary objective in this study was the effect of different PEEP levels on the overlap index.

Conclusions

The application of PEEP at 10 cm and 15 cm H₂O in patients receiving mechanical ventilation with LMA insertion significantly increases the size of the RIJV. However, the overlap index between the RIJV and the RCCA increased as well. A large randomized control trial is still needed to investigate the effect of PEEP on the success rate of IJV puncture and the incidence of CCA puncture in patients with LMA placement.

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Conflict of interests

None.