Int J Clin Exp Med 2019;12(7):8999-9004
www.ijcem.com /ISSN:1940-5901/IJCEM0087852

Original Article

Appropriate pressure for facemask ventilation during induction of general anaesthesia in adult patients: measurement of antral cross-sectional area by real-time ultrasonography

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Received November 4, 2018; Accepted May 7, 2019; Epub July 15, 2019; Published July 30, 2019

Abstract: Objective: An increase in pressure for facemask ventilation, which leads to gastric induction, is the major cause of reflux and aspiration during induction of anaesthesia. Recent studies have indicated that reflux and aspiration during induction can still occur even if patients fast for 8 hours prior to surgery, and such reflux and aspiration are related to increasing pressure for facemask ventilation when part of the gas migrates into the gastric cavity. However, appropriate pressure for facemask ventilation can not only ensure adequate oxygen supply but can also reduce gas entry into the stomach, although such appropriate pressure has not been obtained in adults. In the current study, the aim was to determine the ED_{50} and ED_{95} of pressure for facemask ventilation in adult patients by measurement of antral cross-sectional area (CSA) using ultrasound during induction of general anaesthesia. Methods: Thirty-one American Society of Anesthesiology (ASA) physical status I-II patients undergoing elective operation (age up to 18 years old and body mass index less than 30 kg/m^2) were enrolled. The modified up-and-down method included two steps. The first step involved patients receiving 15 cmH_2O for facemask ventilation by inspiratory pressure during pressure-controlled ventilation. The pressure adjustment space was 2 cmH_2O. The second step resumed the up-and-down sequence results at the closest level with the previous test interval. The pressure adjustment space was 1 cmH_2O. The appropriate pressure for facemask ventilation was defined as cross-sectional area (CSA) < 340 mm^2 and a tidal volume of more than 6 mL/kg. The antral CSA was measured using real-time ultrasonography before and after facemask ventilation. Respiratory parameters were recorded. Results: CSA in all patients was less than < 340 mm^2 before and after facemask ventilation. The number of patients with a tidal volume more than 6 mL/kg was sixteen. The ED_{50} and ED_{95} of pressure for facemask ventilation were 12.31 cmH_2O (95% CI, 11.90~12.67 cmH_2O) and 13.12 cmH_2O (95% CI, 12.74~14.35 cmH_2O), respectively. Conclusion: The ED_{50} and ED_{95} of pressure for facemask ventilation during induction of general anaesthesia in adult patients were 12.31 cmH_2O and 13.12 cmH_2O, respectively.

Keywords: Facemask, ultrasonography, antral area, ventilation pressure

Introduction

General anaesthesia may expose patients to aspiration of gastroesophageal contents because of disappearance of pharyngeal reflexes and can result in morbidity and mortality attributable to aspiration pneumonitis [1, 2]. In addition, in spite of full abstinence and fasting prior to surgery [3, 4], patient pain, delayed gastric emptying (DGE) and other factors often increase the risk of vomiting and aspiration. The techniques for preventing vomiting and aspiration during general anaesthesia can be summarized as follows: cricoid pressure, the use of postural changes, pre-oxygenation without lung inflation, and the placement of gastric tube preoperatively [5]. These techniques give us a relatively clear indication that the most effective way to reduce the occurrence of vomiting and aspiration is closely related to lowering gastric pressure during general anaesthesia. The sensitivity of gas into the gastric cavity, which was determined by auscultation, was low in past studies. Previous reports [6] have shown that application of ultrasonic examination can be a new mathematical model predictive of gastric volume has important clinical value. Furthermore, the volume of the gastric antrum can be qualitatively and quantitatively analysed by ultrasound, which might be applied to measure the volume of the stomach as the gas is pumped into it [7]. Therefore, different degrees of volume changes caused by different facemask ventilation pressure can be detected in real-time. Hence, in the present study, a modified up-and-down method was used to measure the cross-sectional area (CSA) of the antrum by real-time ultrasound to determine the ED_{50} and ED_{95} for facemask ventilation in adult patients during induction of general anaesthesia.

Patients and methods

Patient selection

This study was approved by the Ethics Committee (the First People's Hospital of Kunshan, PR China) and written informed patient consent was obtained. Thirty-One American Society of Anaesthesiologists physical status I or II patients undergoing elective operation (age up to 18 years old and body mass index less than 30 kg/m^2) were enrolled in this Dixon sequential study. Exclusion criteria were as follows: expected difficulty of mask ventilation, pregnancy, and placement of preoperative gastrointestinal decompression tube.

Study protocol

Preoperative fasting and abstinence for 8 hours was enforced. The patient was in recumbent position. Routine monitoring was performed by entering the operating room, involving noninvasive arterial blood pressure monitoring, electrocardiography, pulse oximetry and end-tidal CO_2 pressure ($PetCO_2$). There were 2 minutes of spontaneous breathing before the induction of general anaesthesia. Anaesthesia was induced with 0.05 mg/kg intravenous midazolam in turn (batch number: 20140806, Jiangsu Nhwa Pharmaceutical Co., Ltd), 0.3 mg/kg etomidate fat emulsion (batch number: 20140903, Jiangsu Nhwa Pharmaceutical Co., Ltd), 4 ug/kg fentanyl (batch number: 1140411, hubei yichang f Pharmaceutical Co., Ltd.), and 0.6 mg/kg rocuronium (batch number: 140801, Zhejiang Xianju Pharmaceutical Co., Ltd). Oropharyngeal airways were placed to the depth of the length of the nose to the earlobe after disappearance of the eyelash reflex and complete muscle relaxation. The same anaesthesia physician (more than 5 years working experience) performed a two-handed jaw-thrust technique, and an anaesthesia machine (Draeger, Germany) with implemented pressure-controlled ventilation was used for 2 minutes. Ventilation parameters: oxygen concentration 60%, oxygen flow rate of 3 L/min, ventilation frequency of 12 times /min, and suction ratio 1:2. The setting values for ventilation pressure received by a patient depended on the previous patient's response to the up-and-down sequential method. The spacing of the arithmetic sequence was 2 cmH_2O. If a CSA after induction less than 340 mm^2 and tidal volume less than 6 mL/kg were inappropriate, the following ventilation pressure was increased by 2 cmH_2O. Similarly, if a CSA more than 340 mm^2 and tidal volume more than 6 mL/kg of a patient were also unsuitable, the following ventilation pressure was reduced by the same pressure. The first patient received 15 cmH_2O for facemask ventilation by inspiratory pressure during pressure-controlled ventilation. To increase the accuracy of the experimental results, the interval of airway pressure was adjusted on the basis of the original experiment. This modified up-and-down experiment was divided into two steps: The first stage was the original upper and lower sequence of the equal-spaced pressure until the three changes of the response type appeared. The second step was to reduce the spacing of the initial ventilation pressure, which continued at the closest level of the original test. The second test interval was adjusted to 1 cmH_2O. CSA was measured by real-time ultrasound (SonoSite company, USA) (**Figure 1A**). The probe frequency was 2.0~5.5 mhz. The ultrasonographic images included the left lobe of the liver and the abdominal aorta. CSA was calculated using the formula $\pi \times D1 \times D2 \div 4$ (D1 vertical axis diameter; D2 anteroposterior diameter) (**Figure 1B**). Tidal volume and CSA (measured by the same doctor) were achieved before and after facemask ventilation. The appropriate pressure for facemask ventilation was defined as CSA < 340 mm^2 [8] and a tidal volume more than 6 mL/kg [9].

Statistical analyses

SPSS 23.0 (SPSS Inc., Chicago, IL, USA) software was used for statistical analysis of this

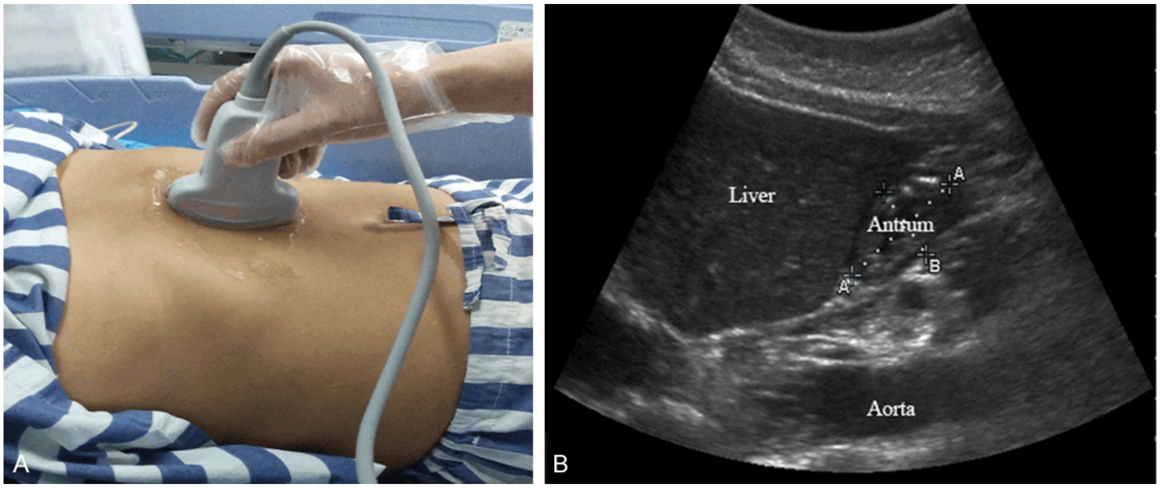

Figure 1. A: The ultrasonic probe was placed at the inferior xiphoid of the patient. B: Method of measurement based on two perpendicular diameters (cranio-caudal and antero-posterior).

Table 1. Demographic profile of study participants

Characteristics	Variables	Overall patients (n = 31)
Age (years, mean ± SD)		49 ± 16
Gender	Male	14 (45)
	Female	17 (55)
Anthropometric characteristics (mean ± SD)	Height (cm)	165.0 ± 7.1
	Weight (kg)	62.0 ± 11.0
	BMI (kg/m^2)	23.2 ± 2.7
Marital status	Married	28 (90)
	Single	3 (10)
Smoking status	Current smoker	13 (42)
	Ex-smoker	7 (23)
	Non-smoker	11 (35)
Employment status	Employed	28 (90)
	Unemployed	3 (10)

Table 2. Measurements of CSA and surgical procedures

Measures	Variables	Overall patients (n = 31)
CSA	Before induction (mm^2)	239.8 ± 59.4
	After induction (mm^2)	289.2 ± 43.5**
Tidal volume (ml)		422 ± 77
Duration surgery (min)		128 ± 41

Data are presented as mean ± SD, **P < 0.01 using by paired-samples T test versus before induction.

test. Measurement data (Age, Anthropometric characteristics, the figures of CSA, Tidal volume and Duration surgery) was presented as the mean ± standard deviation (SD). Counting data (Gender, Marital status, Smoking status and Employment status) is expressed in absolute values and rate when appropriate. CSA before and after induction was analysed by paired-samples T test. The ED_{50}, ED_{95} and 95% confidence interval (CI) pressure for facemask ventilation were obtained by Probit analysis.

Results

Thirty-one patients were screened and included. The analysis was performed on the data from the 31 remaining patients. The characteristics of these patients in this study are shown in **Table 1**. The CSA before facemask ventilation was significantly lower than CSA after facemask ventilation ($P < 0.01$) (**Table 2**).

The ED_{50} and ED_{95} of the appropriate pressure for facemask ventilation during induction of general anaesthesia in adult patients were 12.31 cmH_2O (95% CI, 11.90~12.67 cmH_2O) and 13.12 cmH_2O (95% CI, 12.74~14.35 cmH_2O), respectively (**Figures 2**, **3**).

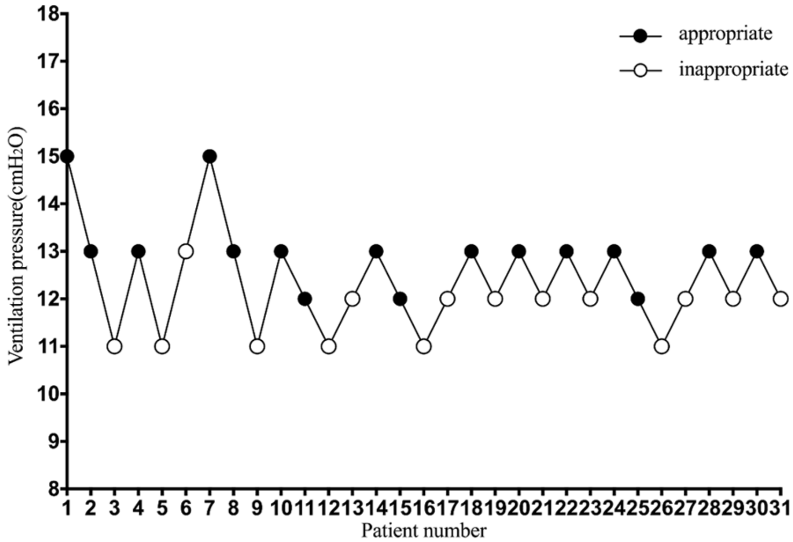

Figure 2. Sequence of patients receiving facemask ventilation. Appropriate ventilation pressure was defined as CSA < 340 mm^2 and a tidal volume more than 6 mL/kg. Values not in this range were inappropriate.

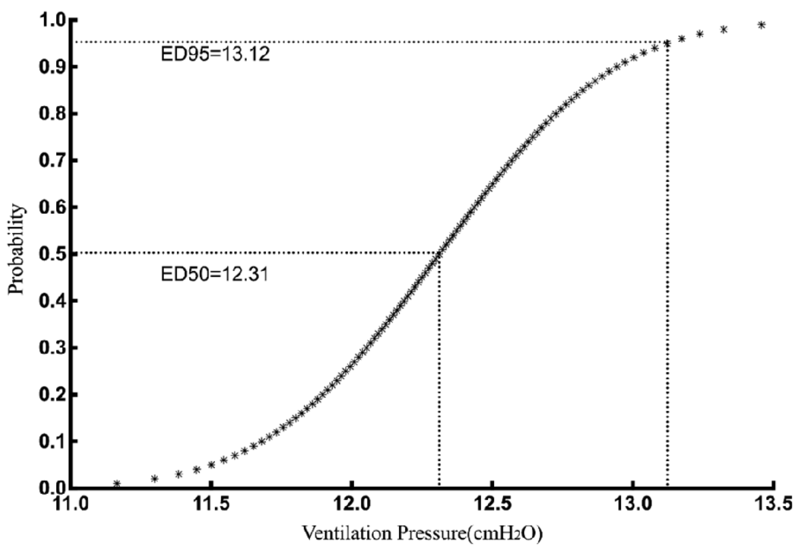

Figure 3. Pressure curve for facemask ventilation during induction of general anaesthesia in adult patients

Discussion

Many methods are applied in clinical practice to assess gastric volume, including epigastric auscultation, magnetic resonance imaging and ultrasound. Several studies have previously shown that the incidence of gastric insufflations increased with inspiratory pressure during the induction of general anaesthesia, with a threshold of 20 cmH_2O [10] in adults and 15 cmH_2O [11] in children by epigastric auscultation. These values are significantly higher than those of this study, which used ultrasonography. Research shows that when auscultation is used, a large amount of diagnostic gas with a mask ventilation pressure of 20 cmH_2O enters the gastric cavity [12]. This difference may be in part attributed to the fact that auscultation is far less sensitive than real-time ultrasound. Auscultation is easily disturbed by personal subjective factors, which can only be caught when the stomach intake accumulates quantitatively. In addition, one study [13] described MRI examination of the stomach that was performed with a slice thickness of 6 mm without a gap, using an 8-channel and 8-element phased array coil that covered the entire stomach area. This detection can fully display the rhythmic movement of the stomach and quantitatively calculate the stomach volume, and is thus more accurate than ultrasonography. However, Magnetic Resonance Imaging is suitable for comprehensive preoperative evaluation of gastric function and fasting conditions. It is not possible to quickly monitor gastric intake during induction of general anaesthesia. In this experiment, ultrasound as a noninvasive instrument can judge the stomach inlet quickly and efficiently. This study shows that CSA of all patients increased a certain extent more after ventilation than it did before ventilation. Hence, ultrasound as a portable tool can judge the volume of the stomach quickly and efficiently.

With the use of ultrasound in clinical anaesthesia, real-time ultrasound is adopted to accurately and reliably predict CSA [6]. Studies have shown that CSA ≥ 340 mm^2 [8] is a risk threshold for diagnosis of pulmonary aspiration. A tidal volume of 6 ml/kg [9] is the minimum threshold for mechanical ventilation. Therefore, this study used a CSA < 340 mm^2 and tidal volume ≥ 6 ml/kg to assess the appropriate mask ventilation pressure. In this study, the first patient received 15 cmH_2O [14] initial pressure, and two patients who underwent anaesthesia with the same pressure turned out to have the appropriate pressure. However, the modified up-and-down method was used to conclude that the lower airway pressure was also suitable for lung ventilation. In the previous studies [14, 15], the mask ventilation pressure was artificially divided into equal groups, and the conclusions obtained may be biased. This improved method can improve the accuracy of the final estimator and reduce the mean squared error under normal tolerance distribution. It has also been proven to be much better than the random grouping method. The initial pressure is a valid measurement and the next test results prove that CSA is within the normal range. The modified up-and-down method was used to determine that the ED_{50} and ED_{95} of pressure for facemask ventilation were 12.31 cmH_2O and 13.12 cmH_2O, respectively. It is worth noting that the area of the gastric antrum was significantly rising after facemask ventilation, which proved that the facemask ventilation does increase the risk of aspiration pneumonia [16].

One double-blind study [15] concluded that an inhalation pressure of 12 cmH_2O was sufficient to provide adequate ventilation in paralyzed children between 2 and 4 years old. The incidence of intra-gastric injection was lower under this pressure. The results of this experiment are fundamentally consistent with those of the adults in our experiment. The minimal difference can be attributed in part to the use of non-depolarizing muscle relaxants in that trial. In addition, the oesophageal sphincter of children is immature compared with that of adults, and so the tone of the oesophageal sphincter is less tense in children. Therefore, non-depolarizing muscle relaxants will further aggravate the function of the oesophageal sphincter, and gas will more easily enter the gastric cavity [17, 18].

To prevent the patients' increased airway resistance caused by the tongue after entrance of mask ventilation gas into the gastric cavity, this study's mask ventilation was placed before the oropharyngeal airway by anaesthesia doctors with more than 5 years of working experience. In this study, there were many limitations in our experiment. First, this research was conducted in a non-blind manner and the anaesthesiologist knew about the group assignments, which may cause observer bias. Second, studies have shown that the correlation between CSA and gastric contents is stronger in the right lateral position [6]. However, because the right lateral position of the patient is not convenient for clinical operation after general anaesthesia, the CSA is measured in the horizontal position. Third, excessive obesity and pregnancy status affected CSA measurement [6, 19], and so this study excluded patients with a BMI of more than 30 kg/m^2, which reduced the difficulty of traditional operation. The sample size of this study was limited and the test efficiency was low, which also may lead to the bias of the results.

Above all, the ED_{50} and ED_{95} of pressure for facemask ventilation during induction of general anaesthesia in adult patients were 12.31 cmH_2O (95% CI, 11.90~12.67 cmH_2O) and 13.12 cmH_2O (95% CI, 12.74~14.35 cmH_2O), respectively. This pressure can ensure adequate oxygen to patients and reduce the gas that enters the stomach cavity. Therefore, this pressure can reduce the risk of aspiration and has potential for clinical application.

Acknowledgements

This work was supported by the Scientific and Technological Special Project of Kunshan (KS-1716), and the Medical Clinical Science and Technology Development Fund of Jiangsu University (JLY20180010).

Disclosure of conflict of interest

None.

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