Original Article

The effect of force applied to the left paratracheal oesophagus on air entry into the gastric antrum during positive-pressure ventilation using a facemask

N. Gautier,[1] **J. Danklou,**[2] **J. F. Brichant,**[3] **A. M. Lopez,**[4] **C. Vandepitte,**[5] **M. M. Kuroda,**[6] **A. Hadzic**[7] and **P. E. Gautier**[8]

1 Registrar, Department of Anesthesiology, University of Louvain, St Luc Hospital, Brussels, Belgium
2 Registrar, 3 Professor, Department of Anesthesia and Intensive Care Medicine, Liege University Hospital, Liege, Belgium
4 Associate Professor, Department of Anesthesiology, Hospital Clinic de Barcelona, Barcelona, Spain
5 Consultant, 7 Professor, Department of Anesthesiology, Intensive Care, Emergency Medicine and Algology, ZOL, Genk, Belgium
6 Epidemiologist-Biostatistician, New York School of Regional Anesthesia (NYSORA), New York, USA
8 Head of Department, Service D'Anesthesie, Clinique St Anne-St Remi, CHIREC, Bruxelles, Belgium

Summary

Cricoid force is widely applied to decrease the risk of pulmonary aspiration and gastric antral insufflation of air during positive-pressure ventilation, yet its efficacy remains controversial. We compared manual oesophageal compression at the low left paratracheal and cricoid levels for the prevention of gastric antral air insufflation during positive-pressure ventilation by facemask in patients scheduled for elective surgery under general anaesthesia. After gaining written consent, participants were randomly allocated by sealed envelope to one of three groups: oesophageal compression by 30 N paratracheal force (paratracheal group); oesophageal compression by 30 N cricoid force (cricoid group); or no oesophageal compression (control group). Gastric insufflation of air was assessed before and after positive-pressure ventilation by ultrasound measurement of the antral cross-sectional area and/or presence of air artefacts in the antrum. The primary outcome measure was the proportion of participants with ultrasound evidence of gastric insufflation. We recruited 30 patients into each group. Before facemask ventilation, no air artefacts were visible in the antrum in any of the participants. After facemask ventilation of the participant's lungs, no air artefacts were seen in the paratracheal group, compared with six subjects in the cricoid group and eight subjects in the control group ($p = 0.012$). Our results suggest that oesophageal compression can be achieved by the application of manual force at the low left paratracheal level and that this is more effective than cricoid force in preventing air entry into the gastric antrum during positive-pressure ventilation by facemask.

Correspondence to: P.E. Gautier
Email: p.gautier@skynet.be
Accepted: 6 August 2018
Keywords: aspiration management; cricoid force; rapid sequence induction; upper airway compression
This article is accompanied by an editorial by Naik and Frek, *Anaesthesia* 2019; **74**: 6–8.

 © 2018 Association of Anaesthetists

Introduction

Cricoid force is used to decrease the risk of pulmonary aspiration of regurgitated stomach contents and to avoid gastric insufflation during positive-pressure ventilation under general anaesthesia [1–3]. The manoeuvre consists of manual force applied at the cricoid level to collapse the upper oesophageal sphincter against the vertebral bodies of the cervical spine [1]. Reported cases of failure to protect the airway suggest that cricoid force may not be consistently applied due to: operator factors (hand position or amount of force applied); patient factors (neck circumference); and/or anatomical factors (location of the oesophagus) [4,5]. Indeed, oesophageal closure may not be complete because the oesophagus lies on the left side in up to 50% of patients [6] and may be further displaced to the left when cricoid force is applied [7–9].

Using an ultrasound transducer, Andruszkievicz et al. recently demonstrated that the oesophagus can be compressed on the left paralaryngeal side at the cricoid level. However, at this level, the oesophagus could not be visualised by ultrasound in 13% of the subjects studied [10]. We hypothesised that a more distal paratracheal approach may allow the oesophagus to be identified on ultrasound more consistently, and that force applied at this level would be more effective than cricoid force in the prevention of gastric air insufflation during positive-pressure ventilation by facemask.

In this study, we aimed to: evaluate the ability to visualise the oesophagus at the low left paratracheal level using ultrasound; investigate whether the application of force at the low left paratracheal level using an ultrasound transducer would result in oesophageal compression as assessed by a decrease in anteroposterior diameter; and to compare the effectiveness of digital compression (using the thumb in place of the ultrasound transducer) at the low left paratracheal and cricoid levels in preventing air entry into the gastric antrum during positive-pressure ventilation by facemask.

Methods

The study was approved by the local ethics committee. Patients were eligible for inclusion if they were: ASA physical status 1–2; aged 18–65 years; scheduled for elective surgery under general anaesthesia; and at minimal risk of pulmonary aspiration from gastro-oesophageal reflux. Patients were not studied if they met any of the following criteria: body mass index (BMI) > 35 kg.m^{-2}; suspected difficult facemask ventilation and/or tracheal intubation; and/or previous gastric surgery. All participants had been fasted for at least 6 h for solids and 2 h for clear liquids before their surgery. No premedication was given before the study interventions.

Oesophageal examinations were conducted with the subject supine and their head in a neutral position (elevated on an 8 cm headrest, without rotation or extension). A linear ultrasound transducer (Applio XG iStyle Toshiba with a 14–7 MHz probe; Toshiba Medical Systems Corporation, Tochigi, Japan) was positioned in a transverse (axial) orientation over the left paratracheal area, just above the clavicle. The presence of the oesophagus on the left side of the trachea was recorded as seen or not seen. When the oesophagus was identified, the anteroposterior diameter was measured and compared before and after application of a 30 ± 5 N force (Fig. 1a). Oesophageal compression was assessed in the paramedian sagittal plane between the trachea and sternocleidomastoid muscle with the oesophagus in the sagittal plane (Fig. 1b). Anteroposterior diameter measurements were repeated before and after applying force with the transducer. Three consecutive measurements for each transducer position were recorded.

Subjects in whom the oesophagus could be visualised at the low left paratracheal level were randomly allocated (1:1:1) by sealed envelopes to oesophageal compression by 30 N paratracheal force (paratracheal group); oesophageal compression by 30 N cricoid force (cricoid group); or no oesophageal compression (control group).

With the subject in the supine position, a curvilinear transducer (Applio XG iStyle Toshiba with a 8–5 MHz probe; Toshiba Medical Systems Corporation) was placed on the epigastrium in a paramedian sagittal orientation to identify the gastric antrum [11]. The cross-sectional area of the antrum was measured at the level where both the aorta and upper mesenteric artery were visible [11, 12]. Three consecutive measures were taken before induction of general anaesthesia. Standard monitoring was then applied, and anaesthesia induced with propofol 2.5 mg.kg^{-1} administered over 45 s and remifentanil (1 μg.kg^{-1} over 60 s during induction, followed by continuous infusion 0.05 μg·kg^{-1}.min^{-1}). No neuromuscular blockade was used. Oesophageal compression was then instituted in the paratracheal and cricoid groups. Two anaesthetic trainees, not informed of the study outcome measurements, were trained to apply sustained force of 30 ± 5 N using an electronic dynamometer (MicroFET2; Hoogan Industries, West Jordan, UT, USA). This method has been described previously for training operators to apply a consistent amount of force to a measurement device such as a weight scale. The trainees had practised the paratracheal and cricoid manoeuvres until 10 consecutive manoeuvres were measured successfully (30 ± 5 N). To apply paratracheal

© 2018 Association of Anaesthetists

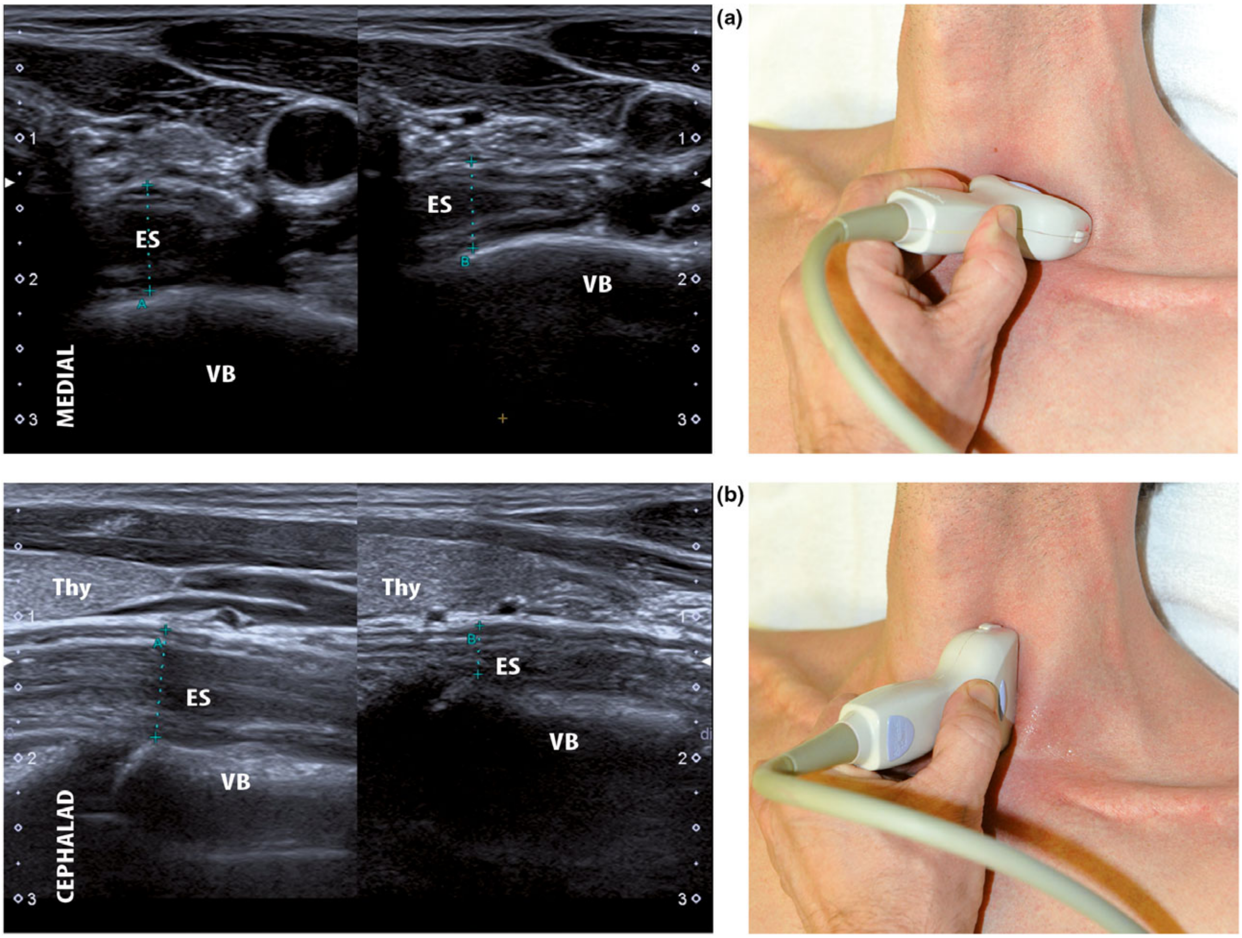

Figure 1 Axial (a) and sagittal (b) views of the oesophagus before and after low left paratracheal compression with an ultrasound transducer. ES, oesophagus; Thy, thyroid; VB, vertebral body.

force, the thumb was placed over the left side of the trachea cephalad to the clavicle and medial to the sternocleidomastoid muscle (Fig. 2), and for cricoid force, the cartilage was compressed with a single-handed three-finger manoeuvre towards the vertebral bodies [1]. The participant's lungs were then ventilated using positive-pressure ventilation via a facemask with an inspiratory pressure of 25 cmH_2O (Zeus ventilator, Dräger, Lübeck, Germany), which has been shown to produce gastric distension and an increase in antral cross-sectional area [11]. The initial ventilator settings were: F_IO_2 1.0; inspiration:expiration ratio 1:2; 15 $breaths.min^{-1}$; and no positive end-expiratory pressure. Adequacy of ventilation was ensured by: chest rise; square, regular capnograph trace; end-tidal carbon dioxide 3.9–5.3 kPa; and tidal volume 6–10 $ml.kg^{-1}$.

After 3 min of ventilation, the gastric ultrasound examination was repeated in an identical manner to that described earlier. The presence of gastric air insufflation was defined as an increase in antral cross-sectional area and/or presence of air artefacts in the antrum (comet tail, posterior acoustic shadow) [11]. These assessments were performed by a sonographer blinded to group allocation by a surgical drape placed between the subject's thorax and abdomen.

The sample size calculation for this study was estimated on the Bouvet et al. study that examined gastric insufflation at inspiratory pressures of 10, 15, 20 and 25 cmH_2O [11]. The proportion of subjects with gastric insufflation ranged from 20% to 60% at these inspiratory pressures. In order to detect a similar difference, 25 subjects per group were required ($\alpha < 0.05$, β 0.85). This was increased to 30 to ensure sufficient numbers after evaluating oesophageal visualisation and compressibility. Differences in antral cross-sectional area were compared using paired t-tests and one-way ANOVA, with Bonferroni correction as appropriate. The proportion of subjects showing the presence of air artefacts was compared using the chi-square test. A p value < 0.05

 © 2018 Association of Anaesthetists

Figure 2 For paratracheal compression applied manually, the thumb is positioned just cephalad to the clavicle between the trachea and the sternocleidomastoid muscle. A force of 30 N is applied to compress the oesophagus against the vertebral body.

was deemed significant. The Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows (v22.0); IBM Corporation, Armonk, NY, USA) was used for the analyses.

Results

Study recruitment is shown in Figure 3; 90 subjects completed the study (30 in each group). Baseline characteristics were similar in all three groups (Table 1). The oesophagus was identified at the left paratracheal level in all 90 patients. The anteroposterior diameter of the oesophagus was reduced by applying a force of 30 $\pm$ 5 N with the ultrasound transducer. Mean overall reduction was 29% in the axial (mean (SD) diameter 9.3 (1.8) mm before and 6.6 (1.4) mm after compression; $p < 0.001$) and 37% in the sagittal view (mean (SD) diameter 8.7 (1.5) mm before and 5.5 (1.5) mm after compression; $p < 0.001$). Proportional reduction in oesophageal diameter with the application of 30 N force did not differ between men and women in the axial (mean (SD) percentage decrease 28.1 (9.9)% vs. 28.7 (8.3)%, respectively) or sagittal (mean (SD) percentage decrease 32.9 (11.2)% vs. 37.8 (12.8)%, respectively) views. Percentage reduction in oesophageal diameter was not related to neck circumference ($r = -0.135$ axial view; $r = -0.020$ sagittal view).

At baseline, no air artefacts were found in the gastric antrum of any subject. After positive-pressure ventilation of the lungs for 3 min, no subject in the paratracheal group had gastric antral air artefacts, but these were found in six and eight patients in the cricoid and control groups, respectively ($p = 0.012$). Moreover, in patients in whom air artefacts were present, there was a significant increase in antral cross-sectional area compared with those subjects in whom air artefacts were absent (Table 2). Antral cross-sectional area was unchanged in the paratracheal and cricoid groups after ventilation of the lungs, but did increase in the control group (Table 2).

Discussion

We have demonstrated that the oesophagus can be identified using ultrasound at the low left paratracheal level, and that compression of the oesophagus by the ultrasound transducer at this level reduces its anteroposterior diameter by about one-third. In contrast, Andruszkievicz et al. reported that the oesophagus can be visualised ‘paralaryngeally’ at the cricoid level in only 87% of study subjects [10]. One possible explanation for the lower rate of visualisation is that the oesophagus deviates from the midline towards the left in its descent [13], making it more visible and accessible for compression distally at the paratracheal level.

Digital paratracheal force applied to the oesophagus was effective at preventing air insufflation into the gastric antrum during positive-pressure ventilation of the lungs via a facemask. Several methods have been used to study the ability of cricoid compression to occlude the oesophagus. Most of the evidence supporting its effectiveness in preventing aspiration of regurgitated contents comes from studies demonstrating its efficacy in preventing gastric insufflation during facemask ventilation in children and adults [3, 14]. However, previous studies used less sensitive air detection methods than ultrasound, such as auscultation by a stethoscope over the epigastrium. Bouvet et al. showed that ultrasonography was more sensitive than auscultation in the detection of gastric air insufflation at different inspiratory pressures [11]. Cricoid compression is an indirect manoeuvre that aims to occlude the upper oesophagus or hypopharynx against the vertebral bodies [15], assuming that the relevant structures are adequately aligned for an effective manoeuvre. In contrast, paratracheal compression is a direct manoeuvre on the oesophagus against the vertebral bodies and prevertebral muscles that can be applied with the ultrasound transducer under direct view or applied blindly by pressing with the thumb.

There are some limitations to our study. First, although the research staff were trained on mannikins before the procedures in subjects, improper application of paratracheal and cricoid force cannot be ruled out. Second, since obese patients and those with potentially difficult airways were not studied, the efficacy of low left paratracheal compression is uncertain in these patient

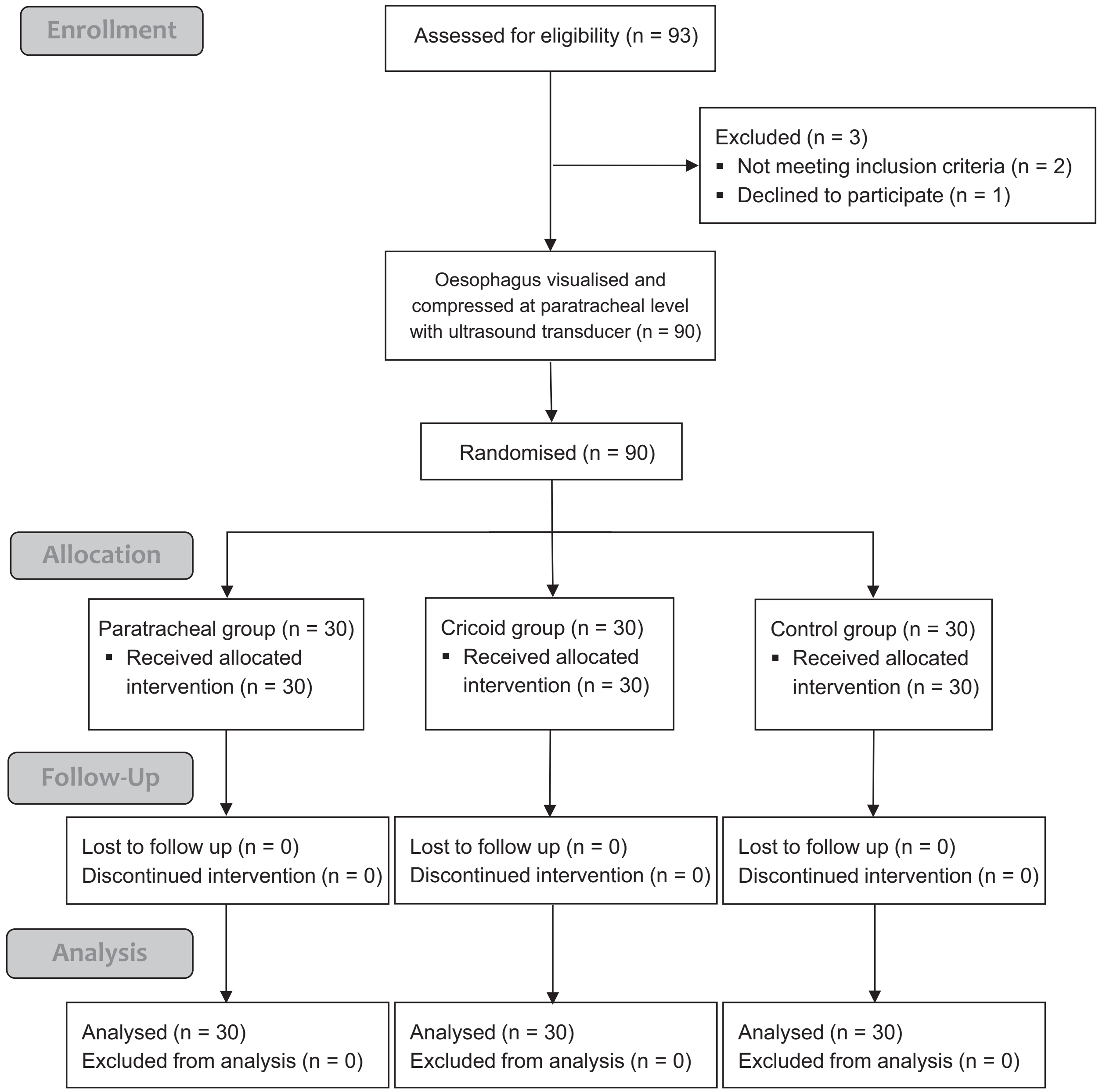

Figure 3 CONSORT flow diagram.

Table 1 Baseline characteristics of participants undergoing oesophageal compression at the low left paratracheal level (paratracheal group) or cricoid level (cricoid group). Participants in the control group had no oesophageal compression applied. Values are mean (SD) or number.

	Paratracheal group (n = 30)	**Cricoid group (n = 30)**	**Control group (n = 30)**
Age; years	46.0 (18.6)	42.3 (14.6)	45.7 (20.6)
Sex; female	20	18	21
BMI; $kg.m^{-2}$	24.3 (3.8)	26.0 (4.7)	26.5 (5.9)
Neck circumference; cm	37.9 (4.3)	39.6 (4.5)	40.3 (5.6)

© 2018 Association of Anaesthetists

Table 2 Gastric antral measurements and presence of gastric air artefacts before and after positive-pressure ventilation of the lungs using a facemask. Participants had oesophageal compression at the low left paratracheal level (paratracheal group) or cricoid level (cricoid group), while participants in the control group had no oesophageal compression applied. Antral cross-sectional area (CSA) was measured at the level where both aorta and upper mesenteric artery were visible. Values are mean (95%CI). Positive differences indicate increase in antral area and negative differences indicate decrease in antral area.

	Paratracheal group (n = 30)	Cricoid group (n = 30)	Control group (n = 30)
Antral CSA before ventilation; mm^2	353 (306 to 400)	333 (286 to 379)	371 (305 to 438)
Antral CSA after ventilation; mm^2	321 (271 to 371)	344 (296 to 391)	491 (401 to 580)
Difference in antral CSA; mm^2	−32 [−2 to −62][a]	11 (60 to −38)[b]	120 (181 to 59)
Antral CSA before ventilation in subjects with new air artefacts; mm^2	n/a	277 (185 to 368)	346 (269 to 422)
Antral CSA after ventilation in subjects with new air artefacts; mm^2	n/a	414 (212 to 616)[c]	617 (502 to 732)[d]
Difference in antral CSA in subjects with new air artefacts; mm^2	n/a	137 (14 to 260)	271 (175 to 368)

[a]$p < 0.001$ compared with control group; [b]$p = 0.005$ compared with control group; [c]$p = 0.006$ compared with baseline before ventilation; [d]$p = 0.001$ compared with baseline before ventilation.

populations. Third, we only studied a single inspiratory pressure (25 cmH_2O); the effect on gastric insufflation at higher and lower inspiratory pressures is not known. Moreover, since neuromuscular blocking drugs were not used, their potential effect is unknown. Fourth, although antral cross-sectional area appears to correlate with the volume of aspirated stomach contents [16], our data cannot be used to predict the actual volume of air that enters the antrum and the consequent risk for aspiration. The effectiveness of paratracheal compression in preventing the passage of air into the stomach during positive-pressure ventilation does not translate into the same efficacy in the prevention of oesophageal contents from reaching the pharynx. Finally, the use of cricoid force has been questioned due to potential impairment of facemask ventilation [17], supraglottic airway device placement [18] and laryngoscopy [19]. In the present study, we did not assess the ease of facemask ventilation or tracheal intubation during the compression manoeuvres.

Our results suggest that oesophagal compression can be achieved by the application of manual force at the low left paratracheal level and that this is more effective than cricoid force in preventing air entry into the gastric antrum during positive-pressure ventilation by facemask. Future studies are needed to address the potential benefits of applying pressure more distally at the paratracheal level as opposed to at the cricoid level, and to substantiate the clinical utility of paratracheal compression in airway management.

Acknowledgements

The authors thank A.L. Balocco for her editing assistance. There was no external funding for this study. AH has consulted and advised for Skypharma, GE, Sonosite, Codman & Shrutleff, Inc. (Johnson & Johnson), Cadence, Pacira, Baxter and BBraun Medical. His recent industry-sponsored research includes Glaxo Smith-Kline Industries, Pacira, Baxter. He receives royalty income from BBraun Medical. None of these entities were involved in the conduct of this study. No competing interests are declared for the other authors.

References

1. Sellick B. Cricoid pressure to control regurgitation of stomach contents during induction of anaesthesia. *Lancet* 1961; **2**: 404–6.
2. Salem MR, Sellick BA, Elam JO. The historical background of cricoid pressure in anesthesia and resuscitation. *Anesthesia and Analgesia* 1974; **53**: 230–2.
3. Moynihan RJ, Brock-Utne JG, Archer JH, Feld LH, Kreitzman TR. The effect of cricoid pressure on preventing gastric insufflation in infants and children. *Anesthesiology* 1993; **78**: 652–6.
4. Cook TM, Woodall N, Frerk C. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: Anaesthesia. *British Journal of Anaesthesia* 2011; **106**: 617–31.
5. Schwartz D, Matthay M, Cohen N. Death and other complications of emergency airway management in critically ill adults. A prospective investigation of 297 tracheal intubations. *Anesthesiology* 1995; **82**: 367–76.
6. Smith KJ, Ladak S, Choi PTL, Dobranowski J. The cricoid cartilage and the esophagus are not aligned in close to half of adult patients. *Canadian Journal of Anesthesia* 2002; **49**: 503–7.
7. Smith KJ, Dobranowski J, Yip G. Cricoid pressure displaces the esophagus: an observational study using magnetic resonance imaging. *Anesthesiology* 2003; **99**: 60–4.
8. Boet S, Duttchen K, Chan J, et al. Cricoid pressure provides incomplete esophageal occlusion associated with lateral deviation: a magnetic resonance imaging study. *Journal of Emergency Medicine* 2012; **42**: 606–11.
9. Kei J, Utschig EE, van Tonder RJ. Using ultrasonography to assess the effectiveness of cricoid pressure on esophageal compression. *Journal of Emergency Medicine* 2017; **53**: 236–40.
10. Andruszkiewicz P, Wojtczak J, Wroblewski L, Kaczor M, Sobczyk D, Kowalik I. Ultrasound evaluation of the impact of

© 2018 Association of Anaesthetists

cricoid pressure versus novel 'paralaryngeal pressure' on anteroposterior oesophageal diameter. *Anaesthesia* 2016; **71**: 1024–9.
11. Bouvet L, Albert M-L, Augris C, et al. Real-time detection of gastric insufflation related to facemask pressure – controlled ventilation using ultrasonography of the antrum and epigastric auscultation in nonparalyzed patients. *Anesthesiology* 2014; **120**: 326–34.
12. Bolondi L, Bortolotti M, Santi V, Calletti T, Gaiani S, Labò G. Measurement of gastric emptying time by real-time ultrasonography. *Gastroenterology* 1985; **89**: 752–9.
13. Zhu SY, Liu RC, Chen LH, Yang H, Feng X, Liao XH. Sonographic anatomy of the cervical esophagus. *Journal of Clinical Ultrasound* 2004; **32**: 163–71.
14. Petito SP, Russell WJ. The prevention of gastric inflation – a neglected benefit of cricoid pressure. *Anaesthesia* 1988; **16**: 139–43.
15. Rice MJ, Mancuso AA, Gibbs C, Morey TE, Gravenstein N, Deitte LA. Cricoid pressure results in compression of the postcricoid hypopharynx: the esophageal position is irrelevant. *Anesthesia and Analgesia* 2009; **109**: 1546–52.
16. Perlas A, Mitsakakis N, Liu L, et al. Validation of a mathematical model for ultrasound assessment of gastric volume by gastroscopic examination. *Anesthesia and Analgesia* 2013; **116**: 357–63.
17. Yoshidome A, Aoyama K, Takenaka I. Positive pressure ventilation through small cricothyroidotomy tubes in a model lung. *European Journal of Anaesthesiology* 2017; **34**: 477–9.
18. Asai T, Barclay K, Power I, Vaughan RS. Cricoid pressure impedes placement of the laryngeal mask airway. *British Journal of Anaesthesia* 1995; **74**: 521–5.
19. Haslam N, Parker L, Duggan JE. The effect of cricoid pressure on glottic view improvement at laryngoscopy. *European Journal of Anaesthesiology* 2005; **60**: 41–7.

 © 2018 Association of Anaesthetists