

Cricoid Pressure Displaces the Esophagus: An Observational Study Using Magnetic Resonance Imaging

Kevin J. Smith, M.D., Julian Dobranowski, M.D., F.R.C.P.C.,† Gordon Yip, M.D., F.R.C.P.C.,‡ Alezandre Dauphin, M.D., F.R.C.P.C.,§ Peter T-L. Choi, M.D., F.R.C.P.C.‖#*

Background: **Cricoid pressure (CP) is often used during general anesthesia induction to prevent passive regurgitation of gastric contents. The authors used magnetic resonance imaging to determine the anatomic relationship between the esophagus and the cricoid cartilage ("cricoid") with and without CP.**

Methods: **Magnetic resonance images of the necks of 22 healthy volunteers were reviewed with and without CP. Esophageal and airway dimensions, distance between the midline of the vertebral body and the midline of the esophagus, and distance between the lateral border of the cricoid or vertebral body and the lateral border of the esophagus were measured.**

Results: **The esophagus was displaced laterally relative to the cricoid in 52.6% of necks without CP and 90.5% with CP. CP shifted the esophagus relative to its initial position to the left in 68.4% of subjects and to the right in 21.1% of subjects. Unopposed esophagus was seen in 47.4% of necks without CP and 71.4% with CP. Lateral laryngeal displacement and airway compression were demonstrated in 66.7% and 81.0% of necks, respectively, as a result of CP.**

Conclusion: **In the absence of CP, the esophagus was lateral to the cricoid in more than 50% of the sample. CP further displaced both the esophagus and the larynx laterally.**

SINCE the description by Sellick[1] in 1961, cricoid pressure (CP) has become a standard of practice for preventing passive regurgitation of gastric contents during the induction of general anesthesia in patients at high risk for aspiration.[2] Nevertheless, the efficacy of CP is still disputed. In one survey, 10% of anesthesiologists had witnessed regurgitation despite the application of CP.[3] Inconsistent CP technique,[4,5] application of inadequate pressure,[3,5] anatomic changes with CP,[6] and anatomic differences between individuals[7] have been suggested as explanations for the failure of CP.

The mechanism for CP assumes that the esophagus lies directly posterior to the cricoid cartilage ("cricoid").[8] The cricoid is a complete ring; therefore, pressure on the cricoid would compress and occlude the esophageal lumen between it and the C5 or C6 vertebral body. Occlusion of the esophageal lumen would prevent regurgitation of gastric fluid.[9] Few studies have examined the anatomic relationship between the cricoid and the esophagus. In one retrospective review of 51 computed tomography scans of normal necks, the esophagus was displaced lateral to the cricoid in 49% of patients in the absence of CP.[7] Because we could find no published imaging study on the anatomic changes associated with CP, we undertook this study to determine the relationship between the cricoid and the esophagus with and without CP using magnetic resonance imaging (MRI).

This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 5A.

Materials and Methods

After obtaining institutional review board approval and informed consent, we studied 22 healthy volunteers aged 16 yr or older who did not have contraindications to CP. Sagittal views of the neck without CP and axial views of the neck with and without CP were obtained with the subject's head positioned neutrally in the cervical, thoracic, and lumbar spine coil on the MRI table. Twenty to 30 N of force (2 to 3 kg) was applied to the subject's cricoid. To minimize variability in the technique, a single investigator (K.J.S.) applied CP to all subjects, and the applied force was standardized by reproducing 2 kg on a weigh scale prior to each application of CP. This method has been used to reproduce accurate amounts of CP previously.[4,5] Because of spatial limitations of the MRI machine, the investigator applied CP using a two-handed technique while positioned at the head of the MRI table. All subjects were asked whether the CP "felt midline" prior to imaging to maximize the reliability of the technique within the confines of the MRI machine. All imaging examinations were performed on a 1.5-T magnet (Twinspeed LX; GE Medical Systems, Milwaukee, WI) with sagittal and axial T1- and T2-weighted sequences. The images were taken independent of the respiratory phase as the dimensions of the structures of interest (cricoid, esophagus, and vertebral body) did not change significantly with the phase of respiration. The images were reviewed in digital format (GE PACS, Pathspeed 8.1; GE Medical Systems).

Images were presented to the participating radiologists (J.D. and G.Y.) for measurements in a blinded fashion to minimize bias. Using standard PACS measuring tools, measurements were taken from the most cephalad image in which the esophagus was seen clearly. The trans-

* Resident, § Associate Clinical Professor, ‖ Assistant Professor, Department of Anesthesia, † Associate Clinical Professor, ‡ Assistant Clinical Professor, Department of Radiology, St. Joseph's Healthcare and McMaster University. # Assistant Professor, Department of Clinical Epidemiology and Biostatistics, McMaster University.

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Address reprint requests to Dr. Smith: Department of Anesthesia, McMaster University, 1200 Main Street West, Room HSC-2U1, Hamilton, Ontario, Canada L8N 3Z5. Address electronic mail to: kevandjo@sympatico.ca.

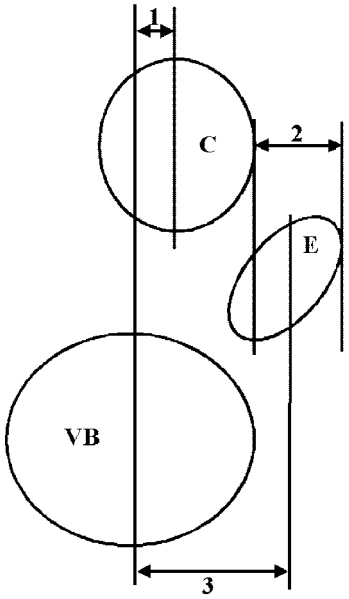

Fig. 1. Schematic diagram of the measurements made in this study. *C* = cricoid cartilage, *E* = esophagus, *VB* = vertebral body. *1* = amount of lateral displacement of C relative to the midline of VB, *2* = amount of unopposed esophagus, *3* = amount of lateral displacement of E relative to the midline of VB.

verse diameters of the cricoid, the esophagus, and the vertebral body were defined as the transverse distance between the structure's right and left borders, which were demarcated with lines drawn along the anteroposterior axis using the PACS measuring tools. Similarly, the anteroposterior diameter of the cricoid was defined as the anteroposterior distance between the cricoid's anterior and posterior borders, which were demarcated with lines drawn along the transverse axis. The midline of each structure was defined as the line intersecting the midpoint of the transverse diameter along the anteroposterior axis (fig. 1). Displacement of the cricoid and displacement of the esophagus were defined as the lateral displacement of the midlines of these structures relative to the midline of the vertebral body. Unopposed esophageal tissue was defined as any part of the esophagus, along its transverse axis, that was not opposed by both the cricoid and the vertebral body (fig. 1). The dimensions of the esophagus and the airway, the length of soft tissue between the airway and the vertebral body, the amount of esophageal displacement relative to the midline of the vertebral body, the transverse distance between cricoid and esophageal midlines, the anteroposterior distance from the cricoid to the vertebral body, the amount of unopposed esophageal tissue, and the amount of laryngeal displacement relative to the midline of the vertebral body, with and without CP, were measured (fig. 1).

Each radiologist read the images independently. When disagreements occurred between the radiologists regarding the image to be used for measurements, we used the following rules. If both the cricoid and the esophagus were seen in both images, the more cephalad image was chosen. If both the cricoid and the esophagus were seen only in one of the two images, the image with both structures was chosen. If no image showed both the cricoid and the esophagus, the image showing the most cephalad portion of the esophagus was chosen.

Table 1. Baseline Characteristics of Subjects Studied

Characteristic	Value
Age (yr)*	38.3 ± 8.1
Sex (male:female)	15:6
Height (cm)*	176.5 ± 12.6
Weight (kg)*	74.6 ± 13.8
History of†	
Gastroesophageal reflux	3 (14.3)
Hiatus hernia	0
Aspiration	0
Neck mass	1 (4.8)‡

* Mean ± SD. † Absolute number and percentage of total population in parentheses. ‡ Right-sided lymphangioma resected 5 years ago.

Statistical Analysis

Our primary objective was to qualitatively describe the anatomic changes in the neck with CP. A convenience sample of 22 subjects was chosen based on economic considerations. In the event of a zero incidence of esophageal displacement during CP in 22 subjects, the maximum risk of esophageal displacement in the entire population would be 13% (upper 95% CI).[10] As 49% (95% CI, 35.3–62.7%) of patients had displacement of the esophagus in the absence of CP in our previous study using computed tomography,[7] we thought that 22 patients would be adequate. Frequencies were expressed as proportions and percentages. For the extent of esophageal and laryngeal displacement, the measures of central tendency and dispersion were expressed as the mean and SD, respectively. We used the chi-square statistic to compare dichotomous measures with and without CP (*e.g.*, frequency of esophageal displacement), and we used the paired *t* test to compare continuous measures with and without CP (*e.g.*, length of esophageal displacement). As these multiple comparisons were secondary outcomes, we applied the Bonferroni correction; $P < 0.01$ was considered statistically significant.

Results

One subject did not complete the study. Table 1 summarizes the demographics and relevant medical history of the remaining 21 subjects. For two subjects without CP, the MRI scan did not extend sufficiently caudad to view the esophagus; however, the cricoid and cricopharyngeal muscle were present, allowing for all measurements except

Table 2. Measurements of the Esophagus and Airway, Relative to the Midline of the Vertebral Body, with and without Cricoid Pressure

Parameter	Without CP	With CP	Difference (*P*)*
Mean transverse esophageal diameter ± SD, mm	14.4 ± 3.6	15.4 ± 4.1	1.0 ± 4.9 (0.41)
Position of the esophagus†			
Left	8/19	16/21	
Midline	9/19	2/21	
Right	2/19	3/21	
Direction of esophageal displacement with CP‡			
Left		13/19	
No further displacement		2/19	
Right		4/19	
Mean amount of esophageal displacement ± SD, mm	1.5 ± 2.7 to the left	5.0 ± 5.6 to the left	3.5 ± 5.4 to the left (0.013)
Mean anteroposterior airway diameter ± SD, mm	17.1 ± 3.6	13.7 ± 3.4	−4.0 ± 4.4 (0.001)
Mean transverse airway diameter ± SD, mm	16.9 ± 3.6	17.2 ± 2.2	0.3 ± 2.2 (0.56)
Position of the cricoid§			
Left	7/21	14/21	
Midline	14/21	7/21	
Right	0/21	0/21	
Mean amount of airway displacement ± SD, mm	0.2 ± 1.9 to the right	3.2 ± 4.5 to the left	3.4 ± 3.9 to the left (0.004)
Mean transverse distance between cricoid and esophagus ± SD, mm	1.5 ± 2.8	2.5 ± 6.7	1.0 ± 6.6 (0.53)
Mean anteroposterior distance between cricoid and vertebral body ± SD, mm	8.8 ± 1.8	6.8 ± 2.2	−2.0 ± 3.0 (0.008)

* Differences in esophageal measurements with and without CP are based on data for 19 subjects. † $P = 0.03$, for the difference in frequencies with and without CP. ‡ For two subjects without CP, the magnetic resonance image did not extend sufficiently caudad to view the esophagus; therefore, numbers are based on data for the remaining 19 subjects. § $P = 0.06$, for the difference in frequencies with and without CP.

CP = cricoid pressure.

esophageal dimensions and degree of displacement from the midline. The esophagus was observed in all subjects with CP.

Interrater Agreement

There was 25% and 50% agreement on images selected with and without CP, respectively. The main sources of disagreement were difficulties in determining the origin of the esophagus and whether the structure was the esophagus or the cricopharyngeal muscle in an image, despite the high resolution of the MRI scans. To determine the interrater agreement for measurements, we defined an allowable measurement error of 2.0 mm, assuming an average esophageal diameter of approximately 15.0 mm, as a representative reproducible measurement based on a study demonstrating up to 15% measurement variability using MRI.[11] Of the images selected identically by both radiologists, there was 80% and 70% agreement in the measurements for esophageal diameter with and without CP, respectively.

Description of Imaging Results

The average position of the cricoid was at the C6–7 intervertebral level (median, C6–7; range, C5 vertebral body to C7–T1 intervertebral level). Of the 19 subjects whose MRI images of the esophagus were available, the esophagus was clearly present at the level of the cricoid in only one subject. In the remaining 18 subjects, the cricopharyngeal muscle was at the level of the cricoid, which was 10.3 ± 4.5 mm superior to the esophagus.

Table 2 summarizes the esophageal dimensions and related measurements. The esophagus was displaced, relative to the midline of the vertebral body, in 10 (52.6%) of 19 subjects without CP and 19 (90.5%) of 21 subjects with CP. In the 19 subjects who had images with and without CP available for comparison, CP shifted the esophagus relative to its initial position to the left in 13 subjects (68.4%) and to the right in four subjects (21.1%). In the presence of CP, the esophageal transverse diameter increased 1.0 ± 4.9 mm ($P = 0.41$; table 2), and the esophageal midline moved 3.5 ± 5.4 mm

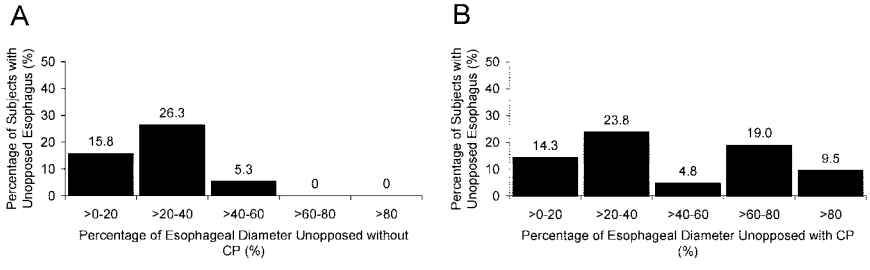

Fig. 2. Histograms of the percentage of unopposed esophageal diameter (*A*) without cricoid pressure (CP) and (*B*) with CP.

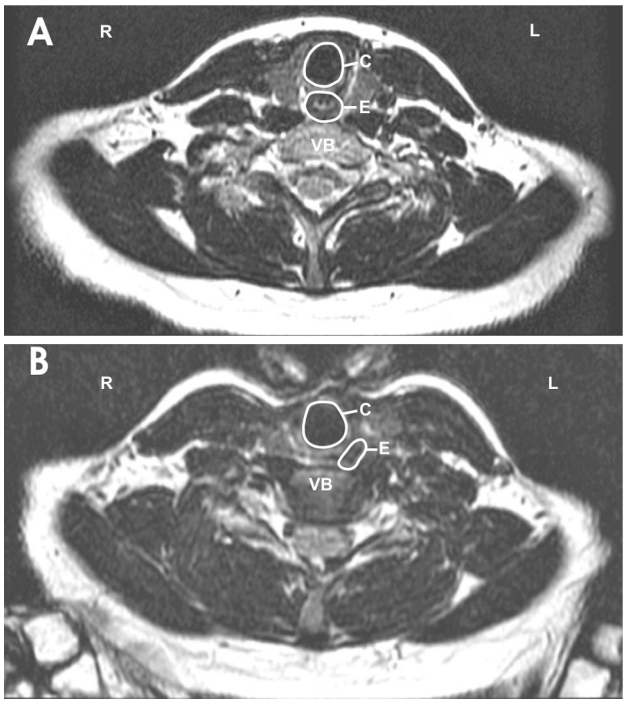

Fig. 3. (*A*) Magnetic resonance image of the neck without cricoid pressure. (*B*) Magnetic resonance image of the same subject demonstrating 12.1 mm of lateral esophageal displacement to the left with application of cricoid pressure. *C* = cricoid cartilage, *E* = esophagus, *VB* = vertebral body.

to the left, relative to the midline of the vertebral body ($P = 0.013$; table 2). The esophagus was not completely opposed between the cricoid and the vertebral body in 9 (47.4%) of 19 subjects without CP and in 15 (71.4%) of 21 subjects with CP (fig. 2). Greater than 40% of the esophageal diameter was unopposed in 1 (5.3%) of 19 subjects without CP and 7 (33.3%) of 21 subjects with CP. Figure 3 illustrates leftward displacement of the esophagus with the application of CP.

The airway was displaced, relative to the midline of the vertebral body, in 7 (33.3%) of 21 subjects without CP and 14 (66.7%) of 21 subjects with CP. Airway compression, defined as a decrease in the anteroposterior diameter by at least 1.0 mm, was seen in 17 CP subjects (81.0%). CP significantly reduced the anteroposterior diameter by 4.0 ± 4.4 mm ($P = 0.001$), displaced the airway to the left by 3.4 ± 3.9 mm ($P = 0.004$), and reduced the distance between the cricoid and the vertebral body by 2.3 ± 3.5 mm ($P = 0.008$) (table 2).

The cricoid and esophagus moved apart by 1.0 ± 6.6 mm with CP. The transverse esophageal diameter and the transverse airway diameter increased 1.0 ± 4.9 mm and 0.3 ± 2.2 mm, respectively, with CP. All these changes were not statistically significant.

Despite all 21 subjects reporting the perception of midline compression, CP was asymmetrically applied in 9 (42.9%) of them with more pressure applied on the right side of the cricoid in 7 of the 9 subjects. Seven of the 17 subjects who were physicians described CP as more painful than expected. The remaining 10 physician subjects and all 4 nonphysician subjects found CP to be tolerable.

Discussion

This study demonstrated that in the absence of CP, the esophagus was lateral to the cricoid in more than 50% of the population. The two-handed technique of CP was associated with a 1.5- and 3-fold increase in the frequency and the degree of lateral esophageal displacement, respectively, as well as a 1.5-fold increase in the frequency of esophagus unopposed between the airway and vertebral body, possibly providing a clear passage for regurgitation of gastric contents.

The mechanism for CP assumes that the cricoid, esophagus, and vertebral body are juxtaposed along the axial plane. Our results challenge this assumption. The anatomic structure lying posterior to the cricoid in nearly 95% of our subjects was the cricopharyngeal muscle. Together with the middle and inferior constrictor muscles, this muscle forms the inferior structure of the laryngopharynx, defined as the part of the pharynx that lies posterior to the larynx.[12] It is a funnel-shaped structure beginning at the superior border of the epiglottis and extending to the inferior border of the cricoid, where it becomes continuous with the esophagus.

On average, the esophagus was located 10.3 ± 4.5 mm inferior to the cricoid. Furthermore, the esophagus was displaced laterally in more than one half of the subjects, which is similar to the results seen in previous studies of normal necks without CP using computed tomography and MRI.[7,13] Below the level of the cricoid, the esophagus is expected to travel to the left of midline.[12]

Although the esophagus proper may not lie directly behind the cricoid, the laryngopharynx also serves as a conduit between the oropharynx and the gastric contents; therefore, compression of the laryngopharynx may prevent passive regurgitation. Because the lumen of the laryngopharynx was not visible on the MRI scans, we could not determine whether the cricopharyngeal muscle was compressed either partially or completely. We cannot determine whether regurgitation would be prevented.

Despite standardization in the technique of CP using a single trained investigator and a standardized pressure reproduced before each application, the frequency and degree of lateral displacement of both the esophagus and the larynx were significantly increased with CP. The CP technique used in this study was modified to accommodate the confines of the MRI machine and the subject who was awake.[10]

Because CP was not performed on unconscious and paralyzed subjects, it is possible that surrounding muscle tone and the swallowing reflex may have influenced the findings. The ideal imaging study would examine subjects without CP before general anesthesia and paralysis,

with CP before anesthesia induction, with CP after anesthesia induction and paralysis, and without CP after anesthesia induction. The ethical issues and the technical challenges of applying CP and providing airway and ventilatory support to an anesthetized, paralyzed, unintubated subject in the confines of the MRI scanner prevented us from performing such a study.

Although the two-handed technique does not represent usual clinical practice, this technique should theoretically result in less lateral displacement than the single-handed technique for the following reasons: CP was applied in line with the axial skeleton by an anesthesia resident, and the sensation of midline and symmetrical pressure was confirmed with each subject prior to imaging. Despite these measures, CP was asymmetrically applied, with greater pressure on the right in nearly 50% of subjects. CP at 20 N compressed the airway, displaced both the cricoid and the esophagus to the left, and widened the lateral distance between them. Our results suggest that CP is unreliable at producing midline esophageal compression without distorting the airway anatomy and raises the possibility of airway obstruction when applied with the proper amount of pressure (20–30 N). Airway obstruction has been demonstrated in a previous study using 30 N of CP in anesthetized subjects.[14]

Sellick[1] originally described CP with the head and neck fully extended. In our study, the head was placed in a neutral position, and possibly, the esophagus was more mobile in this position. However, in our clinical experience, the patient's head is usually placed in either a neutral or a sniffing position to maximize visual alignment of the larynx, even with the application of CP; therefore, the effect of CP on the neck anatomy in the neutral position may be more generalizable to our clinical practice. Furthermore, because the esophagus lies to the left of midline below the cricoid in greater than 90% of people as it begins its course through the left side of the mediastinum,[13] stretching of the esophagus with head and neck extension may pull the esophagus laterally away from the midline.

In summary, this study demonstrated that the cricoid, esophagus, and vertebral body were not aligned in more than half of all normal subjects. The application of CP resulted in an increased frequency and degree of both esophageal and airway displacement relative to the vertebral body.

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