Cricoid Pressure Results in Compression of the Postcricoid Hypopharynx: The Esophageal Position Is Irrelevant

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BACKGROUND: Sellick described cricoid pressure (CP) as pinching the esophagus between the cricoid ring and the cervical spine. A recent report noted that with the application of CP, the esophagus moved laterally more than 90% of the time, questioning the efficacy of this maneuver. We designed this study to accurately define the anatomy of the Sellick maneuver and to investigate its efficacy.

METHODS: Twenty-four nonsedated adult volunteers underwent neck magnetic resonance imaging with and without CP. Measurements were made of the postcricoid hypopharynx, airway compression, and lateral displacement of the cricoid ring during the application of CP. The relevant anatomy was reviewed.

RESULTS: The hypopharynx, not the esophagus, is what lies behind the cricoid ring and is compressed by CP. The distal hypopharynx, the portion of the alimentary canal at the cricoid level, was fixed with respect to the cricoid ring and not mobile. With CP, the mean anterioposterior diameter of the hypopharynx was reduced by 35% and the lumen likely obliterated, and this compression was maintained even when the cricoid ring was lateral to the vertebral body.

CONCLUSIONS: The location and movement of the esophagus is irrelevant to the efficiency of the Sellick's maneuver (CP) in regard to prevention of gastric regurgitation into the pharynx. The hypopharynx and cricoid ring move together as an anatomic unit. This relationship is essential to the efficacy and reliability of Sellick's maneuver. The magnetic resonance images show that compression of the alimentary tract occurs with midline and lateral displacement of the cricoid cartilage relative to the underlying vertebral body.

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Cricoid pressure (CP), as originally described by Sellick,[1] is used to prevent regurgitation and possible aspiration of stomach contents during the induction of general anesthesia. In his original description, Sellick stated that the "... maneuver consists in temporary occlusion of the upper end of the esophagus by backward pressure of the cricoid cartilage against the bodies of the cervical vertebrae." From the original description through present day, CP is depicted as pinching the esophagus between the cricoid ring and the cervical spine.[2–8]

However, Smith et al.[9] reported that the esophagus is lateral to the cricoid ring in more than 50% of subjects; this proportion increased to 90% of subjects after the application of CP. Because this report brought into question the efficacy of Sellick's maneuver, we believed further delineation and clarification was needed to evaluate the efficacy of this maneuver.

Therefore, the purpose of this study was twofold. The first goal was to accurately define the anatomy of the CP maneuver. The second was to investigate the efficacy of the maneuver in compressing the hypopharynx in a cohort of unsedated volunteers.

METHODS

This study was approved by the University of Florida institutional review board, and informed consent was obtained from all subjects. Twenty-four adults (13 men, 11 women, mean height 175 cm [SD ±10 cm], weight 76 kg [±14 kg], and body mass index 23.7 [±3.7]), nonpregnant volunteers who had no contraindication to either magnetic resonance imaging (MRI) or CP were studied from June to July 2008. The standard University of Florida survey and permission form for MRI was completed and signed by each study subject. The imaging studies from all 24 nonsedated subjects were deemed diagnostic for measurement of the study variables by two board-certified radiologists.

Interpretation of the MRI scans was performed by an academic board-certified radiologist (LAD) with 18

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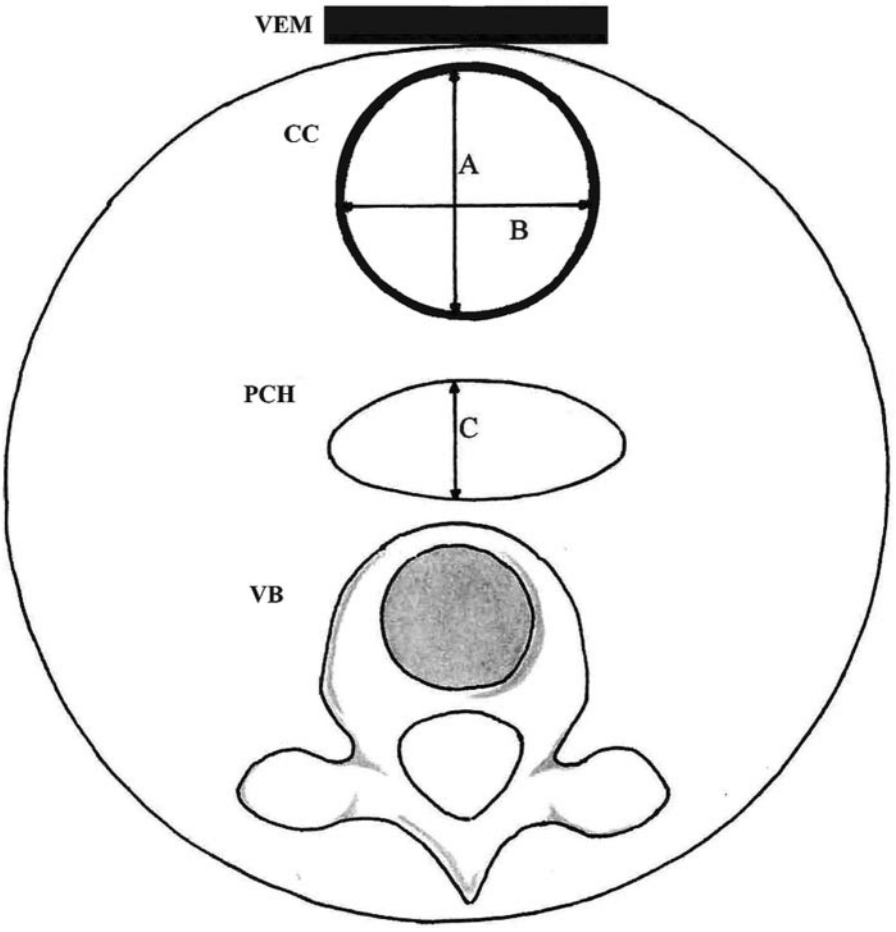

Figure 1. Schematic diagram of the measurements made on the axial magnetic resonance images (MRI). Lines A and B were the measurements of the anterioposterior (AP) and transverse diameters of the airway at the level of the cricoid cartilage, respectively. Line C is the AP diameter measurement of the postcricoid hypopharynx. A localizer (Vitamin E marker, approximately 5 mm in diameter) was placed on the skin by an anesthesiologist, with the subject in the sniffing position, at a level determined by external physical examination to represent the cricoid ring. PCH = postcricoid hypopharynx; CC = cricoid cartilage; VB = vertebral body; VEM = Vitamin E marker (a skin marker commonly used in MRI to localize an anatomic landmark).

yr of experience and with oversight by an academic radiologist (AAM) with more than 30 yr experience who is internationally recognized as an expert in the anatomy of the neck,[10–12] the relevant section of interest to the current investigation. The images were reviewed in digital format on a picture archiving and communication system workstation.

There is evidence that the neck position of the patient affects the position of the cervical esophagus, and thereby possibly the cricopharyngeus muscle.[10] Thus, imaging was done with and without CP in three positions: sniffing,[13] neutral, and extended. In the sniffing position, the subject's head was placed in a comfortable position with a 7-cm thick cushion underneath the head. In the neutral position, the subject's head was positioned with the neck and head parallel to the MRI tabletop. For the extended position, the subject's head was placed in a comfortable position with a cushion placed underneath the subject's neck at the shoulder and neck junction, so that the angle of the mandible formed approximately a 90-degree angle with the MRI tabletop.

Imaging

Imaging was performed with a 0.2-T open MRI scanner by a certified MRI technologist. The open design MRI scanner was chosen, so that the anesthesiologist could be at the subject's right side, mimicking the application of CP in the clinical environment. Although a closed design MRI scanner would have provided somewhat greater resolution of the relevant anatomy, we believed that reproducing the usual clinical positioning was essential to achieve the goals of this investigation. A sagittal scout image was obtained to identify the level of the cricoid cartilage. Multiple series of T2 axial images were obtained with a 5-mm thickness from 3 cm above to 3 cm below the cricoid cartilage in three positions (sniffing, neutral, and extended) with and without CP. CP, using the thumb and index finger, was applied with approximately 2–4 kg of pressure by one of the three experienced anesthesiologists. Before application of CP, a 2.5-kg brick was balanced on the back of the hand to simulate the amount of pressure used in the typical application of CP.

Measurements Made from the Images

Using electronic caliper picture archiving and communication system tools, the following measurements, as illustrated in Figure 1, were made from each set of axial images at the level of the most inferior margin of the cricoid cartilage:

- The anterioposterior (AP) diameter of the postcricoid hypopharynx, which included the thickness of the anterior and posterior walls.

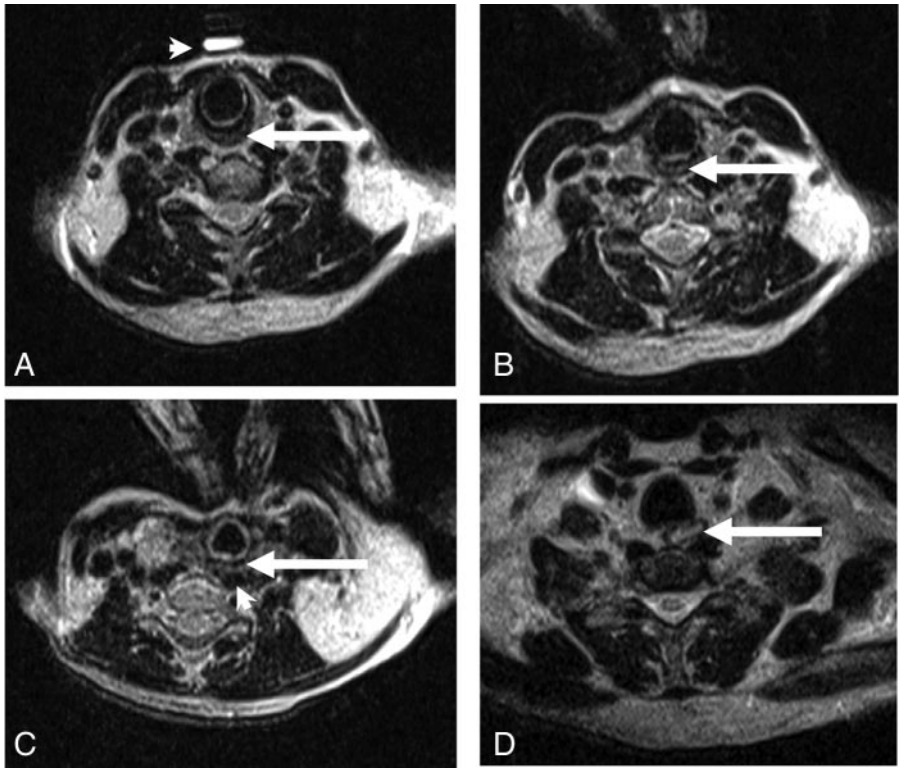

Figure 2. Axial magnetic resonance images in the sniffing position, without (A) and with (B) cricoid pressure. A, shows the postcricoid hypopharynx (arrow) and the Vitamin E marker (arrowhead) placed by the anesthesiologist before imaging. C, an example of postcricoid hypopharynx compression (arrow) lateral to the vertebral body with cricoid pressure. In this image, the postcricoid hypopharynx is compressed against the longus colli muscle group (arrowhead). D, an image 2 cm inferior to the cricoid ring distinctly showing the cervical esophagus (arrow) lateral to the vertebral body. In Panels (B) and (C), the anesthesiologist's thumb and index finger can be seen pushing on the cricoid cartilage. The axial image chosen for each study (A–C) was the image at the most inferior level of the cricoid cartilage.

- The AP and lateral airway diameter, as measured inside the cricoid ring.
- The lateral movement of the cricoid cartilage relative to the vertebral body (left, right, or midline) during CP. Movement was considered to have occurred whenever the cricoid ring was displaced laterally by one third of its diameter relative to its resting relationship with the underlying vertebral body during the application of CP. This measurement was expressed as left, right, or midline.

Statistical Analysis

A sample size calculation was centered around our original hypothesis that movement of the head from an extended to a neutral position would displace the esophagus laterally by some distance. We estimated a difference in the mean values of this distance for these two groups to be approximately 0.8 mm on the basis of previous reports.[9,10,14] Similarly, we considered the SD of each group to be approximately 1.0 mm. Using α and β values of 0.05 and 0.90, respectively, we estimated that approximately 18–24 subjects would be required (StatMate 2.0 for Windows, GraphPad Software, La Jolla, CA) using a repeated observations, nested design wherein each subject served as their own control.

Continuous data are reported as mean ± SD. The normality of distribution was determined using the Kolmogorov-Smirnov test with Lilliefors correction (SigmaStat 2.03, SPSS, Chicago, IL). Potential differences in esophageal or cricopharyngeus muscle position relative to the cricoid cartilage due to head position (Factor 1: sniffing, neutral, and extended) and application of CP (Factor 2: presence or absence) were made using a two-way repeated measures analysis of variance with Bonferroni *post hoc* pairwise testing when appropriate. Categorical data were analyzed by χ^2 with Yates correction. $P < 0.05$ was considered statistically significant.

RESULTS

Figure 2 shows an example of axial MRIs in the sniffing position without (Panel A) and with (Panel B) CP in a representative subject that displayed no lateral movement of the cricoid ring with CP. The arrow shows the cricopharyngeus muscle (the postcricoid hypopharynx) between the cricoid ring and the cervical body in both Panels A and B. With CP, there was no lateral movement of the postcricoid hypopharynx with respect to the cricoid cartilage in any images. The compression of the postcricoid hypopharynx (decrease in AP diameter) is seen when comparing Figure 2, Panel A (without CP) and Panel B (with CP). The esophagus was not present at the level of the cricoid cartilage in any of the images. Panel C shows an example of compression of the postcricoid hypopharynx, with CP causing left lateral movement of the cricoid ring with respect to the vertebral body. The visible compression of the postcricoid hypopharynx is maintained even though the hypopharynx and the ring are lateral to the vertebral body, with the postcricoid hypopharynx being compressed between the cricoid cartilage and the longus colli (LC) muscle group (arrowhead). In Panel D, which is 2 cm below

Table 1. Measurements (mm) of the Postcricoid Hypopharynx, Airway Diameter, and Position of the Cricoid with and Without Cricoid Pressure (CP)

Measurement	Without CP	With CP	Difference (*P*)	Pairwise percentage difference
Postcricoid hypopharynx (AP)				
Sniffing	7.3 ± 1.6	4.7 ± 1.3	2.6 ± 1.1 (<0.001)	35.3 ± 2.6
Neutral	7.3 ± 1.9	4.7 ± 1.4	2.6 ± 1.2 (<0.001)	34.9 ± 2.5
Extended	7.5 ± 1.8	4.5 ± 1.4	2.6 ± 1.7 (<0.001)	34.1 ± 3.1
Airway diameter (AP)				
Sniffing	17.1 ± 3.0	16.4 ± 3.2	0.7 ± 1.6 (0.073)	4.0 ± 1.9
Neutral	16.5 ± 2.7	15.4 ± 3.8	1.1 ± 1.8 (0.005)	7.4 ± 2.5
Extended	16.8 ± 3.5	15.6 ± 3.6	1.2 ± 2.1 (0.002)	7.1 ± 2.7
Airway diameter (transverse)				
Sniffing	16.1 ± 2.6	15.6 ± 3.0	0.5 ± 1.4 (0.043)	3.4 ± 1.8
Neutral	16.1 ± 2.5	16.0 ± 2.7	0.2 ± 1.3 (0.501)	1.1 ± 1.8
Extended	16.2 ± 3.1	15.6 ± 3.0	0.6 ± 1.2 (0.023)	3.4 ± 1.7

AP = anterioposterior.

Table 2. Position of Cricoid Versus Vertebral Body with Cricoid Pressure

	Left	Middle	Right
Sniffing	2/24	20/24	2/24
Neutral	3/24	18/24	3/24
Extended	5/24	16/24	3/24

the level of the cricoid ring, the cervical esophagus (arrow) is clearly seen lateral (left) of the vertebral body.

A summary of the measurements was made on the axial MRIs at the inferior level of the cricoid ring (Table 1). In the three neck positions examined, the mean AP diameter of the postcricoid hypopharynx ranged from 7.3 to 7.5 mm. Application of CP significantly reduced the postcricoid hypopharyngeal AP diameter ($P < 0.001$). These changes did not depend on the head position ($P = 0.81$). With CP, the mean diameter of the postcricoid hypopharynx was reduced by 35% in all the three neck positions ($P < 0.001$), ranging from 4.5 to 4.7 mm. This is narrower than the estimated thickness of the two walls (6.1 mm) as measured previously by Schmalfuss et al.[10] and thus, we infer that the lumen is obliterated. The mean airway diameter was reduced minimally in the AP direction in all the three positions, from approximately 17 to about 16 mm.

The summary of the position of the cricoid cartilage relative to the vertebral body during CP is shown in Table 2. CP resulted in a midline position of the cricoid ring in 83% (20/24), 75% (18/24), and 67% (16/24) of the subjects in the sniffing, neutral, and extended positions, respectively ($P = 0.86$). In only one subject, the movement of the cricoid was further lateral than one half of the transverse diameter of the vertebral body during the application of CP. In all cases of lateral movement, still there was very visible compression of the postcricoid hypopharynx by either the anterior portion of the vertebral body or the deep neck muscles lateral to the vertebral body. Notably, this compression was to the same degree as in subjects in whom the cricoid was midline during the application of CP.

DISCUSSION

This study demonstrates that CP does not result in lateral displacement of the alimentary canal (postcricoid hypopharynx) relative to the cricoid in any of the three neck positions tested. When the cricoid cartilage is moved laterally with respect to the vertebral body, as was observed in 17%–33% of the applications of CP (depending on the neck position), the hypopharynx and cricoid ring moved together as an anatomic unit. Thus, the relationship between the two is preserved, which is essential to the efficacy and reliability of the alimentary tract occlusion maneuver. During the application of CP, a 35% compression of the postcricoid hypopharynx is measured as a reduction of the hypopharynx AP diameter in all positions. The esophagus is not observed at the level of the cricoid cartilage in any of the study group images. Previously reported lateral movement of the esophagus from the midline when CP is applied undoubtedly occurs, but the origin of the esophagus is inferior to the level of the cricoid cartilage (Fig. 2D) and is, thus, not relevant to the value of Sellick's maneuver. Rather, it is the occlusion of the hypopharynx by application of CP to what we term, the CP unit, that is essential to Sellick's maneuver.

The Anatomy of the CP Unit

The postcricoid portion of the hypopharynx, beginning just below the arytenoids at the upper margin of the cricoid cartilage, is shaped like a funnel to direct food into the esophagus. This postcricoid region consists of the posterior wall of the lower larynx. The posterior wall and lateral gutter of the postcricoid area are a continuation of the other hypopharyngeal walls and are formed by the inferior constrictor muscle. The hypopharyngeal walls are continuous with the cervical esophagus situated below. The transition zone between the low postcricoid hypopharynx and the esophagus is often referred to as the esophageal verge

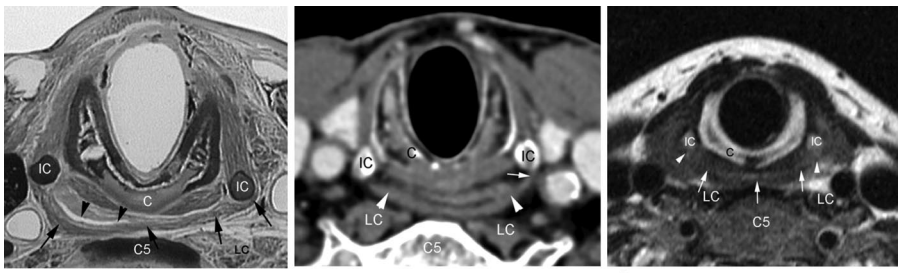

Figure 3. A, Anatomic whole organ section through the inferior aspect of the cricoid cartilage (C). This illustrates the anatomic structures that laterally stabilize the relationships of the cricoid cartilage and postcricoid hypopharynx to create the cricoid pressure unit. The arrows depict the muscular wall of the postcricoid hypopharynx and its lumen (black arrowheads) as it attaches to the inferior cornua (IC) of the thyroid cartilage laminae. These attachments keep the cricoid cartilage and the postcricoid hypopharynx aligned even if the unit is displaced from the midline. If the unit is displaced from the midline (Fig. 2C), the compressive (constrictive) force will then still be effective as applied to the longus colli (LC) muscle group rather than the cervical spine (C5). B, Transverse contrast-enhanced computed tomography (CT) image through a level correlating with (A). The arrowheads depict the muscular wall of the postcricoid hypopharynx aligned posterior to the cricoid cartilage (C) as it attaches (arrow) to the IC of the thyroid cartilage laminae. C5 = 5th cervical vertebral body. C, Transverse T1 weighted magnetic resonance imaging (MRI) through a level correlating with (A) and (B). The arrows depict the muscular wall of the postcricoid hypopharynx aligned posterior to the cricoid cartilage (C) as it attaches (arrowheads) to the IC of the thyroid cartilage laminae.

and is the tip of the funnel connecting the postcricoid region to the cervical esophagus.[11,12]

During CP, the cricoid ring is pressed against the vertebral body or, if the pressure results in the ring being lateral to the vertebral body, the prevertebral and paravertebral muscle groups, mainly the LC muscle. It is the constant relationship of the cricoid cartilage to the laryngeal cartilages, maintained by their connecting ligaments and muscles, which laterally stabilizes the cricoid relative to the thyroid lamina and cornua (Figs. 3A–C, LC). Because the cricoid cartilage and the postcricoid hypopharynx are constantly related by a subset of these muscular attachments, the cricoid cartilage and postcricoid hypopharynx behave as a unit when they are compressed together posteriorly against the cervical spine or the deep neck muscles. This CP unit also has built-in constraints to lateral displacement of the cricoid cartilage relative to the postcricoid hypopharynx with compression. The attachment of the postcricoid hypopharynx with the thyroid cartilage is shown in Figure 3B (arrow). The sealing of the hypopharynx is, therefore, independent of the positioning of the esophagus, given that virtually all of the "action" of CP takes place above the esophageal origin. Even if CP results in positioning of the hypopharynx lateral to the vertebral body (Fig. 2C), the postcricoid hypopharynx is compressed between the cricoid ring and the LC muscle group (arrowhead).

Measurements

Schmalfuss et al.[10] reported the average AP diameter of the postcricoid hypopharynx, as imaged on MRI at the level of the inferior cricoid ring, as 7.2 ± 2.0 mm. This is similar to our measurement of the AP distance of the postcricoid hypopharynx in the neutral position without CP, as 7.3 ± 1.9 mm. With CP, we measured this AP distance as 4.7 ± 1.4 mm, resulting in compression of the hypopharynx by 2.6 ± 1.2 mm (35%).

Although the AP airway diameter before CP was similar (16.8–17.1 mm in the three positions) in our study compared with Smith et al.[9] (17.1 mm), the change with compression was quite different. Smith et al. reported a decrease of 4 mm, which is a 23% decrease (4 mm/17.1 mm) in the AP diameter of the airway with CP, whereas we measured only a 6% decrease (about 1.0/16.8 mm), which is in keeping with application of pressure over a relatively rigid cartilaginous ring such as the cricoid.

Definition of Anatomical Structures—Clarification of Nomenclature

It was clearly confirmed by Schmalfuss et al.[10] that the point where the esophagus begins, within 1 cm below the inferior margin of the cricoid cartilage, can be consistently and reliably identified on transverse computed tomography and MRIs. Figure 3A shows an anatomical whole organ section through the inferior margin of the cricoid ring. In this section, the muscle wall of the postcricoid hypopharynx is depicted by the arrows, with the arrowheads showing the lumen described by Sellick as the "temporary occlusion of the upper end of the esophagus" in his classic article published in 1961.[1] Figure 4B is a reproduction of the figure from Sellick's original report. The occlusion of the column of contrast is clearly seen at the level of the fifth cervical vertebra, which is above the level of origin of the esophagus. This is confirmed with a side-by-side comparison of the sagittal image of the neck and spine (Figs. 4A and B).

Smith et al.[14] using MRI reported that the esophagus was lateral to the cricoid ring in more than 50% of volunteers. In an additional 40% of patients, CP further displaced the esophagus laterally.[9] They concluded that

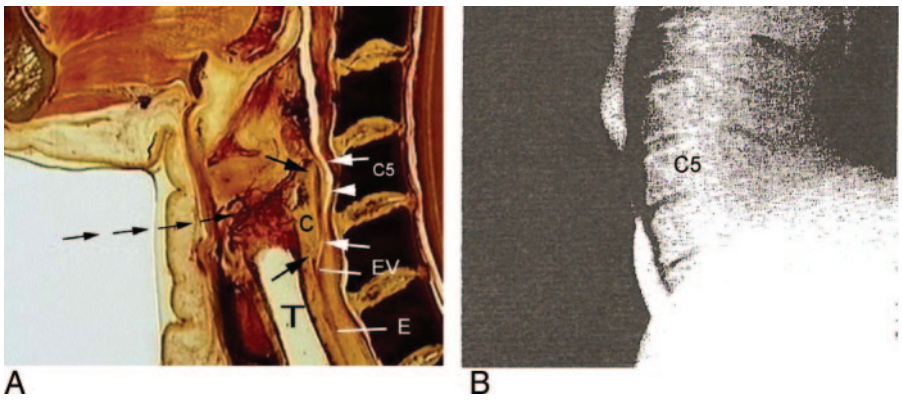

Figure 4. A, A sagittal cadaver image of the cricoid pressure anatomic unit. The cricoid cartilage (C) is the foundation of the cricoid pressure unit with its superior and inferior aspects indicated by black arrows. The postcricoid hypopharynx muscular wall and lumen (white arrowhead) and its superior and inferior limits (white arrows) have a constant and intimate relationship to the cricoid cartilage. As pressure is applied anteriorly (multiple line of black arrows), the unit is compressed against the vertebral body (C5) sealing off the esophagus (E) at the esophageal verge (EV). Because the esophagus is well below the level of the seal, its position is irrelevant to the integrity of the seal produced by the pressure on the unit. B, An image from Sellick's original report showing obliteration of the lumen by CP at the 5th cervical vertebra (Reproduced with permission from Sellick BA, Lancet, 1961, 2, 404–6, Elsevier Limited). T = trachea.

". . . 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." The images and methods in the article by Smith et al. demonstrated that they were observing the esophagus at a level below the cricoid ring. In fact, they stated: "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 cricopharyngeus muscle was at the level of the cricoid, which was 10.3 ± 4.5 mm superior to the esophagus."[9] This article brought into question the efficacy of the Sellick maneuver by stating that the lateral displacement of the esophagus, and the esophagus being frequently unopposed between the airway and the vertebral body, resulted in ". . . possibly providing a clear passage for regurgitation of gastric contents."[9] Smith et al.[9] did state that compression of the laryngopharynx by CP may prevent regurgitation. However, the efficacy of Sellick's maneuver is not affected by esophageal position because the postcricoid hypopharynx is compressed regardless of the position of the esophagus inferior to the cricoid ring.

Does a 35% compression (2.6 mm) of the postcricoid hypopharynx prove the efficacy of Sellick's maneuver? From this study, an answer can only be inferred but not proven. Using a higher-resolution MR scanner, Schmalfuss et al.[10] measured a very similar hypopharynx diameter without compression of the lower cricoid region of 7.2 ± 2.0 mm compared with our measurement of 7.3 ± 1.9 mm. Their measurement of the AP thickness of the anterolateral wall (2.6 ± 1.0 mm) and posterior wall (3.5 ± 1.2 mm) of the postcricoid hypopharynx without compression added up to 6.1 mm. Because our postcricoid hypopharynx AP diameter with compression measured only 4.7 ± 1.4 mm compared with a baseline of 7.3 ± 1.9 mm, we infer that the lumen was indeed obliterated.

CONCLUSIONS

The correct anatomic designation for the alimentary tract at the level of the cricoid cartilage should be the postcricoid hypopharynx and not the esophagus. Because the esophagus is clearly mobile, even at the level of its origin approximately 1 cm below the cricoid ring, this nomenclature should be clarified. In addition:

- There is an approximate 35% "squeeze" of the postcricoid hypopharynx with the application of CP;
- Lateral movement of the cricoid cartilage relative to the body of the vertebra does not reduce the compression of the postcricoid hypopharynx because the cricoid cartilage moves as the "CP unit" with the postcricoid hypopharynx;
- Lateral movement of the esophagus inferior to the cricoid level is not relevant to the efficacy of CP; and
- Most importantly, Sellick's original proposal that CP compresses the conduit between the stomach and the pharynx as intended is confirmed.

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