Deborah J. Culley, M.D., Editor

Cricoid Pressure Controversies

Narrative Review

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ABSTRACT

Since cricoid pressure was introduced into clinical practice, controversial issues have arisen, including necessity, effectiveness in preventing aspiration, quantifying the cricoid force, and its reliability in certain clinical entities and in the presence of gastric tubes. Cricoid pressure–associated complications have also been alleged, such as airway obstruction leading to interference with manual ventilation, laryngeal visualization, tracheal intubation, placement of supraglottic devices, and relaxation of the lower esophageal sphincter. This review synthesizes available information to identify, address, and attempt to resolve the controversies related to cricoid pressure. The effective use of cricoid pressure requires that the applied force is sufficient to occlude the esophageal entrance while avoiding airway-related complications. Most of these complications are caused by excessive or inadequate force or by misapplication of cricoid pressure. Because a simple-to-use and reliable cricoid pressure device is not commercially available, regular training of personnel, using technology-enhanced cricoid pressure simulation, is required. The current status of cricoid pressure and objectives for future cricoid pressure–related research are also discussed. **(Anesthesiology 2017; XXX:00-00)**

IN 1961, Sellick[1] described a new maneuver to control regurgitation of gastric contents during induction of anesthesia. It consisted of "temporary occlusion of the upper esophagus by backward pressure on the cricoid ring to prevent stomach contents from reaching the pharynx, should regurgitation occur." Sellick's[2–5] maneuver rapidly became an integral component of the rapid sequence induction and intubation (RSII) technique and replaced the head-up position that had been commonly used. However, since its inception, clinicians have raised questions about its effectiveness and safety, and some have even suggested abandoning the maneuver.[6–15]

The most recent comprehensive review of cricoid pressure (CP) was published 20 yr ago.[6] Since that time, many (more than 200) peer-reviewed manuscripts, editorials, and correspondences on CP have been published, attesting to the continuing interest and controversy surrounding the maneuver. In view of the many new publications, both in favor and against CP, and the polarization of the proponents and critics of the maneuver, an updated review is warranted. In this review, controversial issues are identified and addressed, including its effectiveness and potential complications associated with its use.

An electronic search was performed in PubMed (January 1961 to March 2016) using word recognition for CP (all fields). The title and abstract of all retrieved articles (more than 550) were screened independently by two authors (M.R.S. and A.K.) for keywords based on the study objectives. The reference list from each selected article was screened for additional relevant information. The articles targeted were those related to CP and not necessarily those that addressed the other components of the RSII technique. We used discretion in deciding which articles to finally include, favoring peer-reviewed articles from highly ranked journals written in English. On-line publications were excluded except when the findings were unique. We were even-handed in our selection of literature, trying our best to give both sides of each argument equal emphasis. Furthermore, the decision to include the articles for this review required the approval of both authors. In case of disagreement, the third author's (A.Z.) decision was the tie breaker after discussion with the first two authors.

Evidence Supporting Effectiveness of CP

Sellick's Original Observations and Subsequent Cadaver Studies

In his initial communication, Sellick[1] reported that firm CP in the cadaver prevented stomach contents from reaching

Submitted for publication March 9, 2016. Accepted for publication November 29, 2016. From the Department of Anesthesiology, Advocate Illinois Masonic Medical Center, Chicago, Illinois (M.R.S., A.K.); Department of Anesthesiology, University of Illinois College of Medicine, Chicago, Illinois (M.R.S., G.J.C.); and Department of Anesthesiology, Procare Riaya Hospital, Al-Khobar, Kingdom of Saudi Arabia (A.Z.).

 Anesthesiology 2017; XXX:00–00

<zdoi;10.1097/ALN.0000000000001489>

the pharynx despite previous stomach distension with water and using the steep Trendelenburg tilt. He demonstrated in an anesthetized and paralyzed patient that CP obliterated the esophageal lumen as seen with a soft latex tube distended with contrast media at a pressure of 100 cm H_2O.[1] Sellick[1] also described the use of CP in 26 high-risk patients. A barbiturate/muscle relaxant technique was his method of choice, while the patient lied supine with slight head down tilt and the head and neck fully extended.[1] In 23 of the patients, no regurgitation or vomiting occurred before, during, or after intubation. In the remaining three, the release of CP after intubation was accompanied by reflux of gastric or esophageal contents into the pharynx, suggesting once again the effectiveness of CP.[1] Using similar methodology to that of Sellick,[1] three studies conducted in the 1970s and 1980s in infant and adult cadavers confirmed the effectiveness of CP.[16–18]

Effectiveness of CP in Preventing Gastric Insufflation

As early as 1774, CP was used to prevent gastric distension during resuscitation of drowning victims.[19] In his seminal publication, Sellick[1,2] suggested that the maneuver can be useful to avoid gastric insufflation during positive-pressure ventilation. In the subsequent four decades, a number of studies evaluated the effectiveness of CP in preventing gastric insufflation. We examined these studies but have focused on only those in which the same patient was evaluated with and without CP and one or more of the following variables were obtained: gas volume in the stomach, exhaled tidal volume, and documented gas entry into the stomach. Cases in which gastric insufflation did not occur without CP, as well as studies using laryngeal mask airway (LMA), were excluded. Four studies met our criteria (three in infants and children and one in adults).[20–23] When viewed collectively, these studies revealed that in 87 of 88 patients, CP prevented gastric insufflation. It is illogical that CP would be unidirectional in its effectiveness and would prevent gastric insufflation during positive-pressure ventilation while not preventing esophageal contents from reaching the pharynx if regurgitation occurs.

Modern Approaches to Assess Effectiveness of CP

The advent of modern modalities and instrumentation have provided additional means for assessing the effectiveness of CP. In a study in awake volunteers, Rice *et al.*[24] evaluated the maneuver in the sniffing, neutral, and extended head positions using magnetic resonance imaging (MRI). They found that the part of the alimentary tract compressed by CP is actually the postcricoid hypopharynx. They also observed that, unlike the cervical esophagus, the postcricoid hypopharynx moved with the cricoid cartilage as an anatomical unit during CP.[24] These findings confirmed Sellick's original observation that CP compresses the conduit between the stomach and the pharynx. Furthermore, they demonstrated that compression of the postcricoid hypopharynx during CP occurs in spite of the variable position of the cricoid cartilage in relation to the vertebral body (midline or lateral position).[24] The postcricoid hypopharynx is also referred to as the cricopharyngeus, which is a major component of the upper esophageal sphincter. Recently, the postcricoid hypopharynx has been referred to as the esophageal entrance.[25]

Zeidan *et al.*[25] provided real-time visual and dynamic evidence for the effectiveness of CP in closing the esophageal entrance in anesthetized and paralyzed patients. In this study, the Glidescope(R) Video Laryngoscope (GVL; Verathon Medical Canada ULC, Canada) allowed the panoramic view of the esophageal entrance and the laryngeal structures. Closure of the esophageal entrance was observed, and it was not possible to insert a gastric tube when 30-N cricoid force was exerted. These findings were independent of the location of the esophageal entrance in relation to the glottis.

Anatomical Basis for Effectiveness of CP

The anatomical relationship of the structures in the area around the cricoid cartilage may explain the effectiveness of a 30-N cricoid force in spite of the variable location of the esophageal entrance.[26] Vanner and Pryle[26] calculated that, when a 30-N force is applied, the convex structures of the cricoid cartilage and the vertebral body are pressed against each other, generating a pressure greater than 200 mmHg posterior to the cricoid cartilage. However, they noted experimentally that applying a 30-N force is effective in preventing regurgitation up to 40 mmHg.[27] This discrepancy was attributed to the uneven distribution of pressure posterior to the cricoid cartilage, with lateral esophageal areas receiving less force than midline areas.[26] Thus, if the esophageal entrance is in a lateral position, it may be pressed primarily against the longus colli muscle rather than the vertebral body and would be subjected to less cricoid force than if it were in a midline position. Because the intragastric pressure rarely exceeds 25 mmHg, a 30-N cricoid force is more than adequate to prevent regurgitation in spite of lateral displacement of the esophageal entrance.[28]

CP and Emergency Cesarean Section

In the Confidential Enquires into Maternal Death in England and Wales from 1964 to 1969 (before the common use of CP), 52 deaths due to aspiration were reported.[29,30] A survey of maternity units in 1994 revealed that CP was routinely applied during induction of general anesthesia in the last trimester of pregnancy.[31] In the last four triennial reports of the Confidential Enquires into Maternal Death in the United Kingdom from 1994 to 2005, there was only two deaths from aspiration.[29] In one patient, aspiration probably occurred during failed intubation attempts, and CP might have been discontinued during this time. In the other patient, CP was not used.[29,32,33] Vanner[29] concluded that during this 11-yr period (1994 to 2005), the use of CP must have been effective in reducing aspiration of gastric contents and deaths, compared with previous periods. These reports lend support to the continuing use of CP in an emergency cesarean section.

Evidence against Effectiveness of CP and Objections to Its Use

MRI Studies

Smith *et al.*[34,35] used computerized tomography and MRI to evaluate the position of the esophagus in awake volunteers with and without CP while the head was in a neutral position. They observed that relative to the cricoid cartilage, the esophagus was laterally deviated in one-half of their volunteers.[35] CP further displaced the esophagus in 90.5% of subjects, to the left in 69.4% and to the right in 21.1%. Using similar methodology, Boet *et al.*[36] found that incomplete esophageal occlusion was always associated with lateral deviation of the esophagus, whereas none of the subjects with complete occlusion had esophageal deviation. The authors of both studies concluded that lateral displacement of the esophagus with CP can result in less effective esophageal compression.[35,36] However, this conclusion is misleading because the hypopharynx containing the cricopharyngeus muscle (rather than the cervical esophagus) is posterior to the cricoid cartilage, and it is the former structure that is compressed by CP. Since the cricopharyngeus muscle is attached to each side of larynx, the postcricoid hypopharynx moves with the cricoid cartilage if the larynx is displaced laterally during CP.[24,26] The aforementioned studies by Rice *et al.*[24] and Zeidan *et al.*[25] clearly demonstrated that such lateral displacement does not reduce the effectiveness of CP.

Reports of Aspiration Despite the Use of CP, Critiques of Early Reports, and Lack of Randomized Studies

Several lines of evidence raise questions about the effectiveness of CP in preventing regurgitation and aspiration. First, case reports provide examples of fatal aspiration in spite of CP.[37,38] Second, surveys revealed that 11 to 14% of anesthesia providers and assistants witnessed regurgitation, usually once in their career, even though CP was applied.[39,40] Third, a 30-yr review of closed malpractice claims reported aspiration in 67 cases despite the use of CP in 17 of these cases.[41] Fourth, in a prospective study of emergency airway management in 297 critically ill patients, 12 showed newer or unexpected radiographic infiltrates even though CP was applied in nine patients.[42] Fifth, in a report of almost 5,000 general anesthetics for obstetrical patients in Malawi, 11 deaths attributable to regurgitation occurred despite application of CP in nine patients.[43] Critics of the CP maneuver have cited the findings listed above as proof of its unreliability.[7–12] Conversely, proponents of the maneuver suggest that these failures could be due to improper application, early release, application by untrained personnel, and the possibility of aspiration before anesthetic induction or after extubation.[28,44–48] They also claim that the incidence of aspiration would be higher if CP was not used.[49]

Early reports supporting the effectiveness of CP have been criticized because they were based primarily on cadaver studies[16–18] and single-case reports.[50] Critics of the maneuver also argue against the need for CP since perioperative aspiration is rare—an incidence between 0.014% and 0.1% for adults and a slightly higher incidence in pediatric patients are generally accepted.[51–63] However, the incidence of aspiration has been shown to be higher in patients undergoing emergency surgery,[58,60] with American Society of Anesthesiologist physical status 3 and 4,[58,60] emergency intubations,[42,64–68] and repeated intubation attempts.[68] A review of 2,833 emergency tracheal intubations revealed a 1.9% incidence of aspiration when laryngoscopy was performed once or twice as compared with an incidence of 22% with three or more attempts.[68] Because of the complexity of airway management in critically ill and trauma patients and the possibility of aspiration before intubation or after extubation, the true incidence is difficult to assess in these patients.[62–74] Although most reports indicate that mortality from perioperative aspiration is rare, values as high as 4.6% have been reported.[62,74,75]

In 2011, the 4th National Audit Project by The Royal College of Anaesthetists and the Difficult Airway Society of the United Kingdom published their findings on airway-related complications.[76] The research was conducted from September 1, 2008, to August 31, 2009. In 1 yr, 16 airway-related deaths were reported in 2,872,600 general anesthetics (one in 180,000).[76] Aspiration of gastric contents was cited as the single most common anesthetic-related cause of death.[76] It was also described as primary (17%) or secondary (5%) event and accounted for 50% of anesthetic-related deaths.[76] In addition, many of those who survived did so after a prolonged period of intensive care. These findings highlight the importance of implementing appropriate measures to prevent aspiration.[76]

The lack of randomized controlled trials comparing the incidence of aspiration with and without CP has been an obstacle in CP gaining widespread acceptance. Because of ethical issues, such a study may not be feasible.[48] With an incidence of 0.15% aspiration in adults, Lerman[8] estimated that a randomized trial (to reduce the incidence of aspiration by one half) would require a sample size of at least 25,000 in each group. Moreover, such a study would require standardization of many variables, including the position of the head and neck, CP technique, measurement of the force, agreement on the use of gastric tubes, and criteria of extubation. Information on the effectiveness of CP in patients at high risk of aspiration, such as those with bowel obstruction, would certainly be more meaningful, but it is unlikely that an institutional review board would approve such a study.

Effectiveness of CP in Rare Clinical Entities

Concern has been raised over the effectiveness of CP in rare entities, such as achalasia and Zenker diverticulum,[77] but no conclusive data have been published. In achalasia, the dilated esophagus is wider than the area under the cricoid cartilage.[77–79] Nonetheless, it is probable that the maneuver would be effective since the compression area is much larger than the surface area of the cricoid cartilage.[77] In Zenker diverticulum, the effectiveness of CP may depend on the location of the pouch and its neck (Fig. 1).[80] If the neck of the pouch is posterior to the cricoid cartilage, CP will occlude the neck, and the contents of the pouch will not be extruded into the pharynx.[80] Conversely, if the pouch is at the level of the cricoid cartilage (because it has no neck), CP may compress the pouch, spilling its contents into the pharynx.[80]

The Cricoid Force

Factors Influencing the Effectiveness of CP in Occluding the Esophageal Entrance

Many factors can potentially influence the effectiveness of CP. These include force applied, method of application; point of contact, surface area and deformability of the cricoid cartilage, distance and type of tissue between the skin and cricoid cartilage, size of the esophageal entrance, intraesophageal pressure, and location of the esophageal entrance relative to the vertebral body and the cricoid cartilage.

Quantitating the Cricoid Force

When CP was introduced, the terms "moderate" and "firm" described the magnitude of the applied force.[1,2] Sellick[1] recommended moderate pressure when the patient was conscious. After loss of consciousness, firm pressure could be applied without obstruction of the patient's airway.[1,2] The term "gentle" was described for CP in children, especially when it was intended to prevent gastric insufflation.[20] Wraight *et al.*[81] recommended the use of a cricoid force of at least 44 N, assuming a theoretical maximum intragastric pressure of 59 mmHg in 50% of patients. However, other investigators suggested that far less force can be effective in preventing regurgitation. Clinical studies have demonstrated that a force of 30 and 34 N occluded a manometry catheter placed posterior to the cricoid cartilage at a pressure greater than 25 and 30 mmHg, respectively.[81,82] In a cadaver study, a 20 N-force prevented regurgitation of esophageal fluid at a pressure of 25 mmHg and a 30-N force prevented regurgitation at 40 mmHg.[27]

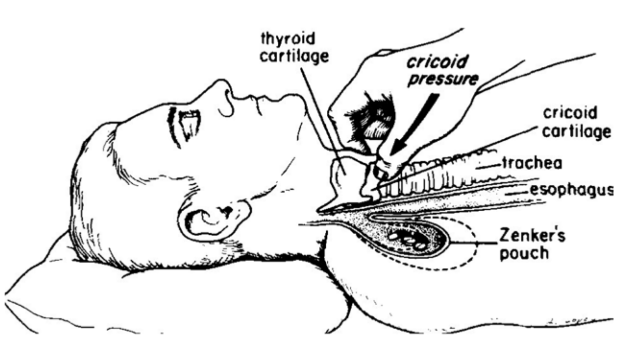

Fig. 1. The Zenker pouch in the hypopharynx, with the opening at the level of cricoid cartilage. Reproduced with permission from Thiagarajah S, Lear E, Keh M: Anesthetic implications of Zenker's diverticulum. Anesth Analg 1990; 70:109–11. Wolters Kluwer Health.

Studies of intragastric pressure measurements also suggest that a smaller cricoid force would be adequate to prevent regurgitation. In anesthetized and paralyzed patients, the intragastric pressure rarely exceeds 15 mmHg.[83–86] Even in pregnant women undergoing emergency cesarean section, the intragastric pressure is less than 25 mmHg in 99% of cases.[87] During succinylcholine fasciculations, variable increases in intragastric pressure occur, and this increase depends on the intensity of the fasciculations.[88–92] Because of a greater increase of the lower esophageal sphincteric pressure in response to the rise of intragastric pressure during fasciculations, gastroesophageal reflux does not ordinarily occur in normal subjects.[92] This "adaptive" increase in lower esophageal sphincter pressure is observed in response to an increase in intraabdominal pressure up to approximately 22 mmHg but may be absent in patients with gastroesophageal reflux and gastric distention.[93] Based on measured values of intragastric pressure, a 20-N force should afford a high degree of protection against regurgitation in most patients.[35,82,86] However, for safe use of CP, the current recommendation is to apply 10 N when the patient is awake and increase the force to 30 N once the patient loses consciousness.[28]

CP-induced Airway Obstruction: Mechanisms and Consequences

Excessive cricoid force could compromise airway patency, make ventilation with a face mask difficult, cause difficulty inserting an endotracheal tube (ETT) or threading an ETT over an introducer, and alter visualization when using a fiberoptic scope.[94–101] However, investigations have yielded inconsistent findings concerning these potential untoward effects of CP. A randomized double-blind trial in 700 elective procedures showed that CP did not increase the rate of failed intubation by direct laryngoscopy or interfere with intubation facilitated by introducers.[102] The authors of the report stated: "the application of CP should not be avoided for fear of increasing the difficulty of intubation by direct laryngoscopy when its use is indicated."[102] McNelis *et al.*,[103] on the other hand, demonstrated an increase in "impingement" with CP in women when intubation was facilitated by introducers. Furthermore, these authors found that a 90° anticlockwise rotation of the ETT was 100% successful in the absence of CP in threading the tube into the trachea, whereas it was not successful in a few patients when CP was applied; thus, the implementation of this technique may necessitate releasing CP.

Studies of airway obstruction with CP are typically performed by recording the changes in expired tidal volume or peak expiratory flow rate during ventilation using a face mask and an oropharyngeal airway.[99,104] An expired tidal volume less than 200 ml in adults is indicative of airway obstruction.[99] The degree of airway obstruction depends on the force applied, the technique of application, and the deformability of the cricoid cartilage.[105] In a study in female patients, a 44-N force caused airway obstruction in 35% of patients; the obstruction occurred less frequently (2%) with 30 N, unless the force was applied in an upward and backward direction, in which case, it occurred in 56% of patients.[102]

Airway obstruction associated with CP may occur at the level of the cricoid cartilage, the glottis, or both.[105] With excessive force, deformation of the cricoid cartilage occurs, which reduces its anteroposterior diameter, resulting in ineffective gas exchange and difficulty in intubation.[105] It is possible that during CP, an ETT may readily pass through the glottis but cannot be advanced.[105,106] Because the internal diameter of the cricoid region is smaller in women than in men (13.9 ± 1.8 *vs.* 17.6 ± 1.9 mm) and because of possible hormonal effects, deformation of the cricoid cartilage is more likely to occur in women at a cricoid force of 30 N or less.[105,106] Approximation of the vocal cords (cord tightening) can occur during CP due to posterior displacement of the arytenoids.[99,105] Supraglottic tumors, undiagnosed lingual thyroid, undiagnosed traumatic injury, improper CP application, and lateral displacement of the cricoid cartilage have been proposed as additional causes of airway obstruction during CP.[94,107]

Cricoid Force in Pediatric Patients

When CP was introduced, clinicians assumed that the same cricoid force used in adults was appropriate for pediatric patients. Subsequently, Walker *et al.*[96] found that the cricoid force that compresses the airway in children is 10.5 N, and it could be as low as 5 N in infants and between 15 to 25 N in teenagers. Furthermore, these investigators demonstrated linear relationships between age and weight and the cricoid distortion force of the airway. They concluded that 30 N is excessive in all pediatric patients and it can cause compression and distortion of the child's airway, leading to airway obstruction and difficult intubation.[96]

A recent study calculated the age-dependent cricoid forces in infants and children necessary to prevent regurgitation at an esophageal fluid pressure of 40 mmHg.[108] The calculations were based on known measurements of the cricoid surface area and the assumption that the compression area is three times that of the cricoid area.[26] These calculated forces were compared with the forces causing 50% distortion of the subglottic airway in children.[96] The analysis indicated that these calculated forces are far less than those causing distortion of the subglottic airway.[108] Since the maximum intragastric pressure recorded in anesthetized and paralyzed children is 18 mmHg,[91] even less cricoid forces (than those calculated) should be effective in preventing regurgitation.

Because of potential airway obstruction and the associated technical problems (the adult hand restricts mouth opening and interferes with proper positioning of the handle of the laryngoscope), the reliability and feasibility of CP have been questioned by pediatric anesthesiologists.[15,96,109–111] In fact, more than half of them have abandoned the maneuver.[109–111] Also, the section on pediatric anesthesia of the German Society of Anesthesia and Intensive Care Medicine issued a recommendation on RSII in children: "Considering the known side effects of CP and lack of demonstrated benefit of CP in general, application of CP is officially no longer advocated in children."[110] The use of the adult RSII in children has been also criticized.[111] A modified version, without CP, and with emphasis on complete muscle paralysis (to avoid coughing, bucking, and straining), gentle ventilation, and maintenance of anesthetic depth before intubation has been proposed.[111]

Other Controversies

CP and Laryngoscopic View

It is well known that when the larynx is displaced cephalad or moved in an upward and backward direction, the laryngoscopic view is improved.[112–115] However, the effect of CP on the laryngoscopic view is a matter of debate. CP has been demonstrated to improve the laryngoscopic view, although it worsens the view in 14 to 45% of patients.[29,116] Some studies have shown that the improved view could be further enhanced by applying CP in an upward and backward direction.[117] Other studies have demonstrated that the combination of the backward, upward, and rightward pressure maneuver with CP worsened the laryngoscopic view in 30% of cases and suggested that there is no benefit in routinely adding the backward, upward, and rightward pressure maneuver when CP is applied.[118] Another investigation demonstrated an improved view of the glottis when a Truview Evo2TM laryngoscope (Truphatek Holdings Ltd, Israel) and 40-N cricoid force were used.[119] In contrast, a recent study showed that CP hinders tracheal intubation when the Pentax-AWS Airwayscope® (AWS; Hoya, Japan) is utilized.[120]

Neck support has been introduced to improve laryngoscopic visualization by preventing head flexion on the neck during CP application.[121] Two methods have been described: placing a cuboid of firm foam rubber support under the neck[122] and bimanual CP application.[121] In the latter approach, one hand performs CP, while the second hand is placed behind the patient's neck to exert counter pressure. Two investigations demonstrated that neck support did not improve the laryngoscopic view.[117,123] A third investigation suggested that the view was better with the bimanual as compared with the single-handed technique.[124] This investigation also suggested that bimanual CP should be the initial method of choice, but that, in a subset of patients, a single-handed CP maneuver may enhance laryngeal visulization.[124]

CP and Supraglottic Devices

Although the role of the LMA in the management of patients with difficult airways has been established,[125] there exists uncertainty about its role in patients who are also at increased risk of aspiration.[126] When CP is applied before LMA insertion, its correct positioning is impeded and adequate ventilation may not be established.[97,127,128] Conversely, although application of CP after LMA placement prevents gastric insufflation,[129] it makes ventilation difficult.[130] This impediment to ventilation is greater without neck support.[130] CP also interferes with subsequent fiberoptic intubation through the LMA regardless of timing of application.[131] The success rate of fiberoptic intubation without CP has been estimated to be between 89 and 95%.[128,131,132] When CP is applied before LMA insertion, the success rate of fiberoptic intubation is only 15%, and release of CP increases the success rate by an additional 20%.[128] When CP is applied after LMA insertion, the success rate of fiberoptic intubation is 60% and the time for intubation is prolonged.[128,131] The success rate of the placement of the i-gel and ventilation through it are also affected by CP but to a lesser extent as compared with the LMA.[132] This is probably related to the design of the i-gel (Intersurgical Ltd, United Kingdom), which is based on the anatomy of larynx rather than the anatomy of the hypopharynx.[132]

The aforementioned findings imply that if CP is used before or after LMA placement, neck support is desirable.[130,131] However, CP may need to be temporarily released to allow correct LMA positioning and facilitating intubation through the LMA. Because of the complexity associated with the combined use of CP and LMA, in patients with predictable difficult airways, who also are at increased risk of aspiration, an approach to awake intubation should be considered.[131,133]

To Ventilate or Not to Ventilate during CP Application

In Sellick's[1,134] original description in 1961, he used manual ventilation during CP before securing the airway. Later, Wylie[135] in 1963 and Stevens[136] in 1964 proposed that ventilation should be delayed until tracheal intubation is completed.[135,136] They hypothesized that positive-pressure ventilation before intubation increases the risk of gastric inflation and the potential for regurgitation.[135,136] Because maximal preoxygenation before anesthetic induction delays the onset of arterial hemoglobin desaturation during apnea, manual ventilation may not be required in healthy patients with normal airways before tracheal intubation.[137] However, in patients with limited oxygen reserves (increased oxygen consumption or decreased functional residual capacity) and if tracheal intubation cannot be easily accomplished, manual ventilation may be necessary to maintain oxygenation.[111]

CP and Lower Esophageal Sphincter

Investigations concurred that CP is associated with a substantial reduction in the tone of the lower esophageal sphincter, without a change in intragastric pressure.[138–140] Thus, the higher the applied force, the lower the esophageal sphincter tone.[138,139] Decreases of 78% have been reported with the use of 44-N cricoid force, and in some patients, the barrier pressure (lower esophageal sphincter—intragastric pressure) disappeared completely.[139] Even a moderate force of 20 N can be associated with a 38% decrease in the lower esophageal sphincter tone.[138] Upon release of CP, the lower esophageal sphincter tone returns immediately to its baseline value.[139]

The mechanism of relaxation of the lower esophageal sphincter tone with CP appears to be "reflex" in nature, triggered by stimulation of mechanoreceptors in the pharynx, and is similar to that which occurs during swallowing, LMA placement, and pharyngeal stimulation.[138,139,141–144] Although metoclopramide increases the lower esophageal sphincter tone, it does not attenuate CP-induced relaxation of the lower esophageal sphincter (Fig. 2). These findings are consistent with a reflex mechanism.[139] CP-induced relaxation of the lower esophageal sphincter can be abolished by remifentanil infusion and a bolus of propofol, suggesting that blocking pain and discomfort can prevent activation of the pharyngeal mechanoreceptors.[145]

Based on the assumption that a decreased barrier pressure facilitates gastroesophageal reflux, especially when associated with elevated intragastric pressure,[146] it has been proposed that the occurrence of aspiration during CP could be due to concomitant decrease in the lower esophageal tone.[138] However, this is rather unlikely. First, improper CP application cannot be ruled out in the patients who aspirated.[39] Second, CP is intended to substitute for the loss of the upper esophageal tone associated with muscle relaxation and not to prevent gastroesophageal reflux.[139] Third, it is difficult

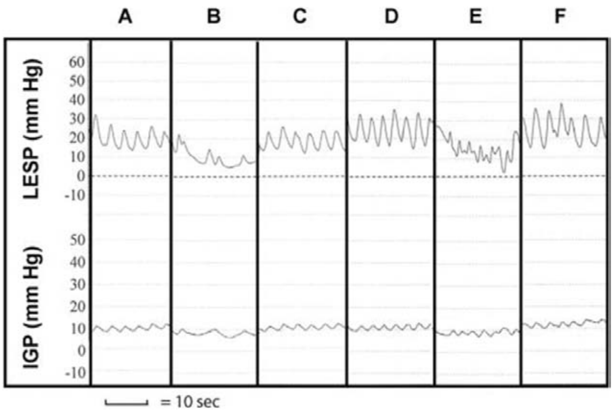

Fig. 2. A typical tracing showing lower esophageal sphincter pressure (LESP) and intragastric pressure (IGP) recordings before application of cricoid pressure (*A*), during application of cricoid pressure (*B*), after release of cricoid pressure (new baseline; *C*), after administration of 0.15 mg/kg metoclopramide (*D*), during application of cricoid pressure (*E*), and after release of cricoid pressure (*F*). Paper speed = 1 mm/s. Reproduced with permission from Salem MR, Bruninga KW, Dodlapatii J, Joseph NJ: Metoclopramide does not attenuate cricoid pressure-induced relaxation of the lower esophageal sphincter in awake volunteers. ANESTHESIOLOGY 2008; 109:806–10. Wolters Kluwer Health.

to ascertain the barrier pressure at which gastroesophageal reflux occurs.[147] For example, the incidence of aspiration associated with the use of supraglottic devices, which also decreases the lower esophageal sphincter tone, is similar to that associated with tracheal intubation.[148]

CP and Gastric Tubes

In his original publication, Sellick[1] hypothesized that the presence of the Ryle tube (the soft latex nasogastric tube [NGT] commonly used at that time) could render the upper and lower esophageal sphincters less competent and may also hinder the effectiveness of CP. Accordingly, he recommended removal of the Ryle tube after final suctioning before anesthetic induction.[1] After anesthetizing more than 100 patients at risk of aspiration using CP, he modified his view and endorsed the safety of keeping the Ryle tube in place during anesthetic induction and CP.[2,77] Studies in cadavers confirmed the effectiveness of CP in obliterating the esophageal lumen around an NGT made of polyvinyl chloride.[17,18] It has also been demonstrated that during CP, the NGT is squeezed sideways in the part of the esophageal lumen that is relatively less compressed,[26] suggesting that placement of an NGT improves cricoid compression.[26,27]

Unfortunately, Sellick's early recommendation for the removal of the NGT before anesthetic induction has been widely practiced.[149] Based on the belief that the presence of the NGT interferes with the lower esophageal sphincter competency, withdrawal of the NGT to the midesophagus has also been suggested.[150] Recently Salem *et al.*[77] proposed an algorithm for airway management in patients prone to aspiration. The algorithm recommends that the NGT should be connected to suction before and during anesthetic induction. When an unanticipated increase in intragastric pressure occurs, a functioning NGT would allow release of gastric contents, whereas CP prevents these contents from being aspirated.[77]

Complications and Contraindications

A number of complications associated with the use of CP have been reported, most being the consequences of airway obstruction.[62,94–101] Minor complications include discomfort, retching, and nausea in the awake patient.[6,27,48,62,100,101,105,151] Other very rare but serious complications have been described, including esophageal rupture,[151,152] esophageal injuries due to the presence of sharp objects,[153] fracture of the cricoid cartilage,[154] and potential worsening of cervical spine injuries.[155,156] Consequently, contraindications for the use of CP have emerged, some based on reported complications and others on merely theoretical grounds. For example, it has been suggested that CP should be avoided in patients with retropharyngeal abscess because of the possibility of rupture of the abscess.[5] However, such a complication has not been reported.

Esophageal Rupture Due to Forceful Vomiting

From its inception, esophageal rupture has been considered a risk when vomiting occurs during the application of CP.[157] We found a single report from 1991, which described an esophageal rupture in an 81-yr-old woman who had vomited while undergoing RSII.[152] However, a review of this case suggests that CP did not have a causal role in the esophageal rupture. During surgery, a 10-cm longitudinal split in the wall in the lower esophagus, extending across a small hiatus hernia, was revealed. In all probability, the hiatus hernia provided a vulnerable site for rupture.[152] The mechanism of this rupture is similar to that of a spontaneous rupture during active vomiting when the cricopharyngeus muscle fails to relax. The rapid build-up of pressure in the esophagus leads to rupture at the weakest point, usually at the posterior wall at the extreme lower end.[152] Sellick[157] emphasized that the risk of rupture should be nonexistent if anesthetic induction is correctly performed—that is, unconsciousness, full muscle relaxation, and CP are timed to occur simultaneously.

Esophageal Injuries Caused by Sharp Objects

CP could be injurious to patients with sharp objects in the esophagus, such as bone chips.[153] In this scenario, CP in the awake patient can cause sharp pain, whereas after anesthetic induction, it can potentially result in puncture of the esophagus.[155] A study in 15 cadavers found that CP in the presence of a sharp object did not cause esophageal damage.[158] This determination was made *via* the naked eye, and therefore, the risk of mediastinitis cannot be excluded.[153] The decision to use CP when a sharp object is knowingly present in the esophagus should be based on a balance between potential risks and benefits.

Fracture of the Cricoid Cartilage

The ability of CP to cause injury to the cricoid cartilage warrants address. The evidence for this complication is not compelling. We uncovered a single report of fracture of the cricoid cartilage in a 67-yr-old patient with status asthmaticus during RSII.[154] This patient had a history of a hanging accident when he was 19-yr-old, which was associated with laryngeal trauma. It cannot be ruled out that this event and the patient's long-term steroid therapy contributed to the fracture.[154] It is highly unlikely that a normal cricoid cartilage would undergo a fracture during CP, even if the application was forceful.[154]

Potential Worsening of Cervical Spine Injuries

It has been hypothesized that any unidirectional force applied to the cervical vertebrae during CP may cause excessive neck movement and exacerbate preexisting injuries.[156] Studies demonstrated that CP causes cervical spine movements (varying from minimal to significant) when the posterior aspect of the neck is not supported.[62,156,159–161] The clinical implication of these movements was assessed retrospectively in patients who had cervical spine injuries and found to be free of neurologic sequelae.[159] However, it would be sensible to avoid movements of the potentially fractured cervical spine, if at all possible.[156] The double-handed CP maneuver, which has been popularized in trauma patients to support the posterior cervical spine and to provide stabilization to the posterior aspect of the neck, seems to be a safer alternative to the single-handed CP maneuver.[155,156] The assistant performing bimanual CP should not be assigned to other duties until intubation is completed.[155,156] Furthermore, the bimanual technique may need to be switched back to a single-handed maneuver to improve laryngoscopic visualization.[117,123]

Techniques of CP Application and Training

Position of the Head and Neck

In his original description, Sellick[1] maintained the head and neck in an extended (tonsillectomy) position. This was intended to stretch the esophagus, prevent its lateral displacement, and bring it posterior to the cricoid cartilage.[1] In a second publication, he modified the position to a slight extension.[2] This position was criticized[8] because, unlike the sniffing position (extension of the head and flexion of the neck), it does not facilitate laryngoscopic visualization.[162,163] Currently, clinicians are in agreement that CP can be done in the sniffing position since the extension of the head component provides all that is needed for effective esophageal compression while maintaining an optimal laryngeal view.[164]

In his studies, Sellick[1] used the steep Trendelenburg position after intubation was completed to test the effectiveness of CP. This position was also criticized[8] on the basis that it is no longer practiced for RSII. It should be stressed that Sellick[1,2] used this position intentionally as an experimental maneuver "to induce regurgitation" and was not recommended for routine use.

One Hand, Which Hand, or Two Hands?

The single-handed three-finger maneuver remains the most popular method used.[1] Typically, CP is applied with the right hand (the dominant hand in most individuals) from the patient's right side.[40] Because this hand may interfere with the movement of the laryngoscope blade, the use of the left hand has been suggested.[165] However, studies have shown that CP can be performed with either hand.[40] Although application with the left hand can be justified, the force may become inadequate if it needs to be sustained.[40] The double-handed (bimanual) maneuver has been popularized in trauma and obstetrical patients.[121,122,155,156] Claimed advantages for this approach include prevention of head flexion on the neck, protection of the cervical spine, and in some cases, improved laryngeal visualization.[121,122,155,156]

How Long Can the Force Be Sustained?

Because of pain and fatigue, a 30-N force is difficult to sustain for a long period.[166] At this force, the shortest time to forced release is approximately 3.5 min.[166] This duration is far more than adequate in the vast majority of patients. However, a 20-N force, which provides adequate protection in most patients, could be maintained for longer than 9 min in case of failed intubation.[166] The use of the extended arm doubles the time to pain and fatigue, but, since the operator's hand may obstruct the laryngoscope handle, this approach is not recommended for routine use.[166]

Use of Devices

Reports have documented improper CP application by a large percentage of operators (47 to 63%).[39,44–47,167–169] Thus, it is no surprise that some airway experts and healthcare provider instructional programs no longer advocate the routine use of CP.[170,171] Indeed, the updated guidelines for Advanced Cardiac Life Support in 2010 stated, "the routine use of CP in cardiac arrest is not recommended."[23,94,99–101,105,170–174] One major problem with the use of CP is that excessive force is applied in the first 5 s, followed by a progressive loss of force in the next 20 s.[167] The wide variation in application and the lack of skilled assistance have prompted the need for proper training and stimulated interest in the design of devices that could provide consistent and reliable CP.[52,167,168] An ideal device should[52] (1) cause no trauma; (2) not interfere with intubation; (3) allow accurate placement on the cricoid cartilage without laryngeal distortion; (4) be simple to use, requiring the minimum acquisition of new skills; (5) indicate to the clinician that the set force has been reached; and (6) be able to provide a wide range of forces (5 to 40 N) and sustain it for 10 min, if needed. Unfortunately, such a device is currently unavailable. Various home-made devices have been described in the literature, and several patents that vary in design have been registered.[46,52,169] The inventors claim that their devices are easy to use and require no previous experience. Some are used as mechanical simulators for training purposes.[167,168,171] So far, none is available commercially. A few of these devices will be discussed briefly.

The first device introduced for CP application was the cricoid yoke (Fig. 3A).[52,168] It consists of a perspex and steel construction having three components: molded concave sponge cushion with a surface area of 10 cm^2 to be applied to the cricoid cartilage, perspex platform activated by means of a contact breaker, and stainless steel flexible wings. The instrument is gripped between the forefinger and thumb by means of the upturns at the tips of the wings (Fig. 3A). The light appears only when the selected force has been reached. Another perspex device, which operates on a hydraulic principle, has also been described (Fig. 3B).[167]

A tactile, plastic, and single-use instrument has been developed recently.[175] This device, which utilizes a wedge and pin combination, has feedback capabilities.[175] The operator grasps the central portion of the appliance using the three-finger maneuver. The lower concave section is placed on the cricoid cartilage, and a downward force is applied. The device is equipped with two locking mechanisms: one,

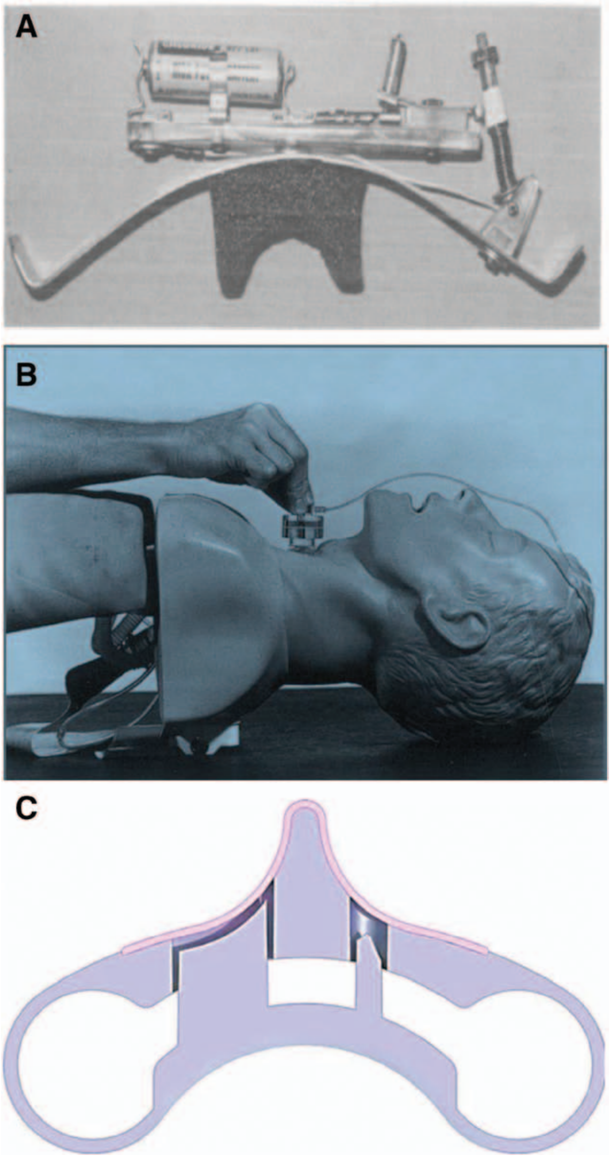

Fig. 3. Three cricoid compression devices. (*A*) The "cricoid yoke" is comprised of a moulded foam contact cushion that is applied to the cricoid cartilage, a perspex platform carrying a simple circuit, and stainless steel flexible wings. The device is gripped between the operator's forefinger and thumb by means of the upturns at the tips of the wings. (*B*) A cricoid pressure measuring device that is utilized by applying a three-finger technique (as shown). (*C*) A cricoid pressure measuring device that utilizes a wedge and pin combination. (*A*) is reproduced with permission from Lawes EG: Cricoid pressure with or without the "cricoid yoke." Br J Anaesth 1986; 58:1376–9. Oxford Journals; (*B*) is reproduced with permission from Ashurst N, Rout CC, Rocke DA, Gouws E: Use of a mechanical simulator for training in applying cricoid pressure. Br J Anaesth 1996; 77:468–72. Oxford Journals; (*C*) is reproduced with permission from Taylor RJ, Smurthwaite G, Mehmood I, Kitchen GB, Baker RD: A cricoid cartilage compression device for the accurate and reproducible application of cricoid pressure. Anaesthesia 2015; 70:18–25. Wiley Online Library.

when a 30-N force is exerted and another, when a 35-N is reached. By careful titration of the force, the operator can be assured that the cricoid force is between 30 and 35 N (Fig. 3C).[175] Another recently described device, which consists of a thin force-sensitive resistors, is designed to be placed on the skin over the cricoid cartilage. Using the three-finger maneuver, the operator can correctly gauge the appropriate cricoid force.[176]

Floor weighing scales have been successfully utilized as a guide to apply the correct cricoid force.[177] While the operator is standing on the floor scale, CP is applied until the weight registered is 2.5 to 3.5 kg less than the initial weight of the operator.[177] This translates into an applied cricoid force between approximately 25 and 35 N (1 kg = 9.8 N).[175] We found that the use of floor weighing scales provides easy means to train residents in applying the correct force (Fig. 4). It is essential that the operator stands upright on the scale and that the force is applied in a downward direction.

Training

Studies utilizing technology-enhanced CP simulation have demonstrated marked improvement in applying the correct force.[44,45,171,178] With proper training, the cricoid force can be reproducible within 2 N.[25,45] A period of practice after instructions is necessary for trainees to learn the correct force.[44,45,52,171] All personnel performing the maneuver should undergo training. Because retention of this skill varies between 2 weeks and 3 months, periodic training is necessary.[44,45,167,171] Misapplication[169] (applying pressure to the thyroid cartilage instead of the cricoid cartilage) can be remedied by including the anatomy of the larynx in the training sessions, stressing the unique features of the cricoid cartilage. It is important to identify the cricoid cartilage before anesthetic induction by rolling the fingers from the thyroid cartilage downward. Marking the cricoid cartilage may be necessary in morbidly obese patients. A large-size laryngotracheal anatomical model, which is placed on a calibrated infant scale, is commonly used for assessing and practicing the recommended cricoid force.[45] (Fig. 5) The scale readout is programmed, so that the force is registered in kilograms and converted to Newtons.[45] Another simple method has proved to be a valuable training tool.[177–179] This method requires a fresh Luer Lock 50- to 60-ml syringe filled with 50 ml of air. The syringe is capped and placed upright. The plunger is depressed (using the three-finger maneuver) by 12 ml to the 38-ml mark to apply 20-N force and by 17 ml to the 33-ml mark to achieve a 30-N force.[180,181]

Conclusions

It is now apparent that CP is not a "simple maneuver that can be taught to an assistant in a few seconds,"[1] as once thought. Although CP was introduced into anesthesia practice more than half a century ago, it is currently not the standard of care. Questions regarding its use remain unanswered. Many

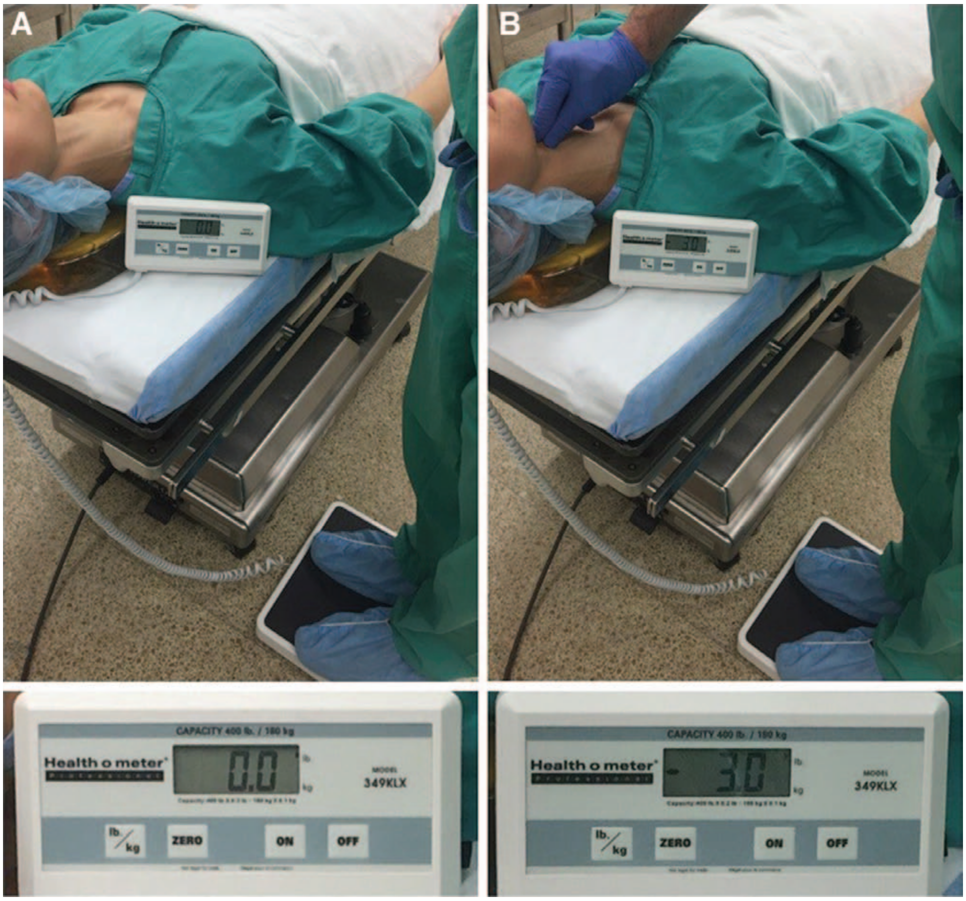

Fig. 4. The operator stands upright on a floor scale. The scale is zeroed to the operator's weight before application of cricoid pressure (*A*). The proper force (3 kg) is determined from the decrease in recorded weight when cricoid pressure is applied (*B*).

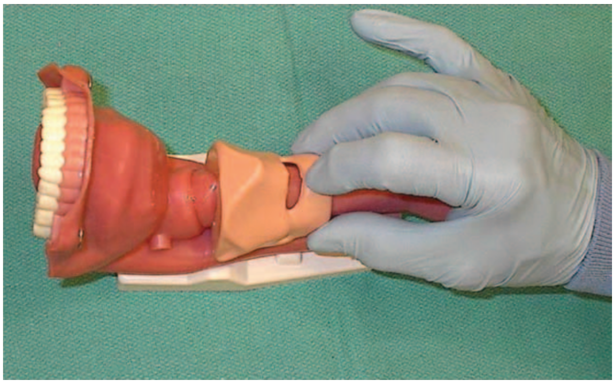

Fig. 5. A laryngotracheal model placed on a calibrated weighing scale is commonly used for applying the appropriate cricoid force.

clinicians use a 30-N cricoid force, but should this force be used in all situations and how should it be measured? Is there a difference between the sexes? Should a different force be used in the morbidly obese or in children? What is the desirable force when CP is combined with other maneuvers, such as head-up position or preanesthetic NGT placement? A wider acceptance of CP has been hampered by the lack of reliable randomized studies demonstrating its reliability in preventing aspiration. The performance of such studies requires that many factors be standardized, including the CP technique and the force applied. A simple comparison of two groups of patients, one with and the other without CP, while ignoring these factors, will yield misleading information and results that are difficult to interpret.

In using CP, the release or adjustment of the cricoid force is justified, particularly if the glottic view is distorted or when mask ventilation or tracheal intubation is not optimal. There are also circumstances when CP (and the entire RSII) is undesirable. In these situations, the anesthesiologist has other options if general anesthesia is to be administered to patients at risk of aspiration. These include awake intubation and the use of 40° head-up position during anesthetic induction in adults.

Recent surveys and guidelines indicate the common use of CP.[182–184] However, some anesthesiologists have advocated abandonment of CP.[185] This does not seem justified on several grounds. First, in the last 7 yr, two well-conducted studies, using different methodologies, have provided convincing evidence of the effectiveness of CP in occluding the esophageal inlet.[24,25] Second, the common belief that aspiration is very rare and the consequences are mild has been shattered by the report of the 4th National Audit in the

United Kingdom, showing that aspiration is the single most common anesthesia-related cause of death.[76] The report further indicated that not all qualifying events were submitted, and the real incidence could be up to four times greater than that reported.[186,187] Other studies concur that aspiration of gastric contents is still the commonest cause of deaths associated with airway anesthetic management and remains a serious concern of anesthetic-related morbidity.[74,188]

Lastly, like other airway management techniques, the use of CP requires preparatory instruction and periodic training. Future investigations are warranted to determine the characteristics of the CP technique that maximize its effectiveness while avoiding the risk of airway-related complications in the various patient populations.

Research Support

Support was provided solely from institutional and/or departmental sources.

Competing Interests

The authors declare no competing interests.

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