The critical airway, rescue ventilation, and the Combitube: Part 1

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Emergency and unexpected difficult airway management can rapidly deteriorate into a critical airway event such as "cannot ventilate, cannot intubate" (CVCI). A critical airway event (ie, inadequate mask ventilation, failed intubation, and CVCI) can be resolved by rescue ventilation, thus avoiding potential neurological disability or death. Recommended options include use of the laryngeal mask airway, the esophageal-tracheal Combitube (ETC; Tyco-Healthcare-Nellcor, Pleasanton, Calif), transtracheal jet ventilation, or a surgical airway.

This article reviews proper use of the ETC in combination with the self-inflating bulb (SIB) and/or portable carbon dioxide detector to resolve critical airway situations. The combined use of these 3 devices provides an ideal integrated system for airway control and ventilation. In addition, critical airway events and rescue ventilation options; ETC design, technical aspects, training, insertion, and ventilation; determining ETC location (ie, esophagus vs trachea); and monitoring ETC lung ventilation are reviewed.

The SIB primarily assesses ETC location within the esophagus or the trachea; the carbon dioxide detector also permits monitoring lung ventilation. Use of the ETC in prehospital, emergency medicine, and anesthesia settings, including ETC advantages, contraindications, and reported complications will be reviewed in Part 2. How to safely exchange the ETC for a definitive airway also will be reviewed.

Key words: Capnography, Combitube, critical airway event, esophageal detector device, rescue ventilation.

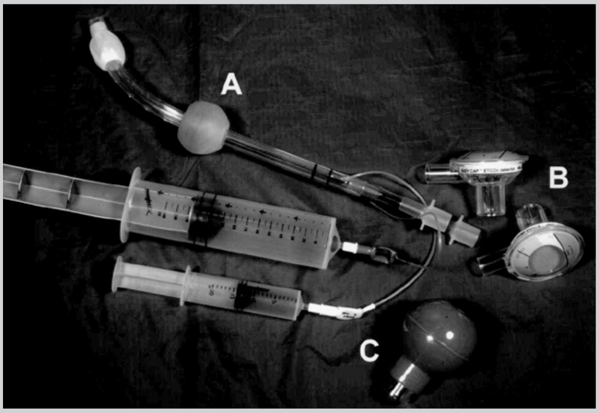
Success or failure of emergency airway management in the prehospital setting,[1] non–operating room hospital locations,[2,3] or the operating room[4-7] is based on multiple factors. Beyond the requirement for basic training and advanced skill in airway management, these factors include familiarity, availability, and application of decision making strategies,[8-13] airway drugs,[2-4,8] adjunctive airway devices,[4,7,8,14,15] apparatus to distinguish esophageal from tracheal intubation,[16-19] and monitoring of lung ventilation.[1,4,16-21]

In 1990, Caplan et al[5] reported an 85% incidence of death or brain damage in an analysis of closed liability claims related to adverse respiratory events that had occurred in anesthesia through 1985. The 3 leading causes of death or brain damage in 72.2% of the adverse respiratory events (377/522) were inadequate ventilation (196/522 [37.5%]), undetected esophageal intubation (94/522 [18.0%]), and difficult intubation (87/522 [16.7%]).[7] Airway management algorithms,[8-13] adjunctive devices to effectively manage the airway when tracheal intubation is not possible,[14,15] and portable devices for confirmation of correct placement of the breathing tube[16-19] and monitoring of lung ventilation[16,21] have assisted in improving the safety of airway management in recent years.[6,19,21] This article is intended as a review of the esophageal-tracheal Combitube (ETC) (Tyco-Healthcare-Nellcor, Pleasanton, Calif) for rescue ventilation[12,13,22,23] and airway control during emergency airway management when used in conjunction with the self-inflating bulb (SIB)[24] and portable carbon dioxide detectors[19,25,26] (Figure 1).

Use of rescue ventilation to resolve a critical airway event

Tracheal intubation remains the preferred method of lung ventilation and airway protection.[27] However, tracheal intubation is not always possible, a problem that sometimes is experienced with the unanticipated difficult airway.[4] The difficult airway reveals a complex relationship among patient factors, the clinical setting, and the skills of the practitioner.[8] The level of difficulty can vary, and problems can surface without warning during mask ventilation or tracheal intuba-

Figure 1. An integrated system for airway control and ventilation



(A) The esophageal-tracheal Combitube 41F (Tyco-Healthcare-Nellcor, Pleasanton, Calif) displayed with (B) the portable carbon dioxide detector and (C) the self-inflating bulb.

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tion. In addition, some patients who are difficult to ventilate with a mask may be easy to intubate and vice versa.[28] Airway difficulty can lead to a critical airway event, which is indicated by the following: (1) any "cannot ventilate, cannot intubate" (CVCI) situation; (2) 3 or more tracheal intubation attempts or 10 minutes or longer attempting tracheal intubation; or (3) sustained hypoxemia ($Sp{O_2}$ ″ 92%)[13] that is refractory to positive pressure ventilation with 100% oxygen.[29] The worst-case scenario of a critical airway event is death due to the CVCI situation.

Recommendations for dealing with CVCI include use of the laryngeal mask airway (LMA), ETC, TTJV, and a surgical airway.[8-13] Both the LMA and ETC should have a higher priority for rescue ventilation than TTJV or a surgical airway because both facilitate lung ventilation, can be inserted blindly, require minimal skill or training, and have few reported complications.[9,21] The ETC and LMA are currently the only 2 adjunctive airway devices with a class IIa recommendation from the American Heart Association.[30] The American Heart Association class IIa designates a therapeutic option for which the weight of evidence is in favor of its usefulness and efficacy.[31] Rescue ventilation involves using 100% oxygen and positive pressure ventilation, ideally via an American Heart Association class IIa adjunctive airway device, to resolve a critical airway event.[29,30]

A working definition of *inadequate or difficult mask ventilation* is the inability to prevent or reverse signs of inadequate ventilation with 1- or 2-person positive pressure bag-valve-mask (BVM) ventilation, using an oropharyngeal or nasopharyngeal airway (or both), and 100% oxygen.[4,8,21] *Failed intubation* is failure to intubate the trachea after multiple attempts, with or without resulting hypoxemia.[8,12,29] Intubation is considered difficult when multiple laryngoscopy attempts, maneuvers, and blades are needed.[28]

The concept of the "crash airway" was introduced by Walls.[10] The crash airway situation occurs infrequently among critical airway events yet requires rapid intervention. Crash airway indicates severe acute respiratory failure in patients who require immediate ventilation and oxygenation. Recently revised indications of the crash airway situation include patients with the following characteristics: (1) unresponsive or minimally responsive, (2) bradypneic (respiratory rate, < 10/min) or tachypneic (respiratory rate, > 30/min), and (3) severely depleted oxygen levels.[29] Mason et al[13] recently proposed a new concept for rapid recognition of the patient with a crash airway.

Mason's PU-92 concept uses a simple method that can be easily memorized.[13] It draws on 2 accepted principles: (1) the need to keep the $Sa{O_2}$ above 90%[4,8,10,13,20] and (2) the importance of rapidly assessing the level of consciousness as a predictor of potential airway problems.[32] It combines an assessment of the level of consciousness using the AVPU scale in conjunction with the $Sp{O_2}$ reading.[13,33] The AVPU system specifies 4 levels of consciousness: (1) A, alert; (2) V, responsive to a voice but not necessarily alert or oriented; (3) P, responds only to pain; and (4) U, unresponsive to pain.[33] An AVPU score of P or U corresponds to a Glasgow Coma Scale score of 8 or less, which shows that the patient meets one of the criteria for intubation.[13,32,33] The PU-92 concept recognizes the fact that pulse oximeters have a tolerance of ± 2%.[20] Therefore, a "yes" answer to the question "PU ″ 92?" following maximal efforts with positive pressure BVM ventilation and 100% oxygen is indicative that a crash airway situation exists.[10,12,13] Rapid recognition and treatment of a patient with a crash airway is vital for there to be any chance for survival.[10]

When a critical airway event occurs, success likely will pivot on timely implementation of rescue ventilation. If the clinical situation suggests that tracheal intubation is likely to be impossible, one should not persist with intubation attempts. Reversal of inadequate mask ventilation by rapid tracheal intubation obviates the need for rescue ventilation. However, allowing inadequate mask ventilation to continue can lead to brain damage or death.[5,21] Attempting intubation beyond several times (by the most experienced laryngoscopist) usually will not lead to success, but rather might cause bleeding and trauma in the airway and potentially create a CVCI situation.[5,7,21] If rescue ventilation is effective (ie, SpO_2 improves to > 92%), a definitive airway can be established by some other means while oxygenation is maintained. If rescue ventilation is ineffective (ie, SpO_2 does not improve or deteriorates), the next step would be to proceed with TTJV or a surgical airway.[4,8,10-12,29]

The ETC vs LMA as a rescue airway option

Much evidence exists on the benefits of the LMA for resolving problems with difficult intubation and difficult ventilation.[34,35] The literature is equally replete with examples of how the ETC has been used as an effective option for rescue ventilation and airway control during emergency airway management (Table).[36-58] Both the ETC and LMA have been available as devices for rescue ventilation and airway control for difficult airway management since the 1980s.[14,15] However, both remain underused options in emergency medicine.[59] The ETC continues to be underused in anesthesiology,[60] despite the long-standing recommendation by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway for its inclusion in the airway kit for difficult airway management and especially for CVCI situations.[8]

Anesthesia providers generally are more accustomed to the LMA than the ETC for difficult airway management and rescue ventilation because of the widespread use of the LMA for general anesthesia.[21,35] However, there are good clinical reasons for anesthesia practitioners to familiarize themselves with the ETC. Anesthesia practitioners who do not use the ETC to resolve a critical airway event such as failed intubation,[28,29,43,45] difficult mask ventilation,[4,8] CVCI,[49,55,56] or a crash airway situation[10,12,13] still might be required to provide anesthesia care for patients in whom the ETC has been inserted by another practitioner to control the airway before the patient arrived in the operating room. In addition, reports exist of successful rescue ventilation being provided by the ETC when the LMA had failed.[55,56]

Although the LMA does not provide an airtight seal around the larynx beyond 20 cm H_2O or completely protect the trachea from aspiration,[21] it does provide reasonable protection against aspiration of regurgitated gastric contents, as evidenced by the much lower level of aspiration than seen with BVM ventilation in conjunction with an oropharyngeal or nasopharyngeal airway (3.5% vs 12.4%, respectively).[61] However, in trauma, and particularly in patients with maxillofacial injuries, the risk of aspiration of gastric contents is likely to be less than the risk of aspiration of blood, and the cuff of the LMA has been shown to provide effective protection against the aspiration of blood arising from the oropharynx.[62]

In the esophageal position, the ETC prevents aspiration by sealing the esophagus rather than the trachea.[21] However, one study[63] found tracheal soiling in some patients (2/27),[63] whereas several other studies[64-66] found complete airway sealing with the ETC in the esophageal position. In the tracheal position, the ETC seals the trachea like an endotracheal tube (ETT).

For rescue ventilation in the patient with a full stomach, the choice of device (ETC vs LMA) is likely to be influenced by several factors, including the following: (1) ease of insertion, (2) availability and familiarity with the device, (3) the greater effectiveness of the ETC in sealing against gastric regurgitation and aspiration, and (4) the ability to use airway pressures in excess of 20 cm H_2O (favoring the ETC).

Beyond this, the airway management instruction anesthesia practitioners provide for paramedical personnel and others would be heightened by teaching both the ETC and LMA as rescue ventilation options when tracheal intubation is not possible.

ETC background, design, and technical aspects

Frass et al[67] invented the ETC as an improvement over the esophageal obturator airway (EOA).[68] It avoids the disadvantages and complications associated with the EOA.[27,68] During the 1980s, recommendations were made for paramedical personnel in the United States to use BVM ventilation or tracheal intubation instead of EOA.[69] Coincidentally, the ETC was introduced in 1987 to bridge the gap between the prehospital phase and arrival to the emergency department and for use when ideal conditions or trained staff for tracheal intubation were not immediately available.[70]

The ETC is available in 2 sizes. The original 41F ETC is for use in patients taller than 6 feet (180 cm)[71]; the size 37F ETC SA (small adult), which was introduced in 1995 and originally approved only for patients shorter than 5 feet, has been used successfully in patients between 3.9 and 6.5 feet (117-195 cm)[72] and is recommended for use in patients from 4 to 6 feet (120-180 cm) tall[73] who are older than 12 years.[27] However, based on the successful use in taller patients, Walz et al[72] recommends general use of the 37F ETC SA without any upper height limitations.

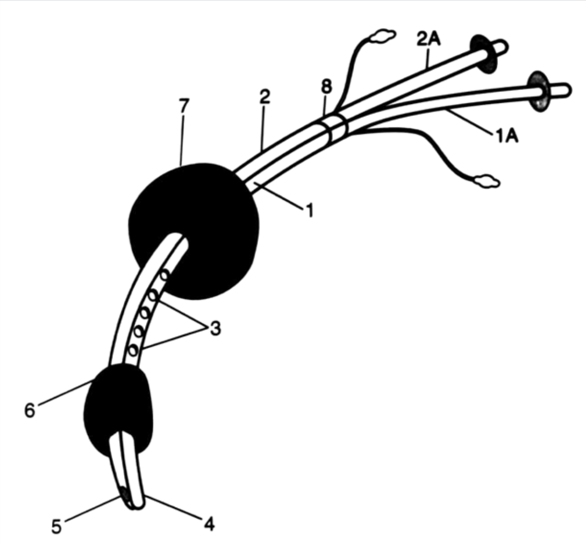
The ETC design (Figure 2) incorporates the benefit of the ETT and the positive aspects of the EOA.[68,74] It is marked with double rings just distal to where the 2 proximal tubes combine to form 1 tube with 2 lumens. The ETC facilitates lung ventilation when placed in the esophagus or the trachea. On insertion, the patient's

Table. Use of the Combitube (ETC) for rescue ventilation and airway control in various clinical settings

Year of report	Emergency airway situation	Clinical setting
1987	Difficult intubation secondary to bull neck with subsequent exchange to endotracheal tube using direct laryngoscopy[36]	In hospital: non–operating room
1988	For airway control during CPR[37]	In hospital: non–operating room
1991	CVCI: successful ETC intubation in 2 patients with rapidly developing cervical hematomas producing Cormack and Lehane grade IV laryngoscopic views[38]	In hospital: non–operating room
1992	Trauma patient with neck impalement with subsequent exchange of ETC with a surgical airway[39]	In hospital: emergency department
1992	CVCI: massive oropharyngeal hemorrhage associated with thrombolytic therapy[40]	In hospital: non–operating room
1993	Prehospital cardiac arrest[41]	Prehospital
1993	Morbidly obese patient with bull neck[42]	In hospital: non–operating room
1993	Failed intubation (ETC with esophageal detector device)[43]	In hospital: operating room
1993	Use of ETC for CPR by ICU nurses untrained in tracheal intubation[44]	In hospital: ICU
1994	Critical airway event after induction of general anesthesia from flexion deformity of the cervical spine due to rheumatoid arthritis[45]	In hospital: operating room
1995	CVCI, 2 cases of failed intubation and difficult mask ventilation resulting in acute hypoxia: (1) limited mouth opening; (2) profuse vomiting[46]	In hospital
1995	Failed intubation from severe acute facial and inhalation burn with subsequent exchange of ETC for ETT using direct laryngoscopy and flexible fiberscope[47]	Prehospital
1996	Asthmatic respiratory distress[48]	Prehospital
1996	CVCI: failed nasotracheal intubation with subsequent massive hemorrhage despite appropriate precautions[49]	In hospital: operating room
1997	Prehospital cardiorespiratory arrest[50]	Prehospital
1998	ETC intubation of 1,594 patients with nontraumatic cardiac arrest[51]	Prehospital
1998	Failed RSI in prehospital trauma patients with mandible fractures, facial trauma, and/or traumatic brain injury[52]	Prehospital
2000	ETC used for prehospital cardiac arrest patients (n = 195) by EMT-Ds (no intubation skills)[53]	Prehhospital
2001	Prehospital: ETC used for confined space airway control; ETC insertion performed through windshield to patient pinned between front seat and dash; exchanged using direct laryngoscopy[54]	Prehospital
2001	CVCI in 2 episodes in 1 patient: seriously ill patient in a halo frame in ICU; first episode of CVCI: LMA #4 was successful; second episode of CVCI: postextubation of ETT, LMA insertion proved to be impossible; blind insertion of 37F ETC SA provided rescue ventilation and airway control[55]	In hospital: ICU and operating room
2002	Case of CVCI in the operating room when a laryngeal mask failed[56]	In hospital: operating room
2002	For failed RSI of patients with severe head injuries[57]	Prehospital
2002	CVCI: rescue ventilation of a morbidly obese patient; exchanged to surgical tracheostomy with ETC in place[58]	In hospital: ICU

CPR indicates cardiopulmonary resuscitation; CVCI, cannot ventilate, cannot intubate; ETC, esophageal-tracheal Combitube (Tyco-Healthcare-Nellcor, Pleasanton, Calif); ICU, intensive care unit; ETT, endotracheal tube; RSI, rapid-sequence intubation; EMT-D, emergency medical technician providing basic life support or defibrillation; LMA, laryngeal mask airway; SA, small adult (ETC size).

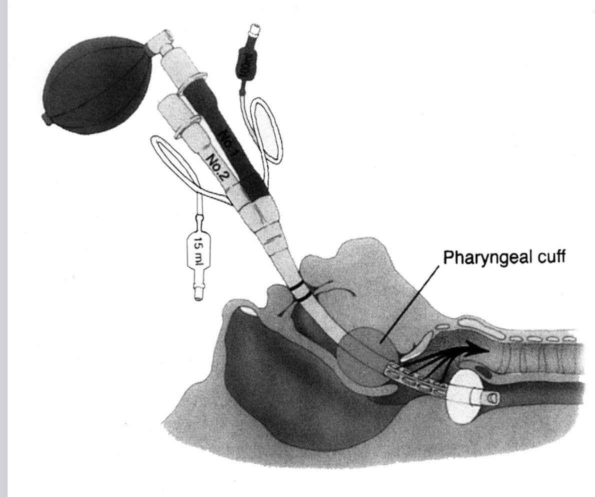
Figure 2. The esophageal-tracheal Combitube (Tyco-Healthcare-Nellcor, Pleasanton, Calif)



(1) "Esophageal obturator" or "pharyngeal" lumen; (1A) short tube for lumen 1; (2) "tracheal" or "tracheoesophageal" lumen; (2A) short tube for lumen 2; (3) perforations of lumen 1; (4) distal blind end of lumen 1; (5) open end of lumen 2; (6) distal cuff; (7) pharyngeal balloon; (8) printed rings indicating depth of insertion.

(Used with permission from Frass et al).[36]

Figure 3. Combitube (Tyco-Healthcare-Nellcor, Pleasanton, Calif) placement in the esophagus



The tube is advanced until the black rings are at the level of the teeth. The pharyngeal cuff is first inflated with 85 mL of air in the Combitube SA 37F and 100 mL of air in the Combitube 41F. This secures the tube in position and occludes the nasal and oral passages. The distal cuff is next inflated with 10 ± 1 mL of air in both sizes of the Combitube to seal the esophagus. Ventilation is first attempted through lumen No. 1 leading to the pharyngeal lumen.

(Used with permission from Suresh M, Wali A. Failed intubation in obstetrics: airway management strategies [guest editorial]. *Anesthesiol Clin North Am.* 1998;16:477-498.)

teeth or alveolar ridges should lie between these rings.

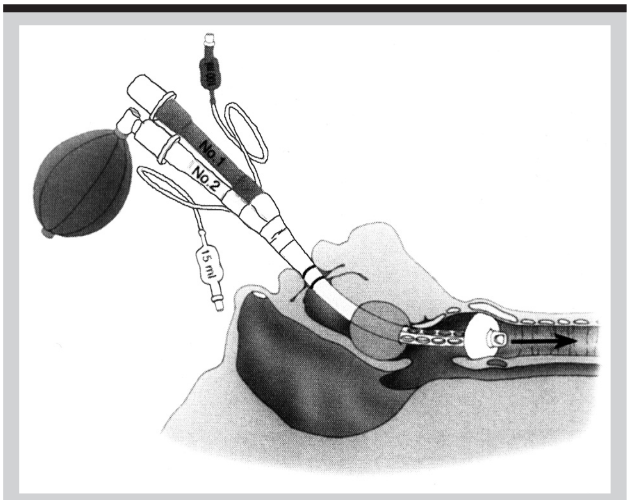
The large proximal oropharyngeal cuff (inflated with 85 mL of air with the ETC 37F SA and 100 mL with the ETC 41F) seals the upper airway. The small distal cuff is inflated with 5 to 12 mL in the ETC 37F SA and 5 to 15 mL in the ETC 41F. Inflation of the proximal oropharyngeal cuff automatically adjusts the ETC to the correct position and seals the airway in the oropharynx just posterior to the hard palate. This anchors the device securely for oxygenation and ventilation during transportation, thus obviating the need for further fixation.[15,54,57,74,75] The proximal oropharyngeal cuff occasionally might require an additional volume of 25 to 50 mL of air to provide sealing in some cases[72]; however, the maximum volume of the distal cuff must never be exceeded to avoid damage to the structures of the esophagus or trachea.[22,76] A small distal cuff inflation volume of 10 ± 1 mL is usually adequate for sealing with either size ETC.[74]

Current recommendations include inserting the ETC using a Macintosh laryngoscope blade[22,72,74,77] (if available), but it was designed originally for blind insertion during cardiopulmonary resuscitation by personnel untrained in direct laryngoscopy during prehospital care.[27,68] Depending on the ETC tip location after placement, the ETC seals the esophagus or trachea and provides airway protection, oxygenation, and ventilation comparable to that provided by routine tracheal intubation.[15,27,64-66,68]

The 2 proximal tubes of the ETC each have a 15-mm connector that is color marked and anatomically designated to correspond to the position it will occupy during ventilation of the lungs (ie, esophageal lumen or tracheal lumen).[55] The longer blue esophageal tube No. 1 is blind at the distal end but opens to side ports (pharyngeal perforations or ventilating eyes) located about midway down the ETC and normally is positioned in the hypopharynx with the ETC in the esophageal position. The side ports permit ingress of air, oxygen, and/or anesthetic gases and egress of exhaled gases with the ETC in the esophageal position. Therefore, ventilation is performed through the longer blue pharyngeal tube No. 1 when the ETC lies in the esophagus (Figure 3).

The shorter clear tube No. 2 (known as the distal or "tracheal" lumen) is patent at the distal end (like an ETT). Therefore, when the ETC occupies the trachea, ventilation is performed through the shorter

Figure 4. Combitube (Tyco-Healthcare-Nellcor, Pleasanton, Calif) placement in the trachea



The Combitube is placed in trachea; the ventilation is shifted to lumen No. 2 leading to the tracheoesophageal lumen.

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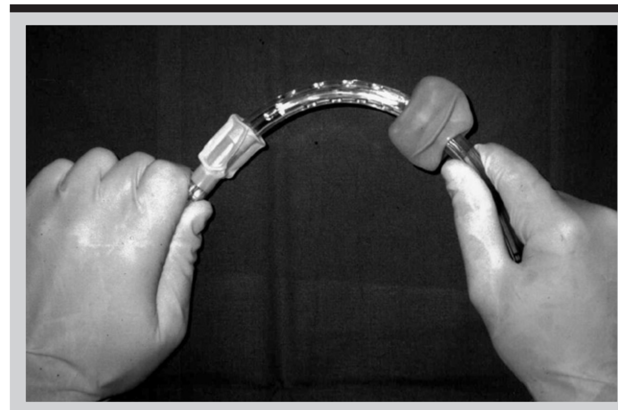
Figure 5. The Lipp maneuver



Hold the esophageal-tracheal Combitube (ETC; Tyco-Healthcare-Nellcor, Pleasanton, Calif) in the shaped position for several seconds just before insertion. Do not touch the area of the ventilating holes and the white cuff. During the time that the tip is returning to its original shape, it temporarily approximates the shape of the palatine pharyngeal arch. This facilitates easier advancement by keeping the tip from contacting the posterior pharyngeal wall at a right angle.

(Used with permission from Professor Markus Lipp, Johannes Gutenberg-University Mainz, Germany.)

clear tube No. 2, enabling it to function as an ETT with inhalation and exhalation occurring through the open distal lumen of the tube (Figure 4).

Manikin training with the ETC

Manikin training is important to facilitate and develop proficiency with the ETC.[41,44,51-53,68,74] Blind insertion usually results in esophageal placement.[13,27,68,77] To optimize the training, the ETC and the mouth of the manikin should be sprayed with silicone or a similar substance to avoid friction.[78] Bending the ETC at the pharyngeal portion between the cuffs for a few seconds (just before insertion; the so-called Lipp maneuver)[22,78] enhances the preformed curvature and eases insertion (Figure 5). For blind insertion, open the mouth of the manikin with the thumb and index finger of one hand by deeply inserting the thumb into the mouth and pressing the tongue in an anterior direction. Then perform a jaw thrust in such a way that the tongue is trapped under the thumb while the jaw is pulled forward. Pass the ETC gently into the mouth along the tongue, and pull the proximal end of the ETC cephalad while advancing the tube. This will position the lower curved portion of the ETC in a parallel orientation with the manikin's chest and keep the tip from contacting the posterior pharynx. The ETC should be inserted until the teeth of the manikin lie between the 2 black rings (see Figures 3 and 4). The proximal oropharyngeal cuff is inflated first, which will cause the ETC to rise slightly in the mouth and might cause the 2 black rings to lie above the teeth of the manikin. The distal cuff is inflated next. Since blind insertion usually results in esophageal placement,[15,27,68,77] the student should be taught to first attempt ventilation through esophageal port No. 1 (proximal blue tube). With these points in mind, the ETC has been inserted by thousands of participants in airway workshops within 10 to 20 seconds, and nearly all agreed that ETC insertion was faster and easier to learn than other alternative airway devices.[78]

ETC insertion

Rapid insertion with the ETC has been reported: 27 ± 8 seconds,[37] 16 ± 3 seconds,[64] and 12 to 23 seconds.[79] Although insertion using a laryngoscope can be practiced with a manikin, it is especially helpful during elective cases.[64-66] The laryngoscope is not used to facilitate tracheal intubation with the ETC but rather to facilitate esophageal insertion by holding the tongue out of the way, like the thumb is used during blind insertion.[27]

As discussed previously, the ETC works in the esophageal (see Figure 3) or tracheal (see Figure 4) position and does not require movement of the head or neck in patients with evident or suspected cervical spine injury or known cervical spine abnormalities.[36,39,44,45,68,80,81] However, it should not be inserted in patients with a rigid cervical collar in place because insertion with the anterior portion of the collar in place has been shown to decrease the rate of successful placement to less than 35%.[82] When using the ETC in this situation, the anterior portion of the collar should be removed while applying continuous manual inline axial stabilization of the neck and maintaining an absolutely neutral head position.[83] Once the ETC has been inserted successfully, the anterior portion of the collar should be reapplied immediately before releasing manual inline axial stabilization.

For blind insertion, the ETC is inserted in the midline of the mouth and parallel to the pharyngeal wall in a caudad direction along the tongue while performing a jaw thrust (Figure 6). Insertion at a right angle to the pharyngeal wall might cause resistance to advancement and can impede proper insertion of the ETC.[41] The aforementioned Lipp maneuver[22,78] is simple and effective for decreasing the incidence of contacting the pharyngeal wall at a right angle, thus simplifying ETC insertion (M. Lipp, Johannes Gutenberg-University Mainz, Germany, personal written communication, August 6, 1999) (see Figure 5).

To prevent injury to the upper airway, the ETC should always be advanced gently during insertion and immediately withdrawn and redirected if resistance to advancement is experienced. If persistent resistance to advancement is encountered despite using proper insertion technique, the ETC should be abandoned and another device used.[41] The ETC can be inserted blindly with the patient in virtually any position. This is beneficial when access to the patient is limited, such as during some prehospital care situations.[54,84] In addition, once the ETC tip location is ascertained, it is important to first inflate the proximal oropharyngeal cuff for proper placement and sealing of the ETC behind the hard palate. Inflation of the distal cuff before the proximal oropharyngeal cuff might anchor the ETC in the esophagus and prevent proper sealing in the oropharynx.[15,41,67,74,75]

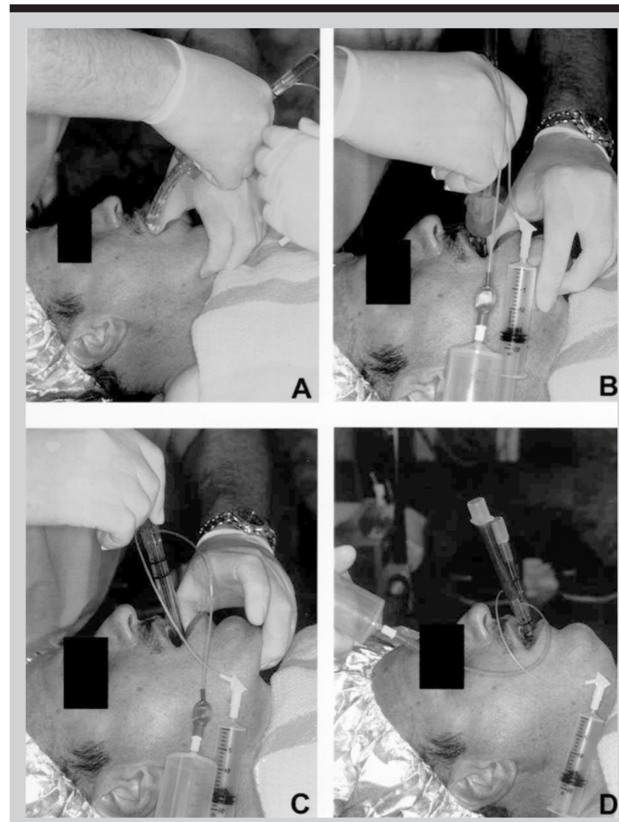
When using the ETC in the operating room, it is not necessary to inflate the proximal oropharyngeal cuff when the tip of the ETC resides in the trachea.[24] This permits suctioning of the mouth and pharynx of the patient. However, with tracheal or esophageal placement in locations outside the operating room and during prehospital care and transport, the inflated proximal oropharyngeal cuff lessens the chance of accidental extubation.[68,75]

Choice of near–fail-safe devices for confirmation of ETC placement and monitoring of lung ventilation

The use of routine clinical signs for confirmation of tube placement (eg, chest movement with bilateral breath sounds, lack of breath sounds over the epigastrium, movement or adequate compliance of the reservoir bag, and fogging of the ETT) are unreliable and not fail-safe.[85-87] Confirmation always should include auscultation bilaterally over the midaxillary lines (axillae), over the epigastrium, and use of an appropriate near–fail-safe device (carbon dioxide detector or esophageal detector device [EDD]).[87]

Capnography remains the "gold standard" for confirmation of tube placement and monitoring of lung ventilation, but its limitations must be understood.[87] The choice of carbon dioxide detectors includes disposable qualitative colorimetric carbon dioxide detectors (eg, Easy Cap II CO_2 Detector, Tyco-Healthcare-Nellcor); portable qualitative electronic carbon dioxide detectors (eg, Nonin Medical, Inc, Plymouth,

Figure 6. Blind insertion of the Combitube (Tyco-Healthcare-Nellcor, Pleasanton, Calif)



(A) The esophageal-tracheal Combitube (ETC) is inserted into the mouth while performing a jaw thrust. (B) and (C) Advancement continues in the midline of the mouth while orienting the ETC so that the distal tip is as parallel as possible to the posterior pharyngeal wall. (D) Advancement stops when the teeth lie between the 2 black rings on the Combitube.

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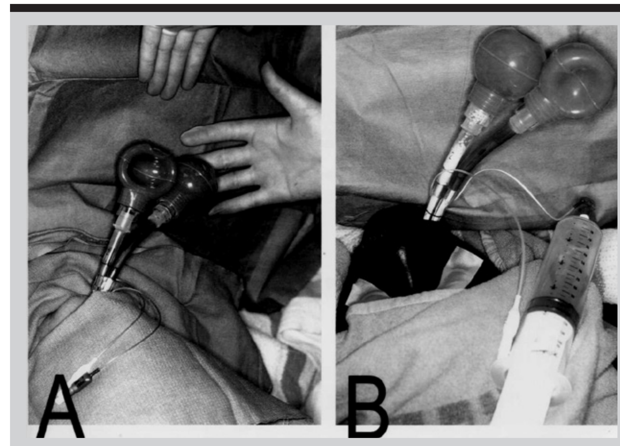
Minn); and portable quantitative electronic carbon dioxide devices (eg, Tidal Wave Sp, Novametrix Medical Systems, Inc, Wallingford, Conn). The EDD and carbon dioxide detector are considered to be near–fail-safe because either occasionally can produce false-positive or false-negative readings.[87,88]

Carbon dioxide detectors measure carbon dioxide, regardless of the source (eg, false-positive reading, tube communicating with esophagus and stomach but carbon dioxide is being detected). Beyond the carbon dioxide that normally resides in the lungs, the stomach occasionally might harbor residual carbon dioxide from esophageal ventilation of expired air into the stomach during mouth-to-mouth rescue breathing or BVM ventilation[89] or after ingestion of carbonated beverages or antacids containing bicarbonate (ie, "cola complication").[90] When carbon dioxide resides in the stomach or the esophagus from any of the aforementioned sources, it can be detected and briefly sustained by a carbon dioxide detection device during bag-valve-tube esophageal ventilation. For this reason, it is recommended to ventilate between 6 and 12 times[25,87] before relying on a colorimetric carbon dioxide detector and ventilate no fewer than 5 times[18,87,90] before relying on an electronic carbon dioxide detector. Continuation of colorimetric changes after 6 to 12 ventilations or electronic detection after 5 ventilations will adequately confirm proper tube placement and lung ventilation.[25,87]

False-negative readings occur with carbon dioxide detectors when an ETC or ETT is communicating with the trachea and lungs but there is no detection of carbon dioxide, as seen with a nonperfusing cardiac rhythm.[87,91,92] Therefore, in patients with nonperfusing rhythms or low cardiac output states, carbon dioxide detectors may be of limited assistance for confirming tube placement and monitoring lung ventilation.[30,31,86,87,91,92]

An effective way to rapidly determine proper ETC placement is to use an EDD[16] such as the self-inflating bulb (SIB)[17,18,26] (Figure 1C). When a compressed SIB is attached to a tube communicating with the trachea and released, it will rapidly reinflate by drawing in gas from the dead space of the rigidly patent trachea (Figure 7A). In contrast, if the tube is communicating with the flat peristaltic esophagus, which collapses under negative pressure, the SIB is prevented from drawing in gas and remains collapsed (Figure 7B).[85,93] However, the SIB occasionally can produce a false-negative result[94] (tube communicating with trachea without reinflation or slow reinflation of SIB) in the following clinical situations: in infants,[95] in people with asthma or severe bronchospasm,[96] in patients

Figure 7. Use of the self-inflating bulb (SIB) for determining the position of esophageal-tracheal Combitube (ETC; Tyco-Healthcare-Nellcor, Pleasanton, Calif) placement



(A) ETC in esophagus: A compressed SIB instantaneously reinflates when connected to the proximal lumen No. 1 that is communicating with the lungs by aspirating gas from the lungs via the perforations and will remain collapsed when connected to the distal lumen (which is communicating with esophagus). (B) ETC in trachea: A compressed self-inflating bulb instantaneously reinflates when connected to the lumen No. 2, which is communicating with the lungs, and will remain compressed when connected to the proximal lumen No. 1 that is communicating with the esophagus.

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with morbid obesity,[97-99] with main-stem bronchus intubation,[100] and with tube obstruction (kinking or blockage).[96,100] The SIB is not recommended for use in parturients because of a reported 30% incidence of false-positive results (tube communicating with esophagus with rapid refill of SIB) in this patient population.[101] In addition, a report revealed that false-positive results can occur when the syringe-aspiration type EDD is used following esophageal ventilation through an ETT resting in the esophagus.[102] However, failure of the SIB to confirm ETC location is uncommon, and, with few exceptions, it is effective for determining esophageal (see Figure 7A) or tracheal placement (see Figure 7B) of an ETC.[18,43,88,93] Therefore, the choice of device for determining correct tube placement (carbon dioxide detector vs EDD) is best based on the clinical situation. A carbon dioxide detector or an EDD can be used in a patient with a perfusing cardiac rhythm.[30,87,91] However, the EDD has been established as a more reliable way of confirming accurate tube placement in patients with a nonperfusing cardiac rhythm.[91]

Once ETC tip location is confirmed,[103] monitoring of lung ventilation is best accomplished using a qualitative or quantitative portable electronic carbon dioxide detector. Colorimetric detectors seem reliable for confirmation of tube placement but should be used with caution for monitoring lung ventilation.[87] Color change during ventilation was shown to stop after an indeterminate time in 1 colorimetric detector (Capno-flo Pulmonary Manual Resuscitator with carbon dioxide level monitor, Kirk Specialty Systems, Carrollton, Tex).[104] In addition, colorimetric detectors are subject to inactivation from moisture and might be difficult to read in low-light conditions, making them less reliable than electronic detectors for monitoring lung ventilation.[19,87,92]

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