Part 7.1: Adjuncts for Airway Control and Ventilation

This section highlights recommendations for the support of ventilation and oxygenation during resuscitation and the periarrest period. The purpose of ventilation during CPR is to maintain adequate oxygenation and sufficient elimination of carbon dioxide, but research has not identified the optimal tidal volume, respiratory rate, and inspired oxygen concentration required to do so. During the first minutes of ventricular fibrillation sudden cardiac arrest (VF SCA), rescue breaths are probably not as important as chest compressions, because oxygen delivery to the tissues, including the heart and brain, appears to be limited more by blood flow than by arterial oxygen content. Thus, during the first minutes of VF SCA the lone rescuer should attempt to limit interruptions in chest compressions for ventilation. The advanced provider must be careful to limit interruptions in chest compressions for attempts to insert an advanced airway or check the rhythm.

Ventilation and compressions are both thought to be important for victims of prolonged VF SCA and for all victims of asphyxial arrest (eg, drowning victims and victims of drug overdose with primary respiratory arrest) because these victims are hypoxemic before arrest.

Because systemic and, therefore, lung perfusion is substantially reduced during CPR, rescuers can support a normal ventilation-perfusion match with a minute ventilation that is much lower than normal. During CPR with an advanced airway in place we now recommend a lower rate of rescue breathing (see Part 4: "Adult Basic Life Support") than that recommended in the *ECC Guidelines 2000*.[1] During the prearrest and postarrest periods, the patient will require support of oxygenation and ventilation with tidal volumes and respiratory rates that more closely approximate normal.

Beyond the first minutes of cardiac arrest, tissue hypoxia develops. CPR provides approximately 25% to 33% of normal cardiac output. This low-flow state maintains a small but critical amount of blood flow to the heart and brain, but tissue hypoxia will persist until restoration of effective spontaneous perfusion. Additional factors that contribute to hypoxia include intrapulmonary shunting with microcirculatory dysfunction and attendant ventilation-perfusion abnormalities. Some patients may also have underlying respiratory disease. Tissue hypoxia leads to anaerobic metabolism and metabolic acidosis. Acid-base imbalance occasionally blunts the beneficial effects of chemical and electrical therapy.

To improve oxygenation, healthcare providers should give 100% inspired oxygen ($Fio_2 = 1.0$) during basic life support and advanced cardiovascular life support as soon as it becomes available. High inspired oxygen tension will tend to maximize arterial oxygen saturation and, in turn, arterial oxygen content. This will help support oxygen delivery (cardiac output × arterial oxygen content) when cardiac output is limited. This short-term oxygen therapy does not produce oxygen toxicity.

Bag-Mask Ventilation

All healthcare providers should be familiar with the use of the bag-mask device for support of oxygenation and ventilation.[2–4] Bag-mask ventilation is particularly helpful during the first few minutes of resuscitation or when placement of an advanced airway is delayed or unsuccessful. Effective bag-mask ventilation requires adequate training and frequent practice.

The desirable components of a bag-mask device are listed in Part 4: "Adult Basic Life Support." When using a bag-mask device (ie, no advanced airway is in place), the rescuer should deliver a tidal volume sufficient to produce chest rise (approximately 6 to 7 mL/kg or 500 to 600 mL) over 1 second.[5] This volume of ventilation minimizes the risk of gastric inflation. The rescuer should be sure to open the airway adequately with a chin lift, lifting the jaw against the mask and holding the mask against the face, creating a tight seal. During CPR, give 2 breaths during a brief (about 3 to 4 seconds) pause after every 30 chest compressions. When an advanced airway (eg, endotracheal tube, esophageal-tracheal combitube [Combitube], or laryngeal mask airway [LMA]) replaces the face mask, rescuers should deliver 8 to 10 breaths per minute during CPR. Deliver each breath over about 1 second while chest compressions are delivered at a rate of 100 per minute, and do not attempt to synchronize the compressions with the ventilations.

For ventilation of patients with a perfusing rhythm (ie, better pulmonary blood flow than is present during CPR), deliver approximately 10 to 12 breaths per minute (1 breath every 6 to 7 seconds). Deliver these breaths over 1 second when using a mask or an advanced airway.

In patients with severe obstructive pulmonary disease and increased resistance to exhalation, providers should try to prevent air trapping that may result in inadvertent generation of intrinsic positive end-expiratory pressure (PEEP), so-called "auto-PEEP." In patients with hypovolemia, auto-PEEP may substantially reduce cardiac output and blood pressure. To prevent this, use lower respiratory rates (eg, 6 to 8 breaths per minute) in these patients, allowing more time for complete exhalation.

Bag-mask ventilation can produce gastric inflation with complications, including regurgitation, aspiration, and pneumonia. Gastric inflation can elevate the diaphragm, restrict lung movement, and decrease respiratory system compliance.[4,6–9]

(*Circulation.* **2005;112:IV-51-IV-57.**)

This special supplement to *Circulation* is freely available at http://www.circulationaha.org

DOI: 10.1161/CIRCULATIONAHA.105.166556

Airway Adjuncts

Oropharyngeal Airways

Oropharyngeal airways should be reserved for use in unconscious (unresponsive) patients with no cough or gag reflex and should be inserted only by persons trained in their use (Class IIa). Incorrect insertion of an airway can displace the tongue into the hypopharynx, causing airway obstruction. Although studies have not specifically considered the use of advanced airways in arrest, airways may aid in the delivery of adequate ventilation with a bag-mask device by preventing the tongue from occluding the airway.

Nasopharyngeal Airways

Nasopharyngeal airways are useful in patients with airway obstruction or those at risk for development of airway obstruction, particularly when conditions such as a clenched jaw prevent placement of an oral airway. Nasopharyngeal airways are better tolerated than oral airways in patients who are not deeply unconscious. Airway bleeding can occur in up to 30% of patients following insertion of a nasopharyngeal airway (LOE 5).[10] Two case reports of inadvertent intracranial placement of a nasopharyngeal airway in patients with basilar skull fractures (LOE 7)[11,12] suggest that nasopharyngeal airways should be used with caution in patients with severe craniofacial injury.

As with all adjunctive equipment, safe use of the nasopharyngeal airway requires adequate training, practice, and retraining. No studies on the use of this device in patients in cardiac arrest have been found. The nasopharyngeal airway may be used in patients with an obstructed airway to facilitate delivery of ventilations with a bag-mask device.

Advanced Airways

Rescuers must be aware of the risks and benefits of insertion of an advanced airway during a resuscitation attempt. Such risks are affected by the condition of the patient and the rescuer's expertise in airway control. Because insertion of an advanced airway may require interruption of chest compressions for many seconds, the rescuer should weigh the need for compressions against the need for insertion of an advanced airway. Rescuers may defer insertion of an advanced airway until the patient fails to respond to initial CPR and defibrillation attempts or demonstrates return of spontaneous circulation (Class IIb). To use any of the advanced airways effectively, healthcare providers must maintain knowledge and skills through frequent practice with these devices. It may be helpful for providers to train in one primary method of airway control and gain experience and expertise in that method. Providers should have a second (backup) strategy for airway management and ventilation if they are unable to establish the first-choice airway adjunct. Bag-mask ventilation may provide that backup strategy.

Once an advanced airway is in place, 2 rescuers no longer deliver cycles of CPR (ie, compressions interrupted by pauses for ventilation). Instead, the compressing rescuer should give continuous chest compressions at a rate of 100 per minute, without pauses for ventilation. The rescuer delivering ventilation provides 8 to 10 breaths per minute. The 2 rescuers should change compressor and ventilator roles approximately every 2 minutes to prevent compressor fatigue and deterioration in quality and rate of chest compressions. When multiple rescuers are present, they should rotate the compressor role about every 2 minutes.

Bag-Mask Ventilation Versus the Advanced Airway

Bag-mask ventilation or ventilation with a bag through an advanced airway (eg, endotracheal tube, Combitube, or LMA) is acceptable for ventilation during CPR. As noted above, all healthcare providers should be trained in delivering effective oxygenation and ventilation with a bag and mask. Because there are times when ventilation with a bag-mask device is inadequate or transport times are prolonged, advanced care providers should also be trained and experienced in insertion of an advanced airway.

The endotracheal tube was once considered the optimal method of managing the airway during cardiac arrest. It is now clear, however, that the incidence of complications is unacceptably high when intubation is performed by inexperienced providers or monitoring of tube placement is inadequate. The optimal method of managing the airway during cardiac arrest will vary based on provider experience, emergency medical services (EMS) or healthcare system characteristics, and the patient's condition.

No prospective randomized trials have directly assessed the outcome of adult victims of cardiac arrest with provision of bag-mask ventilation compared with endotracheal intubation. Studies comparing outcomes of out-of-hospital cardiac arrest in adults treated by either emergency medical technicians or paramedics failed to show a link between long-term survival rates and paramedic skills such as intubation, intravenous cannulation, and drug administration.[13–15] One prospective randomized controlled trial in an EMS system with short out-of-hospital transport intervals[16] showed no survival advantage for endotracheal intubation over bag-mask ventilation in children. In this study providers had limited training and experience in intubation.

In retrospective (LOE 5) studies, endotracheal intubation has been associated with a 6%[17–19] to 14%[20] incidence of unrecognized tube misplacement or displacement. This may reflect inadequate initial training or experience on the part of the provider who performed intubation, or it may result from displacement of a correctly positioned tube during movement of the patient. To reduce the risk of unrecognized tube misplacement or displacement, providers should use a device such as an exhaled CO_2 detector or an esophageal detector device to confirm endotracheal tube placement in the field, in the transport vehicle, on arrival at the hospital, and after any subsequent movement of the patient. These devices are described below.

When prehospital providers are trained in the use of advanced airways such as the Combitube and LMA, they appear to be able to use these devices safely, and they can provide ventilation that is as effective as that provided with a bag and mask (Class IIa).[2,21,22] However, advanced airway interventions are technically complicated, failure can occur, and maintenance of skills through frequent experience or

practice is essential.[23] It is important to remember that there is no evidence that advanced airway measures improve survival rates in the setting of prehospital cardiac arrest.

Esophageal-Tracheal Combitube

The advantages of the Combitube compared with the face mask are similar to those of the endotracheal tube: isolation of the airway, reduced risk of aspiration, and more reliable ventilation. The advantages of the Combitube over the endotracheal tube are related chiefly to ease of training.[2,24] Ventilation and oxygenation with the Combitube compare favorably with those achieved with the endotracheal tube.[25]

In 5 randomized controlled trials involving both in-hospital and out-of-hospital adult resuscitation, providers with all levels of experience were able to insert the Combitube and deliver ventilation that was comparable to that achieved with endotracheal intubation (LOE 2).[21,26–29] Thus, it is acceptable for healthcare professionals to use the Combitube as an alternative to the endotracheal tube for airway management in cardiac arrest (Class IIa).

Fatal complications may occur with use of the Combitube if the position of the distal lumen of the Combitube in the esophagus or trachea is identified incorrectly. For this reason confirmation of tube placement is essential. Other possible complications related to the use of the Combitube are esophageal trauma, including lacerations, bruising, and subcutaneous emphysema (LOE 2[30]; LOE 5[25,31]).

Laryngeal Mask Airway

The LMA provides a more secure and reliable means of ventilation than the face mask.[32,33] Although the LMA does not ensure absolute protection against aspiration, studies have shown that regurgitation is less likely with the LMA than with the bag-mask device and that aspiration is uncommon. When compared with the endotracheal tube, the LMA provides equivalent ventilation[33,34]; successful ventilation during CPR is reported in 71.5% to 97% of patients.[22,25,35–38]

Training in the placement and use of an LMA is simpler than that for endotracheal intubation because insertion of the LMA does not require laryngoscopy and visualization of the vocal cords. The LMA may also have advantages over the endotracheal tube when access to the patient is limited,[39,40] there is a possibility of unstable neck injury,[41] or appropriate positioning of the patient for endotracheal intubation is impossible.

Results from multiple high-level studies in anesthetized patients that compared the LMA with endotracheal intubation (LOE 2)[39,42–46] and multiple additional studies that compared the LMA with other airways or ventilation techniques (LOE 2)[2,47–52] support the use of the LMA in controlling the airway in a variety of settings by nurses, respiratory therapists, and EMS personnel, many of whom had not previously used this device.

After successful insertion a small proportion of patients cannot be ventilated with the LMA.[2,25,33] With this in mind, it is important for providers to have an alternative strategy for management of the airway. Providers who insert the LMA should receive adequate initial training and should practice insertion of the device regularly. Success rates and the occurrence of complications should be monitored closely. It is acceptable for healthcare professionals to use the LMA as an alternative to the endotracheal tube for airway management in cardiac arrest (Class IIa).

Endotracheal Intubation

The endotracheal tube keeps the airway patent, permits suctioning of airway secretions, enables delivery of a high concentration of oxygen, provides an alternative route for the administration of some drugs, facilitates delivery of a selected tidal volume, and with use of a cuff may protect the airway from aspiration.[53]

Endotracheal intubation attempts by unskilled providers can produce complications, such as trauma to the oropharynx, interruption of compressions and ventilations for unacceptably long periods, and hypoxemia from prolonged intubation attempts or failure to recognize tube misplacement or displacement. Providers who perform endotracheal intubation require adequate initial training and either frequent experience or frequent retraining (Class I). EMS systems that provide prehospital intubation should establish a process for ongoing quality improvement to minimize complications (Class IIa).

Indications for emergency endotracheal intubation are (1) the inability of the rescuer to adequately ventilate the unconscious patient with a bag and mask and (2) the absence of airway protective reflexes (coma or cardiac arrest). The rescuer must have appropriate training and experience in endotracheal intubation.

During CPR we recommend that rescuers minimize the number and duration of interruptions in chest compressions, with a goal to limit interruptions to no more than 10 seconds except as needed for interventions such as placement of an advanced airway. Interruptions needed for intubation can be minimized if the intubating rescuer is prepared to begin the intubation attempt (ie, insert the laryngoscope blade with the tube ready at hand) as soon as the compressing rescuer pauses compressions. The compressions should be interrupted only as long as the intubating rescuer needs to visualize the vocal cords and insert the tube. The compressing rescuer should be prepared to resume chest compressions immediately after the tube is passed through the vocal cords. If more than one intubation attempt is required, the rescuers should provide a period of adequate ventilation and oxygenation and chest compressions between attempts.

If endotracheal intubation is performed for the patient with a perfusing rhythm, use pulse oximetry and ECG monitoring continuously during intubation attempts and interrupt the attempt to provide oxygenation and ventilation if needed.

Even when the endotracheal tube is seen to pass through the vocal cords and tube position is verified by chest expansion and auscultation during positive-pressure ventilation, rescuers should obtain additional confirmation of placement using an end-tidal CO_2 or esophageal detection device (Class IIa).[54] There is a high risk of tube misplacement, displacement, or obstruction,[16,20] especially when the patient is moved.[55] No single confirmation technique, including clinical signs[56] or the presence of water vapor in the tube,[57] is completely reliable. Techniques to confirm endotracheal tube

placement are discussed further below. The provider should use both clinical assessment and confirmation devices to verify tube placement immediately after insertion and when the patient is moved.

Clinical Assessment to Confirm Tube Placement

Providers should perform a thorough assessment of endotracheal tube position immediately after placement. This assessment should not require interruption of chest compressions. Assessment by physical examination consists of visualizing chest expansion bilaterally and listening over the epigastrium (breath sounds should not be heard) and the lung fields bilaterally (breath sounds should be equal and adequate). A device should also be used to confirm correct placement in the trachea (see below). If there is doubt about correct tube placement, use the laryngoscope to visualize the tube passing through the vocal cords. If still in doubt, remove the tube and provide bag-mask ventilation until the tube can be replaced.

Use of Devices to Confirm Tube Placement

Providers should always use both clinical assessment and devices to confirm endotracheal tube location immediately after placement and each time the patient is moved. No study, however, has identified a single device as both sensitive and specific for endotracheal tube placement in the trachea or esophagus. All confirmation devices should be considered adjuncts to other confirmation techniques. There is no data to quantify the capability of devices to monitor tube position after initial placement.

Exhaled CO_2 Detectors

Detection of exhaled CO_2 is one of several independent methods of confirming endotracheal tube position. Given the simplicity of the exhaled CO_2 detector, it can be used as the initial method for detecting correct tube placement even in the victim of cardiac arrest (Class IIa). Detection of exhaled CO_2, however, is not infallible as a means of confirming tube placement, particularly during cardiac arrest. Evidence from 1 meta-analysis in adults (LOE 1),[58] 1 prospective controlled cohort study (LOE 3),[59] and several case series and reports (LOE 5)[60–68] indicate that exhaled CO_2 detectors (waveform, colorimetry, or digital) may be useful as adjuncts to confirm endotracheal tube placement during cardiac arrest. The range of results obtained from the reviewed papers is as follows:

- Sensitivity (percentage of correct endotracheal placement detected when CO_2 is detected): 33% to 100%
- Specificity (percentage of incorrect esophageal placement detected when no CO_2 is detected): 97% to 100%
- Positive predictive value (probability of endotracheal placement if CO_2 is detected): 100%
- Negative predictive value (probability of esophageal placement if no CO_2 is detected): 20% to 100%

When exhaled CO_2 is detected (positive reading for CO_2) in cardiac arrest, it is usually a reliable indicator of tube position in the trachea. False-positive readings (CO_2 is detected but the tube is located in the esophagus) have been observed in animals that ingested large amounts of carbonated liquids before the arrest.[69]

False-negative readings (in this context defined as failure to detect CO_2 despite tube placement in the trachea) may be present during cardiac arrest for several reasons. The most common explanation for false-negative readings during CPR is that blood flow and delivery of CO_2 to the lungs is low. False-negative results have also been reported in association with pulmonary embolus because pulmonary blood flow and carbon dioxide delivery to the lungs are reduced. If the detector is contaminated with gastric contents or acidic drugs (eg, endotracheally administered epinephrine), a colorimetric device may display a constant color rather than breath-to-breath color change. In addition, elimination and detection of CO_2 can be drastically reduced following an intravenous bolus of epinephrine[70] or with severe airway obstruction (eg, status asthmaticus) and pulmonary edema.[65,71–73] For these reasons, if CO_2 is not detected, we recommend that a second method be used to confirm endotracheal tube placement, such as direct visualization or the esophageal detector device.

Use of CO_2 detecting devices to determine the correct placement of other advanced airways (eg, Combitube, LMA) has not been adequately studied (Class Indeterminate).

Esophageal Detector Devices

The esophageal detector device (EDD) consists of a bulb that is compressed and attached to the endotracheal tube. If the tube is in the esophagus (positive result for an EDD), the suction created by the EDD will collapse the lumen of the esophagus or pull the esophageal tissue against the tip of the tube, and the bulb will not reexpand. The EDD may also consist of a syringe that is attached to the endotracheal tube; the rescuer attempts to pull the barrel of the syringe. If the tube is in the esophagus, it will not be possible to pull the barrel (aspirate air) with the syringe.

Eight studies of at least fair quality evaluated the accuracy of the EDD (self-inflating bulb or syringe) (LOE 3[18,66,74]; LOE 5[75]; LOE 7 [noncardiac arrest setting][76–79]), but many suffer from small numbers and lack of a control group.

The EDD was highly sensitive for detection of endotracheal tubes that were misplaced in the esophagus (sensitive for esophageal placement) in 5 case series (LOE 5[75]; LOE 7[76–79]). But in 2 studies (LOE 3)[66,74] involving patients in cardiac arrest, the EDD had poor specificity for indicating tracheal placement of an endotracheal tube. In these studies up to 30% of correctly placed tubes may have been removed because the EDD suggested esophageal placement (LOE 3).[67] In the operating room the EDD had poor sensitivity and specificity in 20 children $<$1 year of age (LOE 2).[80] With these findings in mind, use of the EDD should be considered as just one of several independent methods for confirmation of correct endotracheal tube placement.

The EDD may yield misleading results in patients with morbid obesity, late pregnancy, or status asthmaticus, or when there are copious endotracheal secretions,[81,82] because with these conditions the trachea tends to collapse. There is no evidence that the EDD is accurate for the continued monitoring of endotracheal tube placement.

Postintubation Care

After inserting the advanced airway and confirming correct placement, the rescuer should record the depth of the tube as

marked at the front teeth and secure it. Because there is significant potential for endotracheal tube movement with head flexion and extension,[83–85] we recommend ongoing monitoring of endotracheal tube placement during transport and particularly when the patient is moved from one location to another.[86,87] Providers should verify correct placement of all advanced airways immediately after insertion and whenever the patient is moved.

Secure the endotracheal tube with tape or a commercial device (Class I). Two studies in the intensive care setting (LOE 7)[88,89] indicate that backboards, commercial devices for securing the endotracheal tube, and other strategies provide an equivalent method for preventing accidental tube displacement when compared with traditional methods of securing the tube (tape). These devices may be considered during patient transport (Class IIb). After tube confirmation and fixation, obtain a chest x-ray (when feasible) to confirm that the end of the endotracheal tube is properly positioned above the carina.

The 3 most important caveats for rescuers performing CPR after insertion of the advanced airway are

- Be sure the advanced airway is correctly placed (verify).
- Two rescuers no longer deliver "cycles" of CPR (ie, compressions interrupted by pauses for ventilation). Instead, the compressing rescuer should give continuous chest compressions at a rate of 100 per minute without pauses for ventilation. The rescuer delivering ventilation provides 8 to 10 breaths per minute. The 2 rescuers should change compressor and ventilator roles approximately every 2 minutes to prevent compressor fatigue and deterioration in quality and rate of chest compressions. When multiple rescuers are present, they should rotate the compressor role about every 2 minutes.
- Rescuers should avoid delivering an excessive ventilation rate because it can compromise venous return and cardiac output during CPR.

Suction Devices

Both portable and installed suction devices should be available for resuscitation emergencies. Portable units should provide adequate vacuum and flow for pharyngeal suction. The suction device should be fitted with large-bore, nonkinking suction tubing and semirigid pharyngeal tips. Several sterile suction catheters of various sizes should be available for suctioning the lumen of the advanced airway, along with a nonbreakable collection bottle and sterile water for cleaning tubes and catheters. The installed suction unit should be powerful enough to provide an airflow of >40 L/min at the end of the delivery tube and a vacuum of >300 mm Hg when the tube is clamped. The amount of suction should be adjustable for use in children and intubated patients.

Automatic Transport Ventilators

See Part 6: "CPR Techniques and Devices."

Summary

All basic and advanced healthcare providers should be able to provide ventilation with a bag-mask device during CPR or when the patient demonstrates cardiorespiratory compromise. Airway control with an advanced airway is a fundamental ACLS skill. All providers should be able to confirm correct placement of endotracheal tubes and other advanced airways. This key skill is required for safe and effective use of these devices. Training, frequency of use, and monitoring of success and complications affect the long-term impact of any device more than choice of a specific device.

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