J Anesth (2014) 28:87–93
DOI 10.1007/s00540-013-1672-y

INVITED REVIEW ARTICLE

Monitoring during difficult airway management

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Received: 29 May 2013 / Accepted: 27 June 2013 / Published online: 9 July 2013

Abstract Monitoring is crucial to assure safety during difficult airway management. Several reports have indicated that the most of the adverse outcomes associated with difficult airway management could have been avoided with the use of necessary monitors, such as a pulse oximeter and a capnometer. Nevertheless, airway complications continue to be major problems during anesthesia, in particular, in patients with difficult airways. In this brief review, I stress the role of monitoring in detecting inadvertent esophageal intubation, during sedation for awake tracheal intubation, during general anesthesia, and during emergence from anesthesia, in patients with difficult airways.

Keywords Difficult airways · Difficult intubation · Monitoring

Introduction

Monitoring is crucial to assure safety during difficult airway management. In 1990, a report of a U.S. closed claim analysis related to anesthesia practice revealed that adverse outcomes involving the respiratory system had comprised the single largest class of injury, and that the incidence of death or permanent brain damage associated with airway management was much higher than the incidence associated with cardiovascular management [1]. The report indicates that most of these adverse outcomes could have been avoided with the use of necessary monitors, such as a pulse oximeter and a capnometer [1].

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Since then, several major guidelines about difficult airway management have been formulated, new reliable airway devices have been developed, and both pulse oximeter and capnometer have become widely available. The Association of Anaesthetists of Great Britain and Ireland [2] has also issued a recommendation for standards of monitoring during anesthesia and recovery. Probably because of these efforts, a more recent closed claim analysis (reported in 2006) indicated that the incidence of serious adverse outcomes associated with airway management had decreased [3]. Nevertheless, airway complications continue to be major problems during anesthesia, in particular, in patients with difficult airways [4–7].

To prevent adverse outcomes associated with airway management, one should select appropriate anesthesia methods and airway devices, and should plan ahead for airway rescue if it becomes difficult to maintain a clear airway. In addition, appropriate monitoring is useful in reducing complications during difficult airway management.

During induction of anesthesia

Detecting inadvertent esophageal intubation

Inadvertent esophageal intubation is still a major cause of death related to anesthesia [1]. Therefore, it is important to use appropriate methods and monitors to detect this serious complication.

Clinical tests

Several clinical tests can confirm that a tube is correctly inserted into the trachea: visual confirmation of a tube passing through the glottis at laryngoscopy, chest expansion

during inflation, auscultation of the chest and epigastrium, water vapor condensation in the tube, and anesthesia reservoir bag movement. These clinical tests are useful, but frequently they fail to detect esophageal intubation.

Chest X-ray

Chest X-ray seems to be a reliable method, but the time from insertion of a tube to detection of esophageal intubation by chest X-ray may be too long to prevent hypoxia. In addition, there have been some reports that chest X-ray could not differentiate whether the tube was positioned in the trachea or in the esophagus [8, 9].

Fiberoptic endoscopy

The use of a fiberoptic bronchoscope should be a reliable method of detecting esophageal intubation, as it would be possible to detect inadvertent esophageal intubation if the tracheal rings and tracheal carina cannot be confirmed. Nevertheless, the reliability of this method has not been studied formally.

Sonic techniques

A sonic technique may be used to monitor whether the tube is in the trachea or in the esophagus. The SCOTI (sonomatic confirmation of tracheal intubation) was a commercially available device that detected resonating frequencies which vary with the presence of the tracheal tube in an open (trachea) or closed (esophagus) structure. However, the manufacturer discontinued marketing the device [10] as several studies showed that there were high incidences of false-positive and false-negative results.

Esophageal detector device

The lumen of the trachea is splinted open by cartilage rings, in contrast to that of the esophagus. Therefore, when a tube is inserted into the trachea and a negative pressure is applied to the tube, gas can easily be aspirated, whereas if the tube is in the esophagus, no or only a small amount of gas may be collected. A negative pressure to the tracheal tube can be applied using either a syringe [11] or a self-inflating bulb [12]. Several studies have shown that this device is a highly reliable method to detect esophageal intubation. Nevertheless, several instances been reported in which this method was not foolproof [13–18] (Table 1).

Pulse oximetry

Pulse oximetry can indicate hypoxia when a tube is inadvertently inserted into the esophagus. However, there may be a considerable delay in detecting esophageal intubation, especially where the patient has been pre-oxygenated.

Table 1 False-positive (detector indicated esophageal intubation, but actually the tube was in the trachea) and false-negative (detector indicated tracheal intubation although the tube was in the esophagus) findings for the esophageal detector device

False positive
Tip of tracheal tube lying against inner tracheal wall [13]
Infants [14]
Thyroid tumor [15]
Asthma [15]
Mediastinal mass [15]
Parturients [16]
Obese patient [17]
False negative
Gas-filled stomach [18]
Crack in detector

Table 2 False-positive (detector indicated esophageal intubation, but actually the tube was in the trachea) and false-negative (detector indicated tracheal intubation although the tube was in the esophagus) findings for capnography

False positive
Bronchospasm [19]
Cricoid pressure obstructing tracheal tube [20]
Obstruction of sampling tube [21]
Cardiopulmonary arrest
False negative
Presence of carbonated drink in stomach [22]

Capnography

Monitoring of end-tidal carbon dioxide concentration ($ETCO_2$) is the most reliable method for detecting inadvertent esophageal intubation, and thus capnography should be monitored routinely during airway management. However, even with capnography, false-positive and false-negative results occasionally occur [19–22] (Table 2).

Chemical changes to CO_2

The "FEF end-tidal carbon dioxide detector," a commercially available disposable device, uses a pH-sensitive chemical indicator strip that responds quickly to exhaled carbon dioxide by a reversible color change in semiquantitative fashion. This device usually differentiates tracheal and esophageal intubation, but may fail to detect esophageal intubation in some experimental conditions [23]. It should be noted, however, that the color changes caused by pH change from carbon dioxide may also also occur because of the presence of gastric acid, adrenaline, atropine, or lidocaine [24].

Sedation during 'awake' intubation

In patients with difficult airways, it may be necessary to secure the airway before induction of anesthesia ('awake' or 'sedated' intubation). Appropriate local anesthesia to the airway and sedation are crucial for uncomplicated airway management. There are several different ways to sedate the patient, but oversedation can cause upper airway obstruction and respiratory depression. Therefore, monitoring the level of sedation is useful to avoid oversedation.

Intravenous infusion of short-acting drugs (e.g., propofol and remifentanil) is a reasonable approach to performing 'safe' sedation during difficult airway management, as this method allows better control of the level of sedation, fewer side effects affecting hemodynamics and respiration, and more rapid recovery from sedation. Target-controlled infusion (TCI) systems may be used for intravenous sedation because they enable the targeting of effect-site concentration, allowing the level of sedation to be indirectly predicted by the estimated effect-site concentration of drugs.

Appropriate sedation can be achieved by effectively inhibiting responses to noxious stimuli, without inhibiting spontaneous breathing and pharyngeal function (which prevents regurgitation and aspiration). Propofol reduces the minute ventilation by 50 % at a mean effect-site concentration of 1.3 μg/ml [25]. When remifentanil is coadministered at an infusion rate of 0.1 μg/kg/min, propofol at an effect-site concentration of 2.0 μg/ml frequently causes apnea [26]. Propofol in sedative concentration of approximately 1.0 μg/ml inhibits pharyngeal function, permitting possible aspiration [27]. Therefore, during awake tracheal intubation, the ideal effect-site concentration of propofol should be limited to a maximum of 1.0 μg/ml.

The bispectral index monitor (BIS) is used to monitor depth of general anesthesia. The BIS has also been shown to be a reliable indicator of the level of sedation [28, 29] and thus is potentially useful during awake intubation in patients with difficult airways. Although there have been no comprehensive studies on its application to sedation, appropriate BIS measurements for awake tracheal intubation can be deduced from other applications, such as sedation for regional anesthesia, for diagnostic bronchoscopy, and for other invasive procedures [28, 29]. In one study of patients undergoing surgery under regional anesthesia, the BIS index correlated closely with the level of midazolam-induced sedation [28]. Similar results were obtained when propofol was used for sedation [29]. The reported mean BIS index at each level of sedation is summarized in Table 3.

In a recent study of patients undergoing ultrasonographic endoscopy who received target-controlled infusions of propofol and remifentanil, the BIS index was 71–75 when adequate depth of sedation (Ramsay score 4) was achieved [30]. The predicted effect-site concentration pairs of propofol and remifentanil to achieve a Ramsay score of 4 ranged from 1.8 μg/ml and 1.5 ng/ml to 2.7 μg/ml and 0 ng/ml, respectively [30].

Table 3 Mean bispectral (BIS) index to achieve different levels of sedation [28, 29]

Sedation level	Mean BIS index	
	Midazolam	Propofol
Responds readily to name spoken in normal tone	90.3	93.8
Lethargic response to name spoken in normal tone	86.6	84.9
Response only after name is called loudly or repeatedly	75.6	82.4
Responds only after mild prodding or shaking	69.2	75.6

Because awake intubation is indicated when there is an increased risk of airway obstruction and pulmonary aspiration, it would be reasonable to give sedatives (or analgesics) in a way that achieves a relatively lighter level of sedation. Therefore, the target level of the BIS index during awake intubation should be at the minimum value of approximately 80–85.

During maintenance of anesthesia

Airway problems occur in patients with difficult airways mainly during induction of anesthesia and during emergence from anesthesia (see following), but problems may also occur during maintenance of anesthesia.

Major airway problems during maintenance of anesthesia in patients with difficult airways are generally similar to problems occurring in patients without difficult airways: inadvertent tracheal extubation, disconnection of the breathing system, and airway obstruction (caused, for example, by obstruction of an airway device, bronchospasm, and larynogospasm). Close monitoring is particularly required to prevent airway problems in patients with difficult airways because management of airway problems is more difficult in such patients.

Pulse oximetry and capnometry

For routine anesthesia management, both a pulse oximeter and a capnometer should be used throughout the anesthesia period. A capmometer is particularly useful in detecting airway problems at an early stage. For example, a sudden disappearance of carbon dioxide waveforms indicates inadvertent extubation, dislodgement of a supraglottic airway, or disconnection of the breathing system. Changes in the shape of the waveforms may also indicate

Table 4 Causes of increased or decreased airway pressure during anesthesia

Increased airway pressure
Mechanical obstruction of patient's airway (e.g., obstruction by sputum)
Mechanical obstruction of airway device (e.g., kinking of tracheal tube)
Inadvertent bronchial intubation
Partial dislodgement of supraglottic airway
Larynogospasm
Bronchospasm
Decreased airway pressure
Gas leak around airway device
Disconnection of breathing system
Inadvertent extubation
Total dislodgement of supraglottic airway

Table 5 Causes of decreased inspiratory and expiratory volume during anesthesia

Decreased inspiratory and expiratory volume (during pressure–control ventilation)
Mechanical obstruction of patient's airway (e.g., obstruction by sputum)
Mechanical obstruction of airway device (e.g., kinking of tracheal tube)
Inadvertent bronchial intubation
Larynogospasm
Bronchospasm
Decreased expiratory/inspiratory volume ratio
Mechanical obstruction of patient's airway ("check-bulb" effect)
Gas leak around airway device
Disconnection of breathing system
Inadvertent extubation
Dislodgement of supraglottic airway

bronchospasm, partial obstruction of the airway, or gas leakage around an airway device.

Airway pressure monitor and flow monitor

Changes in airway pressure may detect airway problems occurring during anesthesia (Table 4). Inspiratory or expiratory volume monitoring also may indicate airway problems during general anesthesia (Table 5).

Spirometry loop monitor

Some of recent anesthetic machines or anesthetic monitors can display pressure–volume and flow–volume loops. Loops are graphical representations of relationship between pressure and volume or between flow and volume during inspiration and expiration. The pressure–volume loop usually shows the airway pressure at the horizontal axis and the volume on the vertical axis. The flow–volume loop usually shows volume at the horizontal axis and flow on the vertical axis. Changes in the pressure–volume loop indicate changes in compliance, whereas changes in the flow–volume loop indicate changes in resistance. Some reasons for decreased compliance and for increased resistance are shown in Table 6.

Table 6 Some causes of decreased compliance and increased resistance

Decreased compliance
Insufficient neuromuscular blockade
Inadvertent bronchial intubation
Bronchospasm
Pneumothorax
External pressure on airway (bronchus, lungs)
Laparoscopic surgery
Increased resistance
Obstruction of patient's airway
Secretions, tumor, foreign body
Airway collapse (trachea-bronchomalacia)
Laryngospasm (during use of a supraglottic airway)
Bronchospasm
Obstruction of airway device
Kinking of tracheal tube
Dislodgement of supraglottic airway

During emergence from anesthesia

Monitoring during emergence from anesthesia

There are several major guidelines regarding difficult airway management, but they are largely related to management during induction of anesthesia, and less attention has been paid to airway problems during emergence from anesthesia and in the recovery room [31].

In patients who undergo general anesthesia, respiratory complications may occur more frequently during emergence from anesthesia than during induction of anesthesia [32]. One prospective study on respiratory complications associated with tracheal intubation and extubation, in 1,005 patients who underwent elective general anesthesia, showed an incidence of 4.6 % during induction of anesthesia, 12.6 % immediately after tracheal extubation, and 9.5 % in the recovery room [32]. In this study, the most common complication was coughing, which may not be clinically important. Nevertheless, even when coughing was disregarded as a complication, the incidence of potentially serious complications, such as laryngospasm

and hypoxia, was still higher after extubation than during induction of anesthesia [32]. Therefore, appropriate monitoring should be applied not only during induction of anesthesia, but also during the postoperative period.

Residual neuromuscular blockade

Incomplete recovery from neuromuscular blockade is common after general anesthesia and is a major cause of postoperative respiratory complications, such as upper airway obstruction, pulmonary aspiration, or attenuation of the hypoxic ventilatory response [31]. Because patients with difficult airways are at increased risk of postoperative airway obstruction and pulmonary aspiration, it is crucial to minimize residual neuromuscular blockade.

A simple method to minimize postoperative residual neuromuscular blockade is to use a short-acting neuromuscular blocking agent. One meta-analysis has shown that the incidence of postoperative residual neuromuscular blockade is significantly lower after the use of short-acting neuromuscular blocking agents than after the use of long-acting agents [33].

Another method is to routinely administer an antagonist to nondepolarizing relaxants, such as an anticholinesterase drug or sugammadex, during emergence from anesthesia. The omission of such antagonism is associated with a higher risk of residual neuromuscular blockade, even after the use of a short-acting neuromuscular blocking agent [34].

In addition to the use of these drugs, monitoring neuromuscular blockade is useful as it detects residual blockade. Residual neuromuscular blockade can be assessed by observing the motor response to peripheral nerve stimulation, responses to train-of-four (TOF) nerve stimulation being the most widely used.

Conventionally, a TOF ratio (4th to 1st twitch) >0.7 has been considered to illustrate sufficient recovery from neuromuscular blockade. However, several reports have indicated that this may not guarantee sufficient recovery [31]. For example, at a TOF ratio of 0.8, upper airway obstruction with impaired inspiratory flow frequently occurs [35]. In addition, at TOF ratios <0.9, the incidence of pharyngeal dysfunction and pulmonary aspiration is high [36]. From these results, it is wise to ensure that a TOF ratio is >0.9 before transferring the patient to the recovery room.

To assess recovery from neuromuscular blockade, clinical tests, such as head lift and hand grip, are widely used to assess residual neuromuscular blockade, but these tests have been shown to be unreliable. For example, in one study, the majority of patients could lift their head for 5 s, even when a TOF ratio was <0.7 [37].

Visual or tactile evaluation of the evoked muscular response to TOF stimulation has been widely used to judge recovery from neuromuscular blockade. Nevertheless, several studies have shown that such qualitative monitoring did not reduce the incidence of postoperative airway obstruction or hypoxia [38]. Therefore, it can be concluded that qualitative monitoring is not reliable to assess residual neuromuscular blockade.

Quantitative neuromuscular monitoring provides a more objective measure of neuromuscular function. There are five major methods of quantitative neuromuscular monitoring: acceleromyography, electromyography, kinemyography, mechanomyography, and phonomyography. Among these, acceleromyography is the most commonly used method, and the most widely available device for this method is the TOF-Watch.

The use of quantitative neuromuscular monitoring has been shown to be better than qualitative monitoring in reducing respiratory complications after general anesthesia [39]. In one study comparing qualitative monitoring of TOF with quantitative monitoring, there was a lower incidence of hypoxia [39]. Therefore, in patients with difficult airways who are at increased risk of airway obstruction and hypoxia, the recovery of neuromuscular function should routinely confirmed using a quantitative neuromuscular monitor.

Pulse oximeter

During the transfer of the patient from the operating room to the recovery room, and in the recovery room, monitors and equipment are relatively lacking and anesthesiologists are not always present [40]. Therefore, once the patient has left the operating room, despite the high incidence of respiratory complications, detection of these complications may be delayed and prompt treatment may be more difficult. Several studies have shown that, during transfer of the patients from the operating room to the recovery room, arterial hemoglobin oxygen saturation frequently decreases, even when oxygen is given. It is therefore advisable to apply a pulse oximeter during the transfer of the patient to the recovery room.

Capnography

In addition to pulse oximetry, monitoring the $ETCO_2$ can be useful for early detection of airway obstruction. One possible difficulty is that a capnometer may not be available in the recovery room or in the ward. It could be advisable to have a capnometer on the ward to monitor $ETCO_2$, in patients with difficult airways, in particular in those with sleep apnea syndrome or those who have undergone oropharyngeal surgery.

Another possible problem is that it may be technically difficult to sample breathing gas. During general anesthesia,

the $ETCO_2$ can be monitored via a sampling tube attached to the breathing system, and thus disappearance of $ETCO_2$ waveforms indicates the absence of breathing. In contrast, in the ward, monitoring of $ETCO_2$ may frequently fail when a sampling port faces away from the patient's mouth or nose. One solution is to use a nasal cannula to which a sampling tube is attached. Another solution is to attach a sampling tube in the body of the Hudson facemask. Simply, a sampling tube can be passed through the gap between the patient's face and the Hudson mask. However, the sampling tube could easily become dislodged when the patient moves his or her head. By making a slit between two and three of the vent holes of the Hudson mask, a sampling tube with a Luer connector can be passed through the slit into the body of the mask [41]. The sampling tube is unlikely to become detached because the Luer connector acts as an anchor. Frequent readjustment of the sampling tube can thus be avoided with this simple method. The sampling tube can be easily removed from the mask, and the tube can be reused.

Respiratory monitor

Monitoring of breathing pattern can be useful in detecting respiratory problems during postoperative period. Recently, an acoustic respiratory monitor has been developed to monitor postoperative breathing status of the patient [42]. By applying an adhesive sensor with an integrated acoustic transducer, it is possible to monitor respiratory status non-invasively and continuously. One study has shown that, compared with capnography, the acoustic monitor had greater accuracy in detecting pauses in breathing [42].

Conclusions

There is substantial evidence that monitoring can reduce the incidence of respiratory complications during and after anesthesia. As patients with difficult airways are at increased risk of respiratory complications, appropriate monitoring should be used in such patients. Nevertheless, we should be aware that no monitor is infallible. For example, even capnography can fail to differentiate correct tracheal intubation and inadvertent esophageal intubation. We also should be aware that even when monitors correctly give warning that the condition of a patient is deteriorating, we could misinterpret such warnings. For example, when intubation was accomplished after great difficulty but capnography does not show carbon dioxide waveforms, there is a danger that one ignores the monitor's warning by misinterpreting that waveforms are absent because of bronchospasm. Correct interpretation of appropriate monitoring is crucial to assure safety during difficult airway management.

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