Early Detection of Endotracheal Tube Accidents by Monitoring Carbon Dioxide Concentration in Respiratory Gas

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Absence of ventilation, which may result during anesthesia from esophageal intubation, accidental tracheal extubation, disconnection of the endotracheal tube from the mechanical ventilator, or obstruction of the endotracheal tube, produces hypoxia rapidly and death if not detected in a timely fashion. Despite conventional monitors, such as high- and low-pressure alarms and precordial or esophageal stethoscopes to detect breath sounds, cases of profound hypoxia, secondary to any of the causes cited, continue to occur.1,2 Because equipment to monitor carbon dioxide concentrations in respiratory gases is readily available, we investigated how rapidly such accidents could be detected by changes in carbon dioxide concentration.

MATERIALS AND METHODS

Ten adult mongrel dogs in apparent good health had an 18-g plastic catheter inserted into the vein of either the forepaw or hind leg. The animals were anesthetized with sodium pentobarbital, 25 mg/kg, iv. A 20-g plastic catheter was inserted into the femoral artery for intermittent sampling of arterial blood, and a cuffed endotracheal tube was inserted into the trachea. The endotracheal tube was connected to a volume cycled ventilator (J. H. Emerson Co., Cambridge, Massachusetts) set to deliver a tidal volume of 15 ml/kg and an FIO₂ of 0.5. The rate was adjusted to maintain the P\textsubscript{a\textsubscript{CO₂}} between 35 and 45 mmHg. A Goddard capnograph for monitoring carbon dioxide concentrations in respiratory gases was connected by way of a sideport to the Y-connector of the ventilator where the endotracheal tube was connected to it. The percentage of carbon dioxide in respiratory gas was recorded on-line with a strip chart recorder.

Once a baseline tracing for carbon dioxide was obtained, we monitored the response of the carbon dioxide tracing to a disconnection of the endotracheal tube from the ventilator, to deliberate esophageal intubation, to the removal of the endotracheal tube with its tip advanced into the esophagus, to removal of the endotracheal tube with its tip above the larynx and the balloon inflated in the oropharynx, to kinks in the endotracheal tube equal to or greater than 90° with and without total obstruction, and to the insertion of a Fogerty catheter into the endotracheal tube with incremental inflation of the balloon up to total obstruction of the tube.

Not all maneuvers were performed on every dog, and some were repeated in the same animal. The number of trials with each maneuver is listed as “n.” Because the same result was produced each time a maneuver was repeated in each dog and between dogs, it was not necessary to subject the results to statistical analysis.

RESULTS

When the endotracheal tube was disconnected from the ventilator (n = 5), the recording of carbon dioxide ceased within one breath of the disconnection. No breaths were detected by the carbon dioxide monitor when the tip of the endotracheal tube deliberately was placed into the esophagus (n = 5). In contrast, when the tube was inserted into the trachea, carbon dioxide was recorded with the very next breath.

To simulate accidental tracheal extubation, the endotracheal tube was removed from the trachea and placed so that the tip was lodged in the esophagus below the level of the larynx (n = 15); a nonventilatory pattern was detected with the first cycle of the respirator into the esophagus (Fig. 1, top). When the endotracheal tube was removed from the trachea and manipulated into a retropharyngeal position so that the tip was above the larynx, the carbon dioxide pattern changed noticeably. However, carbon dioxide was still detected with some of
the ventilator breaths. The carbon dioxide concentration was lower in this case than when the tube was placed properly in the trachea (fig. 1, bottom).

When the endotracheal tube was kinked to 90° or greater (n = 5), two patterns appeared. The pattern when the tube was obstructed completely was indistinguishable from that when the tube was removed from the trachea and the tip was lodged in the esophagus. If the obstruction was not complete, however, the shape of the carbon dioxide curve changed; but the end-tidal carbon dioxide concentration did not change significantly from what it had been when the tube was completely patent (fig. 2).

![Fig. 2. Carbon dioxide tracing of tidal gas when the endotracheal tube is kinked greater than 90° without total obstruction.](image)

The carbon dioxide concentration of exhaled gas was of no value in detecting partial internal obstruction of the endotracheal tube (n = 5). However, when the obstruction became complete, the carbon dioxide concentration dropped to zero (fig. 3).

![Fig. 3. Carbon dioxide tracing of tidal gas during a gradual decrease until total occlusion of the lumen of an endotracheal tube.](image)
DISCUSSION

The findings of this study are completely predictable. If sampling of respiratory gas is interrupted secondary to disconnection, obstruction, removal, or esophageal placement of the endotracheal tube, no carbon dioxide will be measured. Therefore, whenever there is total loss of ventilation, monitoring carbon dioxide concentration is an accurate method of immediate detection. A partial extubation of the trachea or intermittent kinking or obstruction of the endotracheal tube may create a recognizable, erratic pattern. This pattern can be detected easily when the carbon dioxide concentration is recorded by continuous tracing but may not be apparent when monitoring devices measure carbon dioxide but record only respiratory rate or peak expired values.

Monitoring carbon dioxide in respiratory gas may be especially useful in patients who have distant breath sounds, who are in unusual positions on the operating table where it is difficult for the anesthesiologist to gain easy access for direct monitoring, or in whom rotation and flexion of the head is contemplated during the operating procedure. In patients who are being ventilated with split lung endotracheal tubes, monitoring expired carbon dioxide can detect presence or absence of ventilation in the desired lung. Carbon dioxide monitoring also can be used for immediate confirmation of correct endotracheal intubation in emergency situations, where visualization of the trachea may be difficult or impossible.

All too frequently, patients under anesthesia still suffer catastrophes that damage the brain permanently or even lead to death from hypoxia.1,2 The question whether the endotracheal tube was obstructed or dislodged always must be answered. This question arises both clinically and legally. In some cases, when traditional methods of monitoring, such as precordial and esophageal stethoscopes and pressure alarms, are used, a definite diagnosis cannot be made. One insurance carrier had eight claims for alleged endotracheal tube accidents that were not detected in timely fashion out of 197 total claims made against anesthesiologists. Three of these patients died, two were permanently brain damaged, and three recovered.†

 Routinely monitoring exhaled gases, particularly carbon dioxide, can lead to precise and rapid diagnosis of nonventilatory states and, thus, may better avert these disasters. In 1979, Peters summarized it well when he urged anesthesiologists to monitor expired carbon dioxide concentrations in real time.3 He maintained that no other signal can document the status of both the ventilatory and metabolic systems so readily.

REFERENCES


† Personal communication, Walker J. from the Florida Physician Insurance Reciprocal files.