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Video Analysis of Two Emergency Tracheal Intubations Identifies Flawed Decision-making

Colin F. Mackenzie, M.B., Ch.B., F.R.C.Anaes., Gordon R. Craig, B.M., M.R.C.P., F.R.C.Anaes.,† Michael J. Parr, M.B., B.S., M.R.C.P., F.R.C.Anaes.,† Richard Horst, Ph.D.,‡ the Level One Trauma Anesthesia Simulation Group§*

PROBLEMS with the documentation of a critical incident involving anesthesia care are that recall of the event may be incomplete or self-serving and that the incident may be perceived differently by several participants.[1] According to Allnutt, such incidents may be reported not in terms of what actually happened but in terms of what "must have happened."[2] To overcome some of the problems of lack of real-time documentation we videotaped anesthesiology team performance in each of two resuscitation areas of a trauma center.

We describe two unusual cases of emergency airway management that illustrate the value of videotaping as a tool for education, quality assurance, understanding of human engineering factors, and cognitive decision-making research.

* Professor of Anesthesiology and Associate Professor of Physiology, University of Maryland.

† Visiting Assistant Professor of Anesthesiology, R. Adams Cowley Shock Trauma Center, University of Maryland School of Medicine.

‡ President, Man-Made Systems Corporation, Ellicott City, Maryland.

§ The Level One Trauma Anesthesia Simulation Group includes Dr. Colin Mackenzie (Chair), Dr. William Bernhard, Dr. Gordon Craig, Dr. Kenneth Dauphinee, Dr. Alistair Dow, Dr. Frances Forrest, Dr. Kevin Gerold, Dr. Christopher Grande, Dr. Alexander Hunter, Dr. Richard Horst, Dr. Jane Matjasko, Dr. Brian McAlary, Dr. Jeremy Nolan, Dr. Michael Parr, Dr. Bryce Randalls, Dr. David Tarantino, and Mr. John Wesolowski of the Department of Anesthesiology, University of Maryland; R. Adams Cowley Shock Trauma Center; and Man-Made Systems Corporation, Baltimore, Maryland.

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Address reprint requests to Dr. Mackenzie: Anesthesiology Research Laboratories, University of Maryland School of Medicine, 10 South Pine Street, Room 534, University Center, Baltimore, Maryland 21201-1192.

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Materials and Methods

The study was approved by the Institutional Review Board. To obtain approval we intentionally restricted patients' facial identification by use of camera angle. If the patient was recognizable, after analysis was complete, only a copy with a digital overlay mask was retained. Approval was obtained from the Institutional Review Board to waive the requirement of patient consent because the anesthesia care providers were the study subjects and because we agreed to remove identifiers and camouflage patient identity on the videotapes. The videotapes were maintained according to institutional quality assurance guidelines.

The participant anesthesia care providers gave unrestricted consent to be videotaped and were aware when events were being recorded. In addition, they consented to publication of details of the video analyses related to these two cases and to use of sections of videotape at scientific meetings or in training materials. The surgeons and nurses, as nonparticipants, did not sign a consent form but were made aware of the study by educational material, presentations at several committee meetings, and presentations to small groups. Nonparticipants were offered the option of having their image camouflaged if they could be recognized.

Video images and sound track were acquired respectively by miniature cameras and microphones suspended from the ceiling of two admitting areas at the R. Adams Cowley Shock Trauma Center, University of Maryland. The field of view included the anesthesiology team, anesthesia equipment, drugs, monitors and intravenous fluids. The audio channel employed two directional microphones and captured communications among the entire trauma team consisting of anesthesiologist(s), certified registered nurse anesthetist(s) (CRNA), surgeons, emergency medicine physicians (EMPs), nurses, and technicians.

Physiologic monitors of patients vital signs were interfaced at each location to a personal computer (PC) that included a video overlay board so that digital representations of key physiologic data (heart rate; arterial blood pressure or pulmonary artery or central venous blood pressures; end-tidal CO_2 tension [ET_{CO_2}]; arterial O_2 saturation [Sp_{O_2}]; and temperature) were overlaid onto the video image that was simultaneously being recorded by the video camera. The digital display of each component of the physiologic data appeared on the videotape only when that component of the monitoring system was providing data, such that the time when the anesthesia team initiated the monitoring of each physiologic parameter could be precisely identified.

Videotape insertion into a video cassette recorder located in each patient admitting area activated the video, audio, and physiologic data acquisition and data overlay by means of serial interfaces (RS232) among the video cassette recorder, PC, and physiologic monitors. An image of the date and wall-clock time at the start of videotaping was overlaid onto the first few seconds of the video recording, and thereafter elapsed time from videotape insertion was recorded. Time code data were produced by a time code generator board in the PC (fig. 1).

Videotapes were analyzed using the Observational Coding System of Tools (OCS Tools, Triangle Research Collaborative, Inc., NC), a commercial video analysis software package. This package facilitates a video analyst's note-taking and coding of observed events according to a user defined coding scheme. The analyst's inputs are stored along with time-stamps that are automatically appended, based on the machine-readable time code that is imprinted on the tape during video recording. Synchronization of the various types of data is thus assured as the same machine readable time-code is stamped on the tape, overlaid on the video image, and stored with both the physiologic and observational coding data. We used a frame accurate video cassette recorder (model BR S605U, JVC) connected by serial interface to an 80386 PC in which there was a time code reader/generator/translator board (PC VITC/RGI) and a video overlay board (Altech International, Milpitas, CA). (The video analysis system and OCS Tools software without the 80386 PC cost about $11,500.)

Video analysis began when the attending anesthesiologist involved in each of these two cases reviewed the videotape with a nonparticipant subject matter expert (SME), who was an experienced trauma anesthesiologist. The tape of case 1, the critical portion of which lasted approximately 8.5 min, was reviewed 4 h after videotaping. The critical portion of the tape of case 2 lasted approximately 6.5 min and was reviewed 2 weeks after videotaping. During the review sessions, the attending anesthesiologists provided a running commentary describing the events, communications, and therapeutic interventions that occurred both on and off the camera's field of view during their respective cases. The nonparticipant SME asked questions as appropriate to elicit more detailed information and to probe the attending anesthesiologists about the context

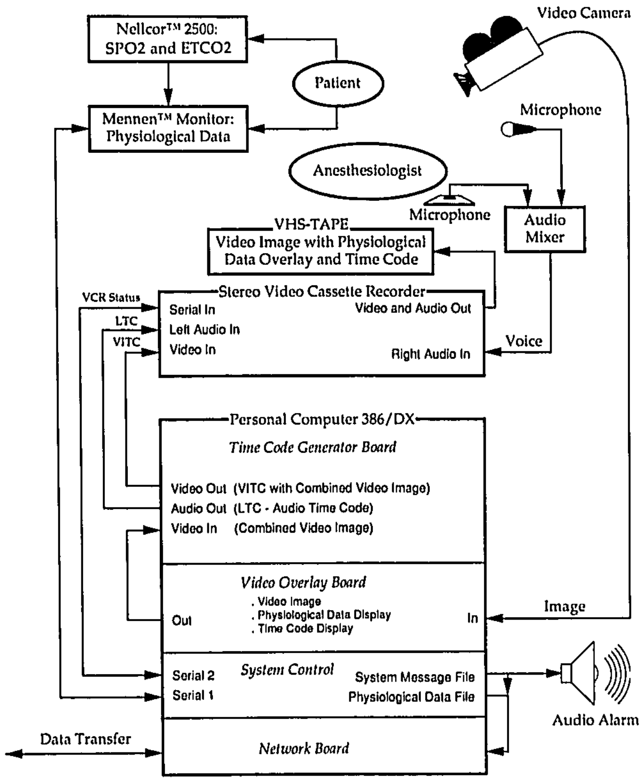

Fig. 1. Video data acquisition system used for videotaping two emergency tracheal intubations. The video camera and two unidirectional microphones were permanently suspended from the roof of the admitting area of a trauma center. They were interfaced with a personal computer located remotely behind the mechanical ventilator and a video cassette recorder (VCR) fixed on top of the anesthesia cart. Sp_{O_2} = arterial O_2 saturation; ET_{CO_2} = end-tidal CO_2 tension; LTC = longitudinal time code; VHS = video home system; VITC = vertical interval time code.

of their observed behavior and the reasoning behind their patient treatment decision-making. These review sessions were audio taped and notes were subsequently entered into an OCS Tools file.

Next the key verbal communications among the trauma team that could be discerned from the audio channel of the videotape were transcribed into another OCS Tools file. These two files were then merged, providing an integrated, time-sequenced transcription of observational notes, commentary, and key verbal communications from the tape. The nonparticipant SME then reviewed the transcriptions and videotapes and recorded in a separate commentary file what he thought had occurred. The nonparticipant SME and attending anesthesiologist then met again and reviewed the videotape together. Key segments of the videotape were repeatedly reviewed with different hypotheses proposed by the nonparticipant SME to explain what had occurred. The attending anesthesiologist then confirmed or rebuffed the ideas proposed by the nonparticipant SME until, with the help of the video image, the sequence of events that occurred was agreed upon. In case 1 there was failure to agree on one aspect of patient management (see below). Other aspects of cases 1 and 2 were agreed upon by consensus among all participants in the analysis.

Case Reports

Case 1

Case 1 illustrates how a procedural error and a knowledge-based error resulted in a risk to the patient. The first of these errors was a failure to monitor ET_{CO_2} and to adequately check ventilation equipment. The second error was a failure of the supervising attending anesthesiologist to be familiar with an esophageal obturator airway (EOA) and to check the management of a trainee undergoing emergency airway management practice. Despite these events, there was no adverse patient outcome.

The patient had a history of a cardiac arrest in the field. There was confusion in the initial reports about whether the patient had sustained a head injury or whether he was under the influence of drugs or had suffered an epileptiform seizure. Later, during resuscitation, it was learned that the patient was assaulted, had a cardiac arrest, was initially resuscitated at the scene, and was also found in possession of drug paraphernalia. On admission, by ambulance, he was unconscious and his lungs were being ventilated using a resuscitator bag through an EOA, which resulted in chest movements. With an anesthesiologist in attendance, 2 min was required to transport him to the admitting area. An abbreviated summary is shown in table 1 of the major events that took place during admission and resuscitation of case 1, as obtained by reviewing the videotape and the video analysis procedure described above.

Table 1. Major Events and Elapsed Time Since Admission During Resuscitation of Patient 1

Elapsed Time (min:s)	Event
00:00	Patient arrives in admitting area receiving O_2 by resuscitator bag attached to EOA
00:03	"He's got a pulse"
00:48	IV working in right arm, IV fluids hanging
1:00	Anesthesiologist listens to both sides of chest
1:26	"Blood pressure 98/60"
2:16	Tracheal tube in hands of EMP
3:01	Thiopental 50 mg, succinyl choline 100 mg given IV
3:10	Anterior half of cervical collar off; cricoid pressure applied
3:20	EMP takes over ventilation through EOA from anesthesia fellow
3:27	EMP disconnects resuscitator bag
3:39	Laryngoscope in, "this (EOA) looks like it's in the trachea"
3:45	EMP asks for suction
3:50–3:56	Laryngoscope out; airway suctioned
4:03	Anesthesiologist:" Just ventilate him again and take it (EOA) out and change to an ET tube."
4:07	EMP ventilates through EOA
4:32	Cricoid pressure on: EOA cuff deflated
4:45	Repeat laryngoscopy
5:01	EOA out
5:21	Conventional tracheal tube insertion begins
5:33	Tube inserted on third attempt
5:42	Ventilating with resuscitator bag
6:00	EMP listens to both sides of chest and stomach
6:21	Anesthesiologist delegates anesthesia fellow to manage a second patient admission
6:23	Ventilating with resuscitator bag; anesthesiologist measuring distance ET tube in trachea; listens to chest
6:45	Anesthesiologist connects ventilator
6:57	Pulls the ET tube back
7:33	Change ventilator setting from pressure support to mandatory ventilation
7:52	$ETCO_2$ monitored
8:36	ET tube taped in place

EOA = esophageal obturator airway; EMP = emergency medicine physician; ET = endotracheal; $ETCO_2$ = end-tidal CO_2.

In the admitting area both the attending anesthesiologist and an EMP, undergoing tracheal intubation training, listened to the patient's chest, but neither made comment on the adequacy of ventilation. The elapsed time in table 1 shows that after 2 min, ventilation was delegated to this EMP. Thiopental and succinylcholine were administered intravenously by the attending anesthesiologist. The EMP had some difficulty visualizing the cords but stated that "the EOA is in the trachea." The attending anesthesiologist who was standing alongside the patient told the EMP to "ventilate again and take it [the EOA] out and change to an ET [tracheal] tube." Cricoid pressure was applied and the EOA removed. The trachea was intubated after the EMP inserted and withdrew a conventional cuffed tracheal tube in and out of the mouth three times before passage through the larynx was achieved. The patient's lungs were then manually ventilated using a resuscitator bag and breath sounds were checked by stethoscope. Right-sided endobronchial intubation was detected and the tracheal tube was withdrawn a few centimeters. The mechanical ventilator was connected but the setting had accidentally been switched from mandatory ventilation to pressure support mode. Because of residual succinylcholine paralysis, the lungs were not ventilated for 48 s. This problem was recognized and then corrected, after tracing the fault. The remaining resuscitation and management proceeded uneventfully. The patient awoke on day 2 and was discharged on day 4 after admission. Analysis of arterial blood gas samples, taken on admission while the lungs were ventilated with the EOA, showed O_2 tension 456 mmHg, *p*H 6.53, and CO_2 tension 94 mmHg during breathing of 100% O_2. The good oxygenation with hypoventilation indicates that the EOA was correctly positioned in the esophagus. Increased arterial CO_2 tension and acidosis are reported to occur frequently when the EOA is used after cardiac arrest.[3,4]

In case 1, video analysis enabled identification of the exact communications that took place between the attending anesthesiologist and the EMP as the anesthesiologist could not recall these before viewing the videotape, nor could he state whether he had monitored ET_{CO_2}. We were able to document the lack of ET_{CO_2} monitoring early on when the EOA was in place. ET_{CO_2} monitoring could have confirmed the correct placement of the EOA. We also determined the exact time that the anesthesiologist did monitor ET_{CO_2}. This occurred after EOA extubation, tracheal intubation with a tracheal tube, and connection to the ventilator. We were additionally able to measure the time for detection (50 s) and correction of endobronchial intubation (84 s) and for detection (42 s) and correction (48 s) of the lack of mechanical ventilation.

Case 2

In case 2 a critical airway incident resulted from three independent events: (1) a knowledge-based error about the intramuscular dose of succinylcholine necessary to produce relaxation; (2) communication failure among the anesthesia care providers; and (3) communication failure between the team leader and the anesthesia team.

On admission the patient was severely obtunded (Glasgow Coma Scale 9/15)[5] and obese (about 100 kg) and had tightly clenched jaws. Blood pressure could not be recorded because of hemorrhage resulting from an abdominal gunshot wound, and intravenous access was not available because the patient was an intravenous drug abuser. The major events, determined from the video analysis procedure described above, during admission and resuscitation before proceeding to the operating room are shown in table 2. The elapsed time in table 2 identifies that during the 1st min the patient's lungs were ventilated *via* face mask, although no quantitative assessment of ventilatory adequacy could be made because Sp_{O_2} and ET_{CO_2} were not monitored. After 1 min the trauma team leader ordered tracheal intubation. Because there was no intravenous access at this time, the anesthesiologist gave 130 mg intramuscular succinylcholine into the tongue. Within 17 s the CRNA began blind nasotracheal intubation because he said he "thought [he] could intubate him." However, the

Table 2. Major Events and Elapsed Time since Admission during Resuscitation of Patient 2

Elapsed Time (min/s)	Event
00:00	Patient arrives in admitting area
00:18	O_2 mask on
00:35	Ventilate patient by mask and resuscitator bag; physical examination begins; no recordable BP; femoral pulse palpated at HR 114/min
1:02	"Intubate" (team leader)
1:35	Succinylcholine injected IM onto tongue
1:52	CRNA inserts nasotracheal tube
1:57	Gagging noise as nasal tube advanced
2:15–2:55	Repeated patient vomiting out of nasal tube
3:28	IV access achieved via cordis; HR 145/min
3:56	Team requests "fat boy BP cuff"
4:34	Succinylcholine given IV; cricoid pressure on
4:39	Patient holding suction catheter pushing anesthesia personnel away
5:19	CRNA manually ventilating patient with bag
5:22	Cordis connected to level 1 infuser
5:39	Still no recordable BP
6:38	Intubation
7:21	HR 146 beats/min; still no BP obtained
8:22	O + packed RBC 2 units started
10:32	Team complains: "We don't even have any BP and the guy's been here ten minutes."
11:20	BP is "over 100 mmHg" (palpation)
11:28	End-tidal CO_2 monitored
11:34	HR down to 133 beats/min; temperature monitored = 36°C
12:39	Another BP cuff placed on right arm
14:04	Subclavian line placed
14:50	BP 110/46 mmHg by arterial line
15:18	3L crystalloid, 2 units RBCs, warm plasma given
22:35–30:23	X-rays
29:58	Still rapid infusion; HR 122 beats/min BP keeps drifting down; bleeding from GSW
30:54	Fresh frozen plasma ordered
31:16	Request made to move to OR as team suspects aorta and vena cava are injured

BP = blood pressure; CRNA = certified registered nurse anesthetist; HR = heart rate; O+ = O Rhesus positive; RBC = red blood cells; GSW = gunshot wound; OR = operating room.

attempts caused gagging and then precipitated repeated vomiting. The tracheal tube stimulated vomiting as it was advanced into the esophagus. Moreover the videotape shows that the tube, when in the esophagus, repeatedly diverted the projectile vomitus out of the nasopharynx preventing aspiration. Gagging sounds can be heard on the audio recording preceding the vomiting. The patient became combative. Four minutes and 25 s after admission, intravenous access was obtained. Succinylcholine 100 mg was given intravenously and cricoid pressure applied. Because of hemorrhagic shock, the intravenous succinylcholine took 2 min to circulate and produce relaxation adequate for intubation. Orotracheal intubation occurred and resuscitation continued with blood and other fluids. ET_{CO_2} monitoring began 5 min after intubation, with temperature monitoring occurring shortly thereafter. Because of the patient's obesity and hemorrhagic shock, blood pressure was not obtained until an arterial catheter was placed by cut-down 15 min after admission. Bleeding from the gunshot wound continued despite external compression and vital signs remained unstable even though 2 U blood and 3 l crystalloid fluids were given within 16 min of admission. The patient died in the operating room 3 h after admission from exsanguination, after receiving 52 U blood, 46 l crystalloid, 20 U fresh frozen plasma, and 10 U platelets. There was an associated coagulopathy secondary to massive transfusion for vascular injuries to the left iliac artery and iliac vein caused by the gunshot wound.

In case 2, video analysis enabled exact timing of the sequence of the order for intubation, giving intramuscular succinylcholine, nasotracheal intubation attempts, and intravenous succinylcholine. The video showed that the patient was still moving after intramuscular succinylcholine before eventual relaxation for oral tracheal intubation after administration of intravenous succinylcholine. The audio channel documented the patient gagging before vomiting and the failure of the anesthesia care providers to communicate with the team leader or among themselves. The physiologic data collection identified that neither ET_{CO_2} nor Sp_{O_2} was monitored before intubation. In neither case 1 nor case 2 did the anesthesia care providers' knowledge that they were being videotaped appear to have influenced their actions.

Discussion

The videotapes document two airway management incidents in real-time. Because of videotaping, this report does not suffer as much from factual uncertainty and absence of recall as many other retrospective reports of airway management. Because the patients' physiologic data were overlaid directly onto the video, there was no need for a second camera to record the patient vital signs. In other studies in which real critical events were captured on videotape in the operating room, analysis was limited because no patient data were available.[6]

We analyzed these two videotapes, in which the participants realized something of interest had happened in relation to emergency airway management, to determine whether there were procedural, interpersonal factors, ergonomic or training implications that could be learned.

Procedural Issues

The procedural issue identified was inadequate use of ET_{CO_2} and Sp_{O_2} monitoring. The cause of the chest inflation observed during EOA ventilation of case 1—air entry into the lungs or gastric inflation–could have been established by ET_{CO_2} or Sp_{O_2} monitoring or by direct laryngoscopy by a laryngoscopist more experienced than the EMP. None of these monitors or examinations were used. Lung inflation could be established by listening to the chest, and although this was done, the supervising attending anesthesiologist did not communicate his findings from chest auscultation to the EMP. As a result of this omission of monitoring and communication, the EOA was removed from the esophagus before protection of the airway from aspiration by placement of a cuffed tracheal tube. In case 2, a normal ET_{CO_2} waveform and digital displays of ET_{CO_2} and Sp_{O_2} could have prompted continuation of mask ventilation until intravenous access was obtained and until succinylcholine could be given by the more predictable intravenous route. If the vomiting had obstructed the airway, deteriorating values of ET_{CO_2} and Sp_{O_2} would be valuable in determining when to either use jet ventilation or request the surgical team to perform a cricothyroidotomy.[7] However, in reality it is likely that ET_{CO_2} would have had limited usefulness in case 2 as the patient was combative, pulmonary blood flow was low and there was potential difficulty in maintaining a mask-fit sufficient to allow adequate monitoring of the low exhaled CO_2. Reduced peripheral blood flow and patient movements would also reduce the likelihood of adequate monitoring of O_2 saturation by pulse oximeter.

Interpersonal Human Factors

The attending anesthesiologist managing case 1 failed to communicate that air entry was acceptable during EOA ventilation and to convey his uncertainty about the type of airway to the EMP. It was the opinion of the nonparticipant SME that the attending anesthesiologist was willing to let the EMP struggle with the management of the EOA and intubation of the trachea as part of the learning process. The participant anesthesiologist confirmed his reluctance to intervene, on review of the videotape, because he did not think the patient was at risk. The subsequent events including detection and correction of endobronchial intubation and detection of why the mechanical ventilator was not ventilating the lungs all occurred within 1.5 min of tracheal intubation. For these actions the attending anesthesiologist did intervene and he took over diagnosis and management from the inexperienced EMP, though he disagreed with the nonparticipant SME that he had accidentally changed the ventilator controls to pressure support.

During management of case 2 there was a failure of communication between the attending anesthesiologist and CRNA, and between the anesthesia care providers and the team leader. The attending anesthesiologist did not clearly communicate the plan of giving intramuscular succinylcholine to the CRNA, nor was there any discussion of the merits of attempts at blind nasotracheal intubation. Both the attending anesthesiologist and the CRNA failed to communicate to the team leader that ventilation was adequate by face mask. There was time and peer-pressure stress induced by the surgical team leaders' order to intubate and immobilize the combative patient so that the surgical aspects of resuscitation could proceed expeditiously. Such social pressures may have been operative in case 1 when the supervising anesthesiologist failed initially to intervene and in case 2 when the anesthesia care providers abandoned face mask ventilation.[8] Omission of communication and failure of team coordination have been reported in other time-stress situations, such as may occur during emergency tracheal intubation.[8]

Ergonomics

As a result of videotaping these two cases we also established that neither anesthesiologist had recall of the ET_{CO_2} when tracheal intubation was achieved and the ventilator was connected and functioned. The CO_2 monitor (Nellcor 1000) sampling site was at the Y-piece of the ventilator tubing and in case 1, arterial CO_2 tension was grossly abnormal. Despite this abnormality, because of the placement of the monitor (which displays both Sp_{O_2} and ET_{CO_2}) on a shelf behind the anesthesiologist in the patient admitting area, the abnormality in ET_{CO_2} was not recognized and the alarm was scarcely audible in the videotape above the background noise of the resuscitation team. Further ergonomic findings, established on testing after the videotapes were analyzed, were that the Nellcor 1000 takes 2 min to warm up and cannot be tested (by breathing into the circuit) before a patient admission without an alarm's sounding continuously after testing is completed. However, if the Nellcor 1000 is switched off after testing, it does not alarm when switched on again, provided it is not retested. Monitors besides the Nellcor 1000 also have the annoying feature of alarming if set up in a ready mode. The Siemens 900C mechanical ventilator is a complex device with multiple switches and dials making it time-consuming to trace faulty control settings. It cannot be left in the switched-on ready state delivering a tidal volume without a continuous auditory alarm unless it is attached to an anesthesia circuit reservoir bag that acts as a model lung. Both of these ergonomic factors—together with the complexity of the Seimens 900C control panel, the necessity to disable the apnea alarm, and the position of the Nellcor 1000 behind and remote from the anesthesiologist—made implementation of ventilation and monitoring of ET_{CO_2} and Sp_{O_2} during initial resuscitation more difficult. The Nellcor 1000 has now been relocated in the patient admitting area to an eye-level position above the Siemens 900C and both the Nellcor 1000 and the Seimens 900C can be tested to ensure correct operation and then switched off to prevent continuous auditory alarms. These changes have made Sp_{O_2} monitoring more readily available, but have not increased the use of ET_{CO_2} monitoring during resuscitator bag ventilation and immediately after intubation because this requires an additional Y-piece connector. We have recommended placement of such an ET_{CO_2} monitoring connector in the resuscitator bag circuit, but have not yet assessed whether it has changed the frequency of ET_{CO_2} monitoring.

Training

From the analysis of the management of case 1 it is clear the anesthesia care providers and trainees need training in alternate airway management devices such as EOA,[3] EGTA,[4] the Combitube,[9] and laryngeal mask[10]. Unfortunately, there are no training devices that entirely substitute for real emergency tracheal intubation so that it is common practice to train people using the "hands on" approach, although training devices can be used to provide the rudimentary training about the EOA that was missing in case 1.

Management of the patient in case 2 identified a knowledge based error about the dose of intralingual succinylcholine. Although succinylcholine by this route has over twice as rapid an onset (in normal children), than when give intramuscularly,[11] the dose given in case 2 of 1.3 mg/kg was much lower than the 3–4 mg/kg recommended for intramuscular use.[12] If intralingual succinylcholine is given, even to normovolemic patients, it is clear that more than 17 s must elapse (table 1) before tracheal intubation is attempted. One of the lessons learned from this videotape was that intralingual succinylcholine was not efficacious in hemorrhagic shock. A second lesson was that the decision to intubate was correct, but the timing of implementation was erroneous. Mask ventilation could have continued until intravenous access was obtained.

Both case 1 and case 2 suggest that the anesthesia care providers would have benefitted from use of Sp_{O_2} and ET_{CO_2} monitoring to confirm the adequacy of oxygenation and ventilation before deciding to remove the EOA (case 1) or abandon mask ventilation (case 2). These monitors were available. As noted in the analysis of pilots' errors in the cockpit, problems encountered often are due to the crews' inability to use readily available resources.[13,14]

Neither of the two scenarios videotaped during emergency tracheal intubation appears in the Anesthesia Crisis Resource Management training in a comprehensive anesthesia simulation environment,[14,15] in the Gainesville Anesthesia Simulations,[16] nor in the Anesthesia Simulator-Recorder for general anesthesia training.[17] The Anesthesia Crisis Resource Management course, although including intravenous failure, does not identify inability to start an intravenous infusion as a critical incident.[14] These and other unusual and interesting occurrences recorded from real clinical care could usefully be incorporated into simulator-based anesthesia training.

Videotaping as a Tool for Research

There are both strengths and weaknesses in analysis of videotape of real patient management for education, quality assurance, and ergonomics research. The major advantages are that the participant anesthesia care providers are not dependent as much on memory, as the video image and audio recording recreate the event, including comments by the team members and alarms that might not have been heard or noted at the time. In our experience with these two cases, discussions among the participant and nonparticipant SMEs provided additional information that would not necessarily have been revealed without the video image and audio recording. We think that it would have been more difficult to target points where performance could have been changed without the video image and audio channel. The participant anesthesia care providers found that video analysis allowed them to reflect on their performance in greater detail than is otherwise possible. They found it revealing to discuss the video with the nonparticipant SME; for instance, in case 1, the attending anesthesiologist did not realize, other than emergency replacement of the EOA, that the management was not ideal. Only with viewing of the videotapes did it become apparent how improved communication, checking of the EMP's clinical examinations and diagnosis, and use of ET_{CO_2} monitoring would have avoided the need to remove the EOA without first intubating the trachea.

The video acquisition system acquired physiologic data in the same manner as an automated anesthesia record by serial interface with patient monitoring systems.[18] The added advantage of video acquisition is the ability to see when events occurred and what was done. We were able to see when the anesthesia care providers interacted with the anesthesia machine (*e.g.*, to change vaporizer settings), the ventilator (*e.g.*, to check or change control dials), the monitoring systems (*e.g.*, to initiate or calibrate), or the patient (*e.g.*, to suction the trachea, inject drugs, or give intravenous fluids). We also could more easily check physiologic data for artifacts (*e.g.*, transducer balancing or flushing, pulse oximeter probe adjustment) by viewing a video than observing the printout of an automated anesthesia record. The audio channel provided information about team interaction, verbalization in relation to tasks, and data on which the anesthesia care providers were focusing, and not just information about the patient status. Video acquisition allowed gathering of information after the procedure about events or interventions not considered or attended to at the time.

The weakness of video analysis is that it is tedious and time-consuming. It is difficult to accurately estimate how much time was required to analyze each of these videotapes because much work was spent in development of the analysis system and database necessary to facilitate video analysis of these cases and others. About 10 h was spent in discussion, viewing and transcription of the 8.5 min of case 1. Case 2 took less time to analyze because the issues of interest that were unusual occurred within 6.5 min culminating with the intubation of the trachea. The critical event of no airway access and no intravenous access combined with patient vomiting was more obvious than the events in case 1. Discussion of case 2 was more straight forward in reaching a consensus and required only about 4 h for analysis.

Other weaknesses of video analysis are that even with a two-microphone system it is difficult to pick up all the utterances and the audio record could be improved. However, we believe it would be more obtrusive to equip the anesthesia care providers with microphones. The video image does not include the entire field of view and cannot identify events occurring off the screen, though the audio channel can be helpful. In analyzing a video image with the physiologic data overlaid there is a tendency to think that the participants were aware of these data, when in reality this is unlikely because of selective attention to other aspects of anesthesia care. Because analysis is performed after the procedure, the anesthesia care providers have time to rationalize the decisions made as they are aware of the outcome. Thinking aloud, and interviews conducted in the middle of case management have been used in simulated anesthesia cases to overcome this problem.[14,15] Nonetheless, video analysis is better than an automated anesthesia record at determining how decisions occurred because the video and audio recording of all the decision-makers can be repeatedly reviewed. As a result, it is more difficult to make convincing rationalizations for alternate decisions when reviewing a videotape than the automated anesthesia record.

We believe the real anesthesia environment has many advantages for the study of critical incidents over simulation, including more variability, uncertainty, management options, stress, complexity, and potentially adverse consequences than simulation. Videotaping of the real environment enables management of critical incidents and current anesthesia practices to be repeatedly and intimately analyzed. We believe that simulation should be used to practice ideal management of critical incidents. Video analysis of such real events will be important in development of the database necessary for simulation and to improve anesthetic practice and equipment in the future.[19]

Video analysis of these two emergency intubations suggests measures that may improve anesthesia care providers management of similar cases, including:

1. Skills training[14,||,#]: *e.g.,* correct intramuscular dose of succinylcholine, withdrawal of tracheal tube with gagging, conventional tracheal tube insertion before removal of EOA, and monitoring of ET_{CO_2} and Sp_{O_2}
2. Crew training[14,#,**]: *e.g.,* improvement of communication and coordination among members of trauma team
3. Stress reduction[20,||]: *e.g.,* education targetted at stressors, rehearsal of previous difficult cases including stressors, and application of stress reduction techniques in clinical practice

These three measures should be discussed in an educational setting, ideally practiced in a simulated environment then implemented in real-life. We believe it is by systematic study of such real critical incidents that the mechanisms involved in their genesis will be understood and from these analyses preventive measures or particular approaches to training may be devised.

|| Backer PR, Orasanu J: Stress, stressors and performance in military operations: A review. Final report. United States Army Research Institute Contract DAAL03-86-D001, 1992.

Lauber JK: Cockpit resource management: Background and overview, cockpit resource management training, Cockpit Resource Management Training: Proceedings of the NASA/MAC Workshop. Edited by Orlady HW, Foushee HC. Moffett Field, CA, NASA–Ames Research Center, 1977, CP-2455.

** Ruffell-Smith HP: A simulator study of the interactions of pilot workload with errors, vigilance and decisions. NASA TM-78482. Moffett Field, CA: NASA–Ames Research Center, 1979, pp 1–54.

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References

1. Utting JE, Gray TC, Shelly FC: Human misadventures in anaesthesia. Can Anaesth Soc J 26:472–478, 1979
2. Allnutt MF: Human factors in accidents. Br J Anaesth 59:856–864, 1987
3. Smith JP, Bodai BI, Seifkin A, Palder S, Thomas V: The esophageal obturator airway: A review. JAMA 250:1081–1084, 1983
4. Auerbach PS, Geehr EC: Inadequate oxygenation and ventilation using the EGTA in the prehospital setting. JAMA 250:3067–3071, 1983
5. Teasdale G and Jennett B: Assessment of coma and impaired consciousness. Lancet 2:81–84, 1974
6. Goldman LI, McDonough MT, Rosemond GP: Stress affecting surgical performance and learning: I. Correlation of heart rate, electrocardiogram, and operation simultaneously recorded on videotapes. J Surg Res 12:83–86, 1972
7. Practice Guidelines for management of the difficult airway. ANESTHESIOLOGY 78:597–602, 1993
8. Gaba DM, Maxwell M, DeAnda A: Anesthetic mishaps: Breaking the chain of accident evolution. ANESTHESIOLOGY 66:670–676, 1987
9. Neimann JT, Rosborough JP, Myers RAM, Scarberry EN: The pharyngotracheal lumen airway: Preliminary investigation of a new adjunct. Ann Emerg Med 13:591–596, 1984
10. Brain AIJ: The laryngeal mask: A new concept in airway management. Br J Anaesth 50:801–805, 1983
11. Mazze RI, Dumbar RW: Intralingual succinylcholine administration in children: An alternative to intravenous and intramuscular routes? Anesth Analg 47:605–615, 1968
12. Liu LMP, DeCook T, Goudsouzian NG, Ryan JF, Liu PL: Dose response to intramuscular succinylcholine in children. ANESTHESIOLOGY 55:599–602, 1981
13. Caro PW: Flight training and simulation, Human Factors in

Aviation. Edited by Wiener EL, Nagel DC. San Diego, Academic Press, 1988, pp 228–262

14. Howard SK, Gaba DM, Fish KJ, Yang G, Sarnquist FH: Anesthesia crisis resource management training: Teaching anesthesiologists to handle critical incidents. Aviat Space Environ Med 63:763–770, 1992

15. Gaba DM, DeAnda A: A comprehensive anesthesia simulation environment: Recreating the operating room for research and training. ANESTHESIOLOGY 69:387–394, 1988

16. Good ML, Gravenstein JS: Anesthesia simulators and training devices. Int Anesthesiol Clin 27:161–166, 1989

17. Schwid HA, O'Donnell D: The Anesthesia Simulator-Recorder: A device to train and evaluate anesthesiologists' responses to critical incidents. ANESTHESIOLOGY 72:191–197, 1990

18. Moon J: Data interfacing in automated record and alarm systems: The alpha PC, The Automated Anesthesia Record and Alarm Systems. Edited by Gravenstein JS, Newbower RS, Ream AK, Smith NT. Boston, Butterworths, 1987, pp 157–162

19. Mackenzie CF: Simulation of trauma anesthesia, Textbook of Trauma Anesthesia and Critical Care. Edited by Grande C. St. Louis, Mosby–Year Book, 1993, pp 1180–1191

20. Spettel CM, Liebert RM: Training for safety in automated person-machine systems. Am Psychol 41:545–550, 1986

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Right Upper Lobe Resection after Left Pneumonectomy

Brian W. King, Ph.D., M.D., Kenneth P. Gross, M.D.†*

SURGERY of the airway or lungs remains a challenge to the anesthesiologist because adequate oxygenation and ventilation can be difficult to maintain. We report an unusual case that illustrates the use of low-frequency catheter jet ventilation for improving surgical conditions in thoracoscopic procedures.

Case Report

A 59-yr-old, 90-kg man was admitted for thoracoscopic resection of a right upper lobe mass. He had a 150-pack-yr smoking history and in 1990 had undergone a left pneumonectomy for adenocarcinoma. His medical history also was significant for three myocardial infarctions. Medications were diltiazem and isosorbide dinitrate. His preoperative pulmonary function tests showed a forced vital capacity of 2.37 l and a forced expiratory volume in 1 s of 1.43 l. Preoperative arterial blood gas analysis revealed a *p*H 7.45, a carbon dioxide tension (P_{CO_2}) of 39 mmHg, and an oxygen tension (P_{O_2}) of 84 mmHg at a fraction of inspired oxygen of 0.21.

A radial artery catheter and a 16-G intravenous catheter were placed before induction. In addition, an epidural catheter was inserted at the T7–T8 interspace in case an open thoracotomy would be needed. After induction of anesthesia with thiopental and vecuronium and initiation of anesthesia with isoflurane in oxygen, bronchoscopy was performed, and the bronchus intermedius was intubated with an 8.0-mm tracheal tube (TT). Fiberoptic bronchoscopy of the TT confirmed that the cuff of the TT was occluding the right upper lobe bifurcation. Because this patient had previously undergone a left pneumonectomy, a right endobronchial intubation was done to attempt deflation of the right upper lobe to improve operating conditions while still maintaining ventilation to the remainder of the lung. Hemoglobin oxygen saturation measured by pulse oximetry remained 100% with an inspired oxygen concentration of 100%, a tidal volume of 420 ml, and a respiratory rate of 10 breaths/min. The peak inspiratory pressure was 20–30 cmH_2O.

After the patient was turned to the left lateral decubitus, thoracoscopy was begun. However, visualization was hampered by inadequate deflation of the right upper lobe and the continued ventilation of the remaining right lung. To decrease the excursions of the lung, we elected to try low-frequency jet ventilation by insufflating 100% oxygen at 50 psi through a small-diameter (2-mm-ID tubing) suction catheter (Rüsch, Duluth, GA) positioned at the distal end of the TT. The technique and apparatus were similar to those described by Salzer *et al.*[1] The oxygen supply of the operating room was connected to a reducing valve with a manometer. Distal to the reducing valve was high-pressure tubing with an interrupter valve with a toggle switch handle; the jet was controlled by intermittently manually activating this valve. The 2-mm–ID tubing of the suction catheter was attached to the outlet of the valve. The proximal end of the TT remained open to the atmosphere.

Because we had no easy way of continuing an inhalational anesthetic, the epidural catheter was injected with 6 ml 1% lidocaine with epinephrine, and an intravenous propofol infusion was begun

* Resident in Anesthesia. Current affiliation: Windham Community Hospital, Willimantic, Connecticut.

† Instructor in Anesthesia.

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Address reprint requests to Dr. Gross: Department of Anesthesiology, Harvard School of Medicine, Brigham and Women's Hospital, 74 Francis Street, Boston, Massachusetts 02115.

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