Video as a Tool for Improving Tracheal Intubation Tasks for Emergency Medical and Trauma Care

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Study objective: We illustrate how audio-video data records can improve emergency medical care, using airway management to show how such video data may help to identify unsafe acts, accident precursors, and latent and systems failures and to evaluate performance.

Methods: This was a retrospective analysis of videos of real patient resuscitation in a trauma center. Participant care providers reviewing their own videos of tracheal intubation identified failures to use diagnostic equipment, fixation errors, and team and communication errors.

Results: Neutral expert observers noted team coordination failures and poor error recovery. Comparison with a consensus guideline for a tracheal intubation task/communication pathway showed that communications were unclear or not made, and key tasks were omitted by team members. Differences were detected between performance of tracheal intubation in elective and emergency circumstances. Revised practices ("3 Cs": clinical examination, communication, carbon dioxide) mitigated task performance and communication deficiencies.

Conclusion: Video is complementary to traditional quality improvement methods for improving performance in airway management and emergency medical and trauma care, assessing standard operating procedures, and reviewing communications. Video data identify performance details not found in quality improvement approaches, including medical record review or recall by participant care providers. Weaknesses in using video for data include lengthy video review processes, poor audio, and the inability to adequately analyze events outside the field of view. Opportunities are to use video audit for quality improvement of other emergency tasks. Video buffering reduces personnel requirements for capture and simplifies data extraction. Medicolegal and confidentiality threats are significant. [Ann Emerg Med. 2007;50:436-442.]

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INTRODUCTION

Data collection is a major challenge in studies of emergency medical care because of the unexpected nature and timing of care events. Real-time data collection is needed to counteract hindsight biases in retrospective construction of past events[1] and to capture dynamically evolving emergency situations. An influential tool that may assist such data collection is audio-video recording.[2] Analysts of video data can repeatedly examine activities in emergency medical and trauma care settings and extract detailed qualitative and quantitative data.[3-6] Additionally, emergency care providers can review their own care through audio-video records and provide comments on covert mental processes cued by audio-video records.[3] Such a cognitive approach to examination of real emergency medical events is a powerful tool to uncover many facets of the nature of emergency care work,[4] including clinician performance, diagnosis, planning, communications during stressful tasks, and identification of patient and practitioner safety issues.

Editor's Capsule Summary

What is already known on this topic

Retrospective medical record review is an inadequate method for examining quality-of-care issues that occur during complex medical procedures.

What question this study addressed

Do the video recording and subsequent analysis of emergency department tracheal intubations provide an effective means of identifying failures and improving care pathways for this procedure?

What this study adds to our knowledge

The analysis of 50 videos, including one of an undetected esophageal intubation, revealed many breaks in protocol that could not have been discovered through traditional quality improvement processes such as medical record review and postevent interviews.

How this might change clinical practice

Video analysis can provide useful information for process improvement. However, the process is time intensive and creates medicolegal and confidentiality issues.

When compared with direct observation, video data can help overcome difficulties in capturing subtle cues, fleeting errors, brief utterances, or team interactions and communications. There is a great need to understand what occurs in uncertain emergency medicine workplaces, where risky but lifesaving procedures such as tracheal intubation are carried out, often in nonoptimal circumstances. Video data may be helpful to identify what Reason[7] has termed unsafe acts, precursor events, accident opportunities, and latent and systems failures that traditional observational data collection methodologies may fail to capture.[3,8] This article illustrates how video can be used as a tool to examine performance and the nature of the emergency medical domain, using the example of video analyses of elective and emergency tracheal intubation. Video records may identify problems and solutions to improve processes in emergency tasks that are likely to be generalizable to other high-risk emergency medical procedures.

MATERIALS AND METHODS

The setting for video capture was emergency care in a US statewide primary adult resource center for trauma that has admitted more than 5,000 patients per year for the last 10 years. Audio-video data were captured of the emergency care team by using 2 ceiling-mounted cameras to record team events in an overview image. One of the cameras had pan-tilt zoom functions to record details of emergency care as previously described.[9] Two directional microphones were attached to the ceiling, one above the care team, the other at the back of the resuscitation bay pointing outward. Video images and audio and vital signs waveforms collected from the physiological monitors were synchronized by a machine-readable time code. The video analysis software used has been previously described.[8,10] Institutional review board (IRB) approval and legal counsel support were obtained for audio video data collection of IRB-approved specific research questions. Fifty cases of tracheal intubation were video recorded in 1993 to 1994, from which a best-practice performance template and tracheal intubation analysis questionnaire were established (see below). Among these first 50 cases of tracheal intubation, there was a single case of a previously reported prolonged undetected esophageal intubation, from which a consensus task/communication algorithm was proposed.[11]

In this article, the video analysis of the esophageal intubation was compared with 49 other video records of emergency tracheal intubation obtained in 1993 to 1994. The use of the task/communication algorithm (clinical examination, communication and timing of carbon dioxide analysis after tracheal intubation) data were obtained from viewing 1995 and 2005 video recordings of tracheal intubation obtained under different IRB-approved projects.

The key elements of video analyses used included (a) review by the participant care providers; (b) review by "neutral" expert observers, colleagues who worked in the same trauma center; (c) review of the video record in comparison to a consensus "best practice" developed locally and clinical opinion about the subject matter of the video; and (d) comparison to an ideal performance time template of multiple other video-recorded occurrences of the same tracheal intubation task performed at different levels of urgency (eg, emergency and elective performance). The nature of emergency care was characterized with different methods for various stages of video analyses (eg, critical incident technique was used during interviews with experienced clinicians to establish ideal performance measures).[12] Task decomposition analyses were used to break the tracheal intubation task into a template of 24 steps (see below).[13] Performance time technique[13] assessed task performance times between preoxygenation and completion of tracheal intubation[8] (eg, start of laryngoscopy, cuff inflation, checking carbon dioxide). A multidisciplinary approach was taken for video analysis and data extraction (using the tracheal intubation analysis questionnaire) from the first 50 video records of tracheal intubation.

Video review was by 12 experienced trauma clinicians, as well as experts in industrial engineering, psychology, and applied technology. Each video record had an average of 2.7 reviewers who identified whether the task performance template of 24 steps in the overall tracheal intubation task was completed (Appendix E1; available online at http://www.annemergmed.com). Each of the 24 steps in the template was assigned an "importance score." This score was used to weight the task performance, if omitted. The video reviewers were audio-recorded "thinking aloud" while viewing the video records, and they completed the 13-part tracheal intubation analysis questionnaire that included clinical information (monitors used/indication); assessed completion of 24 tracheal intubation tasks; evaluated psychomotor skills, decisionmaking, and communications; and recorded times of reaching tracheal intubation landmarks.[8] When something ambiguous, uncertain, or unusual occurred, or if the video showed a complex tracheal intubation, their comments were transcribed and linked by machine-readable time stamp to the video event. Other reviewers then viewed the record and added their comments. This process provided the reviewer's explanation for behaviors or verbalizations and identified comments about unsafe acts, failures, and performance. Interrater reliability was assessed by intraclass correlation coefficiency. Unpaired *t* tests were used for comparison of task omissions and time to checking end-tidal carbon dioxide after emergency and elective tracheal intubations.

RESULTS

Information generated from each of the 4 analyses of the esophageal intubation, in comparison to 49 other video records of tracheal intubation obtained in 1993 to 1994, is reported below. This video review approach identifies factors allowing the window of error opportunity to occur and potential solutions to prevent recurrences. The results show how key findings, translated into revised practices, mitigated the errors.

The care providers at the esophageal intubation were part of an ad hoc team and until video review were unaware that it was a medical student, on his first clinical rotation in the trauma center resuscitation team, auscultating the chest and communicating that he heard breath sounds after tracheal intubation. The anesthesia care providers observed that the video showed that they did not check for breath sounds at this time. A second communication from the student, "It's also going in here too," when he listened over the stomach was picked up by the directional microphones but was not heard by the team members standing 2.5 feet away, because the communication was obscured by conversation and laughter from a nearby area. Reviewing their own video, the care providers saw their failure to use the capnometer to detect $ETCO_2$ until 5 minutes after passage of the endotracheal tube. They observed why the patient appeared stable, despite the misplaced endotracheal tube, because they had given oxygen by facemask for 8 minutes before attempts at tracheal intubation. They identified their error[14] with looking frequently at the vital signs monitors rather than the patient. The vital signs monitors were seen to cycle repeatedly for 3 minutes after esophageal intubation, without displaying data (the vital signs digital readouts were displayed as an overlay on the video image at the same time that they appeared on the monitors[15]). Such unreliable patient monitoring was observed to be a frequent deficit in emergency care, when patients can have impaired peripheral perfusion. The least team communications occurred during the 3 minutes when no vital signs were displayed on the monitor and there was the most uncertainty about patient status.

Table. Specific video review findings of esophageal intubation.

Video data presents	Detail of Video findings
Precursor events	Lengthy preoxygenation with facemask before esophageal intubation delayed recognition of lack of oxygenation after tube misplacement.
	Ventilation circuit used before and after emergency tracheal intubation had no carbon dioxide analyzer connection (positive carbon dioxide waveform assesses adequacy of bag-mask-valve ventilation and confirms tracheal, not esophageal intubation).
	Patient physiologic monitors of oxygenation and blood pressure failed to provide signals for nearly 3 minutes after third attempted tracheal intubation, resulting in esophageal intubation.
Fleeting events	Anesthesia team member blows down tracheal tube, causing "gurgling" sounds, indicating air going down esophagus into stomach after first unsuccessful attempt at tracheal intubation.
	Trauma team failed to assist the anesthesia team for 30 s when misplaced tube removed.
Subtle cues	Uncertainty about tube misplacement revealed by comments heard on audio record between team members "Should you pull the tube out?" "He's got a good pulse" "We're in there!" "Do you want a new tube?"
Brief utterances	"It's also going in here too" comment by medical student listening over abdomen, not heard by team, because of nearby loud conversation.
	"Correlates well with pulse and says 39 to 40" (nurse commenting on both the accuracy and low pulse-oximeter monitor value of first display; normal level 98-100). Correlation with pulse suggests value is accurate.
Unsafe acts	Video record showed neither anesthesia care provider carried a stethoscope to listen to chest (standard operating procedure).
	Carbon dioxide analysis (criterion standard to detect lung ventilation) was delayed for 5 min after esophageal intubation.
	No reoxygenation ("holding pattern") established before reattempted tracheal intubation.
	Team coordination failure when lack of cricoid pressure during and after esophageal extubation.

The neutral observers noticed the reluctance of other members of the medical and nursing teams to intervene, even when the pulse oximeter provided a signal showing very low levels of oxygen saturation. Five to 7 team members surrounded the patient for the 6-minute duration of the unrecognized esophageal intubation and did not directly offer suggestions or question the management, although they communicated subtle cues of concern (Table). The neutral observers also noticed the poor error recovery because the patient was not reoxygenated before reattempted tracheal intubation, when the patient showed signs of severe hypoxemia, even though a nurse can be seen on the video offering the needed facemask for bag-valve-mask reoxygenation. Team members did not coordinate the recovery efforts after the endotracheal tube was removed from the esophagus by protecting the airway with cricoid pressure[16] or by immediately assisting the repeated tracheal intubation. The only documentation of this event in the patient or quality management records was "intubation #1 esophageal intubation."[11]

The standard operating procedure task/communication algorithm after passage of an endotracheal tube, recommended by the experts' consensus, is for the clinician who inserts the tube to auscultate—first to the left and then right sides of the chest—and communicate to the team whether the breath sounds are heard and whether they are equal on both sides of the chest. After this, the clinician auscultates the stomach and, hearing no air entry, communicates, "no breath sounds in the abdomen." The last check recommended is to test to see whether carbon dioxide is present in the exhaled gas. The communication "carbon dioxide positive" provides the definitive confirmation to all the resuscitation team of correct placement of the endotracheal tube in the trachea, and equal left and right breath sounds suggest there is neither an endobronchial intubation nor a hemo/pneumothorax.[11]

In this video, the anesthesia care providers did not auscultate the chest until the patient showed severe oxygen desaturation and used the carbon dioxide monitor only when it was clear from other data that the endotracheal tube was misplaced. The inexperienced medical student did auscultate the patient's chest and abdomen in the recommended sequence but misinterpreted hearing breath sounds in the chest, possibly because of hearing the transmitted sounds of air entering the stomach or because these sounds were amplified by the patient's left-sided pneumothorax. The significance of air entry into the stomach was not recognized by the student, and his communication and auscultation examination were not repeated.

Data were extracted from each of the 49 other video records of tracheal intubation (emergency, n=28, within 60 minutes of trauma center admission; elective, n=21, in the operating room >60 minutes after admission) by timing performance and completion of the task template and tracheal intubation analysis questionnaire, usually within 5 days of the event. Some of these data have been previously reported[8,17] in less accessible sources. Care providers (participant and neutral) reviewed all cases; 24 care providers reviewed their own videos. Intraclass correlation coefficients among different raters were 0.2 to 0.99 (fair to excellent), depending on the data. Intraclass correlation coefficient for timing was 0.99, whereas subjective assessments (eg, tracheal intubation rated as difficult) were only moderate, at 0.57. Consensus was reached with the reviewers while they viewed the video record in cases in which interrater reliability was poor or care deviated from standard. Twenty-eight independent tracheal intubation–related performance deficiencies were observed.

Duration to checking $ETCO_2$ to confirm correct tracheal tube position in those patients intubated urgently in the resuscitation area, rather than electively in the operating room, was (mean±standard error) 52±5.3 seconds after elective and 205±16.8 seconds after emergency tracheal intubations ($P<.05$). The same procedures were used and the same personnel performed the tracheal intubations in each location. However, in the resuscitation area there was no connection to allow carbon dioxide sampling in the manual resuscitator bag-valve circuit used to provide oxygen before tracheal intubation and mechanical ventilation. In the operating room, a mechanical ventilator circuit was used for preoxygenation, with in-line capnometry sampling.

The key findings from video analyses were that significantly more tasks of greater importance ranking were omitted in emergency than elective tracheal intubation ($P<.05$). The 28 performance deficiencies were grouped under 5 general headings: communication failures, lack of timely vital signs monitoring, omission of chest auscultation, failure of pretracheal intubation equipment checks, and not following standard operating procedures.[17] The last 4 deficiencies are illustrated in a Web video available online at http://hfrp.umm.edu/esophagealvideo.

The following problems were observed. Often as many as 5 people were seen to listen to the chest, but none verbalized their findings or detection of carbon dioxide in exhaled gas. There was a 4-fold greater interval to carbon dioxide analysis in emergencies. Laryngoscopists routinely delegated chest auscultation. There was a failure of equipment checks, eg, stethoscope not available. Standard operating procedures were not followed (no reoxygenation before reattempting tracheal intubation).

Early use of in-line capnometry in the operating room prompted us to insert a 25 Cent connector into the resuscitation area ventilation circuit to allow carbon dioxide sampling during bag-valve-mask ventilation before and immediately after tracheal intubation. Routine use of the capnometer did not change, just the timing of the application, which was critical, when brought to the attention of care providers, in preventing future recurrences of prolonged undetected esophageal intubation.

Standard operating procedures were changed because of these video analysis findings: to ensure that the clinical examination task was carried out by the laryngoscopist, to stress communication of the clinical findings by using the task/communication algorithm, and to advocate conduct of carbon dioxide testing immediately after all tracheal intubations (the "3 Cs": clinical examination, communication, and carbon dioxide). Further tracheal intubation video records analyzed in 1995 and in 2005 showed that early carbon dioxide analysis (within 1 minute of tracheal intubation in all but 3 of 50 videos in the resuscitation area during 2005) and the task communications during auscultation were routinely occurring. The quality management records of the trauma center were reviewed for unrecognized esophageal intubation, and attending anesthesiologists (who attended more than 98% of tracheal intubations) were questioned to follow up on these procedural changes. In the 12 years since this prolonged uncorrected esophageal intubation occurred and after implementation of the task/communication algorithm and insertion of the carbon dioxide sampling connector, more than 16,000 tracheal intubations have been performed, with no recurrence of undetected esophageal intubation.

DISCUSSION

Many traditional techniques for improving quality of emergency care, such as process-of-care measures,[18] can reveal some of the performance deficiencies identified by video and suggest means to improve outcome. However, video allows identification of the precursor events, communications, subtle cues, and fine-grained detail of evidence for the link to outcome that are frequently not available through other sources. Video should be considered complementary to other quality improvement efforts. Aggregating the quantitative and qualitative data from multiple performances of the tracheal intubation task carried out at 2 levels of urgency was found to be a particularly revealing video analysis technique. A major educational strength of video is feedback to the participant health care providers reviewing their video-recorded care by allowing them to be less dependent on memory because the video image and audio recreate the event.[3] Video records make it more apparent than discussion alone how performance could be improved.

Video data can be used as input to root-cause analyses or other quality improvement practices and provide contextual detail, enable repeated raw data reviews by multiple reviewers, and allow assessment of a critical event, using measures developed subsequent to the video-recorded event. In this way, video analysis can be a powerful supplement to existing quality assurance methodologies for understanding the context and the proximal contributors to an adverse event. Tracheal intubation analyses illustrate how audio-video records identified unsafe acts, precursor events, and subtle cues and system failures related to performance deficiencies in emergency medical and routine clinical care for airway management (Table). The analyses of events and communications leading to the misplaced tracheal tube and delayed detection are another example to show how powerful video is as data to examine team and individual behaviors during trauma patient resuscitation.[19-22]

Video review is useful to improve advanced trauma life support based trauma resuscitation and survival[23] and for identification of errors of omission, commission safety issues, and misprioritization.[24-28] Video analysis shows adequacy of adherence to universal precautions, shows team communications, and can verify that staff recall of critical events may not accurately reflect what actually occurs[11] (eg, in the video-recorded esophageal intubation, the attending anesthesiologist was sure, until reviewing the video, that he had auscultated the chest soon after tracheal intubation). Other forms of self-report (such as the notes on esophageal intubation in the patient and quality management records) do not identify deficiencies uncovered by video records of actual care.[17] Video is perceived as the richest medium to capture the minutest and briefest particulars of human interaction while retaining the context of the event and making it available for analyses by multiple reviewers.[29] An important strength of video records (in the form of 30-second to 3-minute video clips) is in training and education of health care providers. Video clips from continuous video records of clinical care facilitate buy-in from care providers and can convince senior staff of the need to change existing practices.

A weakness of video analysis for examining emergency medical care is that it is tedious and time consuming and the level of effort is significant.[3] As an example, about 10 hours were spent in discussion, viewing, and transcription of the 8-and-a-half minutes of video of prolonged uncorrected esophageal intubation,[11] whereas aggregated data obtained from the tracheal intubation analysis questionnaire analysis of the remaining 49 video records of tracheal intubation took about 30 minutes for each 10 minutes of video record.

Even with a 2-microphone system, it is difficult to pick up all the utterances, and the audio record could be improved. The video images do not include events occurring off the screen, though the audio channel can be helpful to understand comments occurring outside the field of view. In analyzing a video image with the patient physiologic data overlaid, there is a tendency to think that the participant care providers were aware of these data, when in reality, this is often not the case, because of selective attention to other aspects of clinical care. Because video analysis occurs after the fact, the care providers have time to rationalize the decisions made because they are aware of the outcome.

In the complex environment of resuscitation, communication remains problematic. Even when experienced clinicians are involved, communication of significant clinical decisions fails more than 50% of the time.[30] Linking computer-generated prompts through visual and auditory displays within the resuscitation bay may enhance clinicians' interaction and reduce errors of omission and miscommunication. Compliance with the prompts, rather than prelearned algorithms, can then be undertaken with video audit.[31] Such an approach may allow an objective and streamlined means of audit, reducing the time-consuming process associated with peer review. Video analyses of real emergency medical care events will be important in the development of the database necessary for simulation and the improvement of clinical practice and equipment in the future.[26]

Opportunities to simplify video acquisition and reduce personnel requirements for video recording 24 hours a day, 7 days a week in multiple locations simultaneously include using a digital video buffer with commercially available digital video-recording devices. Digital video buffer can continuously and simultaneously acquire multiple video inputs, with selectable quality settings for picture size and frame rate.[32] The duration of buffer retention is controllable (and negotiable with the IRB) from hours to weeks, with continuous looping and overwrites after retention time is exceeded. The IRB and hospital legal counsel at the trauma center in which these video data were collected approved such a video buffer, with 72-hour overwrite for capturing all occurrences of central line placement, the focus of a research protocol and quality management effort.[33]

A major concern of those included in video records in health care is privacy and the confidentiality of these records. The ubiquitous use of video surveillance in the community has made health care workers and patients well aware of the detailed information that can be extracted from video. To enable the potential benefits of video analysis to be realized while protecting the rights and privacy of individuals creates a dilemma for which there is no single answer.

The clinical care providers in a trauma center were the research subjects and gave consent to be video recorded. Protection of human subjects (both research subjects and patients) was secured through a formal protocol submission and approval process by the IRB. The IRB agreed to allow video recording without patient consent because it was not thought feasible to obtain consent consistently in the emergency circumstances in which the video records were made, and precautions were made to ensure patient privacy by procedures such as masking of faces in video images.[3] The original video records were retained until video analyses were completed and then erased. Clinician input into the video collection protocols was obtained at in-services and a weekly meeting attended by medical and nursing staff. The research subjects knew when events were being video recorded, and they consented to publication of details of video analyses and to use of video clips (30-second to 3-minute duration) for presentations or in training materials.

However, video is a powerful medium. A concern is that even when researchers obtain a subject's consent, it is not always clear that the subject understands the implications of that consent. Despite advantages of video recording, challenges abound, such as gaining support from those being recorded, securing patient confidentiality, overcoming medicolegal obstacles, and effectively using the medium. A major challenge with video recording is social acceptance and potential impact on the recorded behavior. Because of the nature of consent, the awareness of video recording can change the very behavior being recorded. So far, the impact of the subject's knowledge of video recording on behavior has been deemed insignificant.[34] The primary concern for many people being recorded is possible legal implications of video recording.[35] Patient identifiers were removed from paperwork associated with video records. Only care providers and researchers were given access to the video records, which were kept secured under 2 sets of locks. A sign at the entrance to the operating rooms and inside the resuscitation area was posted to identify that image recording was occurring. The wording "Be aware, filming is under way" displayed in the trauma center complies with Joint Commission of Accreditation of Hospital Organizations regulations for video recording in hospitals.[36] Removal of the patient from the video (eg, by masking) is also suggested by the commission when there is no patient consent. Experience with 13 years of video recording in the emergency medical workplace at this trauma center reveals that there have been no medicolegal subpoenas, nor have employment-related or liability issues resulted.[3]

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Appendix E1. Checklist of 24 items observed in each video recording of tracheal intubation.

Preintubation Checks	
Preoxygenation	
Head positioning	
In-line stabilization (neck not cleared)	
Suction ready	
SaO_2 monitor placed preinduction	
$ETCO_2$ Monitored preinduction*	
BP monitored preinduction	
HR monitored preinduction	
IV running preinduction	
All anticipated drugs drawn	
Stethoscope at hand	
Cricoid pressure applied correctly	
Check for means of ventilating with 100% oxygen	
Assistance immediately available	
Intubation equipment ready	
During Intubation	
Reoxygenation after 3 attempts during intubation	
Modification of technique between attempts	
Reoxygenation/change laryngoscopist or approach after 2 min of attempts	
Reoxygenation if SaO_2 falls below 95%	
Cricoid pressure maintained till cuff inflated	
Tube insertion distance checked	
Auscultation of both sides of chest and upper abdomen	
Postintubation Checks	
$ETCO_2$ Monitored within 2 min of intubation*	
Check of ventilator parameters (FiO_2, Vt, and frequency)	

SaO2, External oxygen saturation; *BP,* blood pressure; *HR,* pulse rate; *IV,* intravenous (fluids); *FiO2,* fractional impaired oxygen; *Vt,* tidal volume.
*$ETCO_2$ Ideally monitored by waveform capnometer.