Rate of Decline in Oxygen Saturation at Various Pulse Oximetry Values with Prehospital Rapid Sequence Intubation

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Abstract

Background. A high incidence of desaturations has been observed during prehospital rapid sequence intubation (RSI). The rate of decline in oxygen saturation (SpO2) at various pulse oximetry values has not been defined with emergency RSI. **Objective**. To define the rate of SpO2 decline at various pulse oximetry values and identify a threshold below which active BVM should be performed during prehospital RSI. **Methods**. Traumatic brain injury (TBI) patients undergoing RSI by prehospital providers were included in this analysis. The time period from the highest to the lowest preintubation SpO2 value was selected for review. The mean rate of SpO2 decline was calculated for each SpO2 value and then used to define a theoretical SpO2 desaturation curve. The rate of desaturation to hypoxemia (SpO2 $\leq$ 90%) was defined for intubation attempts initiated at each SpO2 value. **Results**. A total of 684 SpO2 values from 87 patients were included. Lower SpO2 values were associated with a faster rate of SpO2 decline, with an inflection point occurring at 93%. The rate of desaturation to hypoxemia with intubation attempts initiated with SpO2 $\leq$ 93% was much higher than with SpO2 above 93% (100% vs. 6%, $p < 0.01$). In patients undergoing multiple attempts, SpO2 values with BVM between attempts was consistently higher than the preintubation SpO2 value. **Conclusions**. The rate of SpO2 decline increases as SpO2 decreases, with an inflection point occurring around 93%. Intubation attempts below this value are almost always associated with subsequent desaturation, suggesting that BVM should be used prior to laryngoscopy in these patients.
Key words: rapid sequence intubation; desaturation; hypoxemia; pulse oximetry.

PREHOSPITAL EMERGENCY CARE 2008;12:46–51

Introduction

Endotracheal intubation (ETI) is a critical skill in the early management of critically ill and injured patients.[1] Benefits to ETI include reversal or prevention of hypoxemia, airway protection, and ventilatory support.[2–5] Although some patients can be intubated without the use of neuromuscular blocking agents, many require rapid sequence intubation (RSI) for optimal laryngoscopic visualization.[6–13] While RSI clearly facilitates ETI and increases intubation success rates, inherent risks with the procedure include apnea and resultant hypoxemia. Desaturations to hypoxemia may occur in more than half of prehospital and more than one-third of ED RSI procedures, with an associated increase in mortality when pulse oximetry (SpO2) values fall below 70%.[14–17]

The anesthesiology literature has defined optimal preoxygenation in non-emergent surgical patients, including both passive oxygenation strategies and assisted ventilation using bag-valve-mask (BVM).[18,19] With these optimal preoxygenation techniques, apnea times can extend for up to 8 minutes before desaturation occurs. Patients' inability to cooperate with preoxygenation instructions and concerns regarding gastric insufflation and aspiration may discourage incorporation of these techniques into emergency airway management, which may explain the high desaturation rates observed with prehospital and ED RSI.[1,14–17] This investigation was performed to explore the occurrence of desaturations during prehospital RSI. The first objective was to define a desaturation curve, with the hypothesis that a predictable rate of SpO2 decline could be defined for each SpO2 value. The second objective was to explore the rate of desaturation as related to the SpO2 value when intubation attempts were initiated. We hypothesized that a threshold SpO2 value could be identified below which laryngoscopy should not be initiated without first attempting active preoxygenation, potentially including BVM ventilation.

Methods

Design

Data for this analysis were collected prospectively. Waiver of informed consent was granted by our institutional investigational review board.

Setting

San Diego County has a population of approximately 3 million in an area of over 4,200 square miles. The emergency medical services (EMS) system includes a tiered response, with fire-based units serving as first responders followed by transport crews. Both

Received December 23, 2006, from the Department of Emergency Medicine, University of California San Diego, San Diego, California. Revision received February 24, 2007; accepted for publication March 12, 2007.

Presented at NAEMSP National Meeting, Naples, FL, January 2007.

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doi: 10.1080/10903120701710470

first response and transport units provide advanced life support (ALS). In addition, air medical crews can be activated by ground personnel based on anticipated transport delays or the need for advanced procedures.

Air medical crews consist of a flight nurse and either a flight paramedic or emergency medicine resident. The use of RSI to facilitate ETI has been in the air medical scope of practice for many years. The air medical RSI protocol includes the use of etomidate 0.3 mg/kg IV followed by succinylcholine 1.5 mg/kg IV; following confirmation of tube placement, midazolam and vecuronium are administered. In addition, a paramedic RSI protocol for severe TBI was in place for 4 years from 1998 through 2003. Midazolam up to 5 mg IV followed by succinylcholine 1.5 mg/kg IV were used to facilitate laryngoscopy; rocuronium was used for paralysis following confirmation of tube placement.

Subjects

Patients with severe TBI (Glasgow Coma Scale score 3–8) undergoing prehospital RSI were included in this analysis. These included patients from two sources. The first group was enrolled during the San Diego Paramedic RSI Trial. All of these patients were from a single agency that implemented the use of handheld oximeter-capnometers (TidalWave Sp Model 710; Novemetrix Medical Systems, Inc., Wallingford, CT) during the trial. These units can store and export oximetry and capnometry data for later analysis. The second group was enrolled by air medical crews in 2005. The same oximeter-capnometer units were used by these crews during the study period. In addition, preoxygenation was performed in an identical fashion by both groups using passive oxygenation via nonrebreather mask for at least 60 seconds prior to administration of RSI medications. Crews were generally discouraged from performing BVM ventilation after administration of succinylcholine.

Data Collection

Data for SpO2, heart rate, end-tidal carbon dioxide ($EtCO_2$), and ventilatory rate are recorded every 8 seconds by the oximeter-capnometer units and stored for later analysis. The RSI protocol for both groups included application of the SpO2 finger probe prior to administration of RSI medications and use of quantitative EtCO2 to confirm tube placement immediately following intubation attempts.

Data Analysis

Oximeter-capnometer data were exported to Excel (Microsoft Corporation, Redmond, WA) for analysis. Because we were interested in the rate of SpO2 decline at various pulse oximetry values, the primary analysis was limited to the period of decreasing SpO2 values. This period was defined by a continuous decline in SpO2 from the initially recorded value until a nadir was reached (Figure 1). This eliminated initial values representing spontaneous respiration as well as the recovery in SpO2 that accompanied successful intubation or rescue BVM ventilation.

In the resultant dataset, the rate of SpO2 decline was calculated for each individual data point. This was defined by the following equation:

$$\Delta SpO2/\Delta t = (S_i - S_{i+1})/0.1333 \text{ min}$$

with S_i representing a particular SpO2 value and S_{i+1} representing the subsequent value, recorded 8 seconds (0.133 minutes) later. A mean rate of SpO2 decline was then calculated for each SpO2 value from 99% down to 90% or less. Because the dataset was limited to the period of decreasing SpO2, no recordings for a value of 100% were included. The mean rate of SpO2 decline was

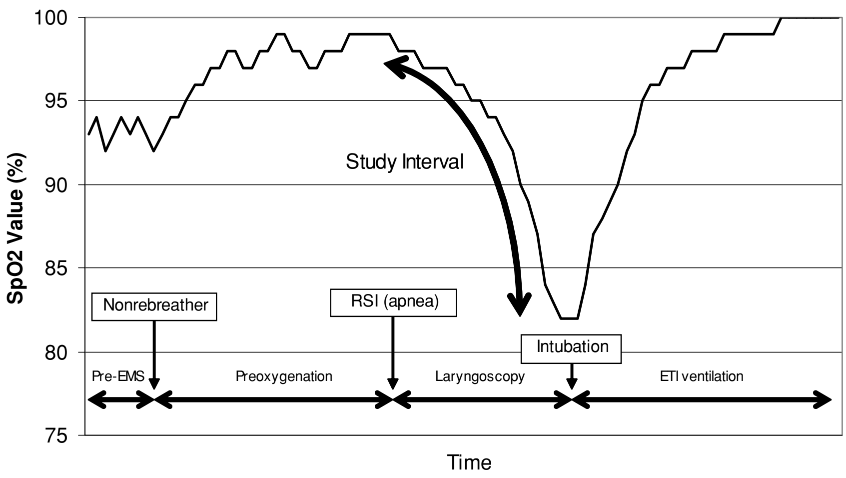

FIGURE 1. Study interval for desaturation data.

TABLE 1. Demographic and Clinical Data for Study Population

Parameter	Mean or % (95% CI)
Demographics	
Mean age (years)	38.4 (35.1–42.2)
Male gender (%)	83 (75–89)
Mechanism of injury (%)	
Motor vehicle accident	36 (28–45)
Motorcycle accident	5 (2–10)
Fall	30 (22–39)
Pedestrian versus automobile	7 (3–14)
Gunshot wound	10 (5–17)
Other	11 (6–19)
Initial vital signs	
SBP ≤ 90 mmHg (%)	24 (17–32)
Mean GCS score	5.1 (4.8–5.5)
Mean intubation attempts	1.5 (1.4–1.7)
Air transport (%)	23 (15-33)

SBP = systolic blood pressure; GCS = Glasgow Coma Scale.

then used to calculate the anticipated amount of time required to drop 1% from each SpO2 value (i.e., 99% to 98%, 98% to 97%, ...). This allowed construction of a hypothetical desaturation curve. The rates of desaturation to hypoxemia for intubation attempts initiated at various SpO2 values were calculated, and receiver-operator curve (ROC) analysis was used to define the optimized inflection point. Desaturation to hypoxemia was defined as a decrease in SpO2 from above 90% to ≤90% or a continued decrease in SpO2 by at least 2% if the initial SpO2 was ≤90. Finally, patients with an initial unsuccessful intubation attempt were analyzed separately, with interim SpO2 values (following BVM ventilation after the initial intubation attempt) compared to initial SpO2 values to identify whether BVM might have been successful in reversing hypoxemia.

RESULTS

A total of 87 patients were included in this analysis. This included 54 patients from the San Diego Paramedic RSI Trial and 33 air medical patients. Demographic and clinical data for these patients are displayed in Table 1. A total of 684 individual SpO2 values were used in the primary analysis, which results in about 8 data points (64 seconds) per patient. A mean rate of SpO2 decline was generated for each SpO2 value and used to generate a hypothetical desaturation curve (Figure 2). The inflection point where the decline in SpO2 transitions from horizontal to nearly vertical was 93%.

The incidence of desaturation to hypoxemia based on the initial SpO2 value is displayed in Table 2. The ROC analysis (area under the curve 0.91) defined an optimized inflection point at 93%, which is identical to the inflection point for the desaturation curve. Intubation attempts were initiated above this point in 83% of patients, with only 6% of these experiencing subsequent desaturation to hypoxemia (SpO2 ≤ 90%). Desaturations were observed in all remaining patients, in whom intubation attempts were initiated at SpO2 of 93% or below. This difference was statistically significant ($p < 0.01$). Finally, 59% of all patients undergoing multiple intubation attempts (86% of those with initial SpO2 ≤ 93%) had interim SpO2 values that were higher than their initial SpO2 value. This suggests that BVM ventilation would have been effective in increasing the initial SpO2 value prior to laryngoscopy, potentially avoiding subsequent desaturations.

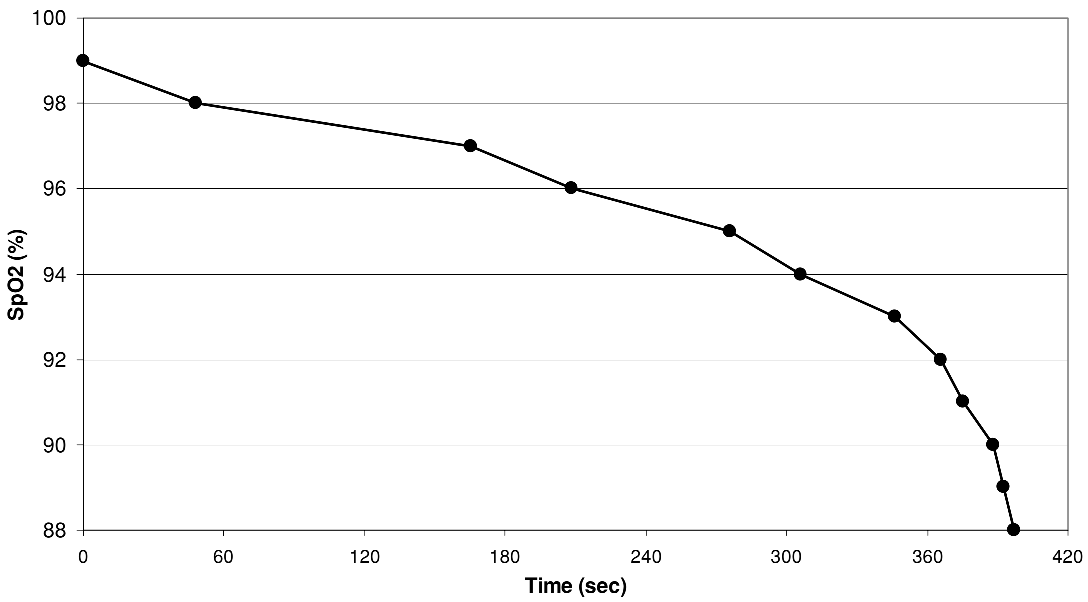

FIGURE 2. Theoretical oxygen desaturation curve combining data from all 87 patients.

TABLE 2. Initial SpO2 Values with Initiation of Intubation Attempts and the Incidence of Desaturation to Hypoxemia. For attempts initiated with SpO2 above 93%, the desaturation rate was 6%, and for attempts initiated with SpO2 of 93% or below, the desaturation rate was 100% ($p < 0.01$)

Initial SpO2 Value	% of Total	Incidence (%) of Desaturation
99%	18.6	9.1
98%	20.3	0.0
97%	15.3	0.0
96%	15.3	11.1
95%	10.2	16.7
94%	1.7	0.0
93%	3.4	100.0
92%	1.7	100.0
91%	0.0	N/A
≤ 90%	11.9	100.0

Hypoxemia was defined as a decrease in SpO2 from >90% to ≤90% or a continued decrease in SpO2 by at least 2% if the initial SpO2 is ≤90%.

DISCUSSION

Recent studies have shown that desaturations associated with prehospital RSI are common and associated with increased mortality.[14,15] This is one of the first studies to specifically address the question as to how fast the SpO2 falls for a given SpO2 value using patients undergoing emergent RSI. The ability to download pulse oximetry data provided a unique opportunity to explore this question and help guide the clinical decision regarding active versus passive preoxygenation prior to laryngoscopy. It appears that a threshold SpO2 value exists around 93%, with intubation attempts initiated at or below this value associated with a high incidence of desaturation to hypoxemia. This may justify BVM ventilation, even in patients requiring emergency intubation with the risk of gastric insufflation, regurgitation, and aspiration.

Numerous studies have documented optimal preoxygenation strategies to maximize apnea time, or the time from cessation of ventilation until SpO2 reaches 90% or less, in patients undergoing elective surgeries.[20,21] By increasing the duration of safe apnea times, providers have more time to achieve ET intubation and potentially manage the difficult airway. These studies focused on well-perfused patients who were able to follow commands and perform maximum tidal volume breathing while maintaining a sitting position, which is not relevant to emergent RSI.[18,19,22] In addition, these studies did not focus on the decision to provide BVM ventilation based on initial SpO2 value but instead approached each patient in a standardized fashion.[20]

We believe that providers should learn to use pulse oximetry data to determine when a particular intubation attempt should be abandoned rather than relying on time-driven strategies alone. Several observations support this approach. First, there was substantial variability in initial SpO2 values as reflected by Table 2, making it difficult to calculate an optimal time for any given attempt. In addition, we assumed that the rate of SpO2 decline for a given SpO2 value was predictable across individuals; however, multiple variables appear to affect the rate of SpO2 decline during apnea, such as body surface area, blood volume, cardiac output, hemoglobin concentration, oxygen consumption, shunt fraction, alveolar volume, and alveolar fractions of oxygen and carbon dioxide.[23,24] This leads to tremendous variability for apnea time across individual patients. However, these variables primarily affect the duration that patients remain at nearly complete oxygen saturation, and once the SpO2 begins to decrease into the low-90% range, the rate of decline appears to follow a predictable pattern.[19] It is also notable that our desaturation curve is a near-perfect reflection of the oxyhemoglobin dissociation curve, suggesting that this transition point is driven largely by predictable cellular physiology rather than individual patient variables.

If the primary determinant of desaturation is the SpO2 value at the time when an intubation attempt is initiated, then more aggressive preoxygenation may be justified with initial SpO2 values below 94%. This warrants reanalysis of the cost-benefit ratio between active BVM to prevent hypoxemia and the threat of inducing gastric insufflation, regurgitation, and pulmonary aspiration. Whether BVM increases the risk of aspiration is unclear.[25] Peak airway pressures below 20 cmH20 appear to carry low risk of gastric distention.[26,27] In addition, it is possible that most aspiration events occur in the moments immediately following injury, in the immediate period of apnea present prior to the arrival of EMS personnel.[28,29] Furthermore, it is not clear that aspiration of gastric contents leads to aspiration pneumonia and may only result in aspiration pneumonitis with volumes greater than 0.3–0.4 mL/kg body weight and pH < 2.5, although this is a subject of much debate.[27,30–34] If the main concern with aspiration is the potential for hypoxemia, then it would seem a reasonable risk to perform BVM ventilation in response to SpO2 values below 94% rather than attempt intubation and virtually guarantee desaturation.

It is also possible that the risk of aspiration of gastric contents with BVM ventilation can be mitigated with use of cricoid pressure. First described in 1961 by Sellick, the technique was intended to divert air with noninvasive positive-pressure ventilation away from the stomach and into the trachea while preventing regurgitation and subsequent aspiration of gastric contents.[35] Several studies suggest that posterior pressure of 30–40N can prevent regurgitation despite increased gastric pressure and prevent gastric insufflation despite intraesophageal pressures greater than 75 cmH_2O.[32,36] Rare complications, such as esophageal rupture, can be avoided if pressure is released when active vomiting occurs.[37] In addition, cricoid pressure may displace the esophageal laterally, decreasing the effectiveness of the maneuver, and may decrease lower esophageal sphincter tone.[38–42] Finally, the possibility of airway distortion during laryngoscopy, especially when misapplied, requires that cricoid pressure be adjusted appropriately, releasing pressure as indicated.[43–45]

Strengths of this study include the uniform and systematic collection of objective data using identical devices. Our patient population was relatively homogeneous, and a standardized approach to data analysis with a priori definitions was applied. Several important limitations should be considered. First, it was not possible to determine exactly when RSI medications were administered. Thus, we waited until the period of SpO2 decline, which may have underestimated the time available for laryngoscopy because high SpO2 values may have been maintained for some time before decreasing. Similarly, we could not identify when BVM ventilation was performed. The similarity of our hypothetical desaturation curve to the oxyhemoglobin dissociation curve suggests the accuracy of recorded values. Our results may not be generalizable to other populations, because the rate of SpO2 decline may differ in the setting of shock or with various body morphologies. Nevertheless, the transition from a relatively horizontal to a vertical descent appears to occur with SpO2 values in the low-90s, regardless of patient factors. It is the time to this inflection point that varies, as discussed above. Finally, we did not explore the influence of other patient or clinical variables on the suggested relationship between the rate of SpO2 decline and the absolute SpO2 value.

CONCLUSIONS

A hypothetical desaturation curve was created from this cohort of TBI patients, with a gradual SpO2 decline until a threshold of 93% is reached, at which point the rate of decline accelerates dramatically. Intubation attempts above this threshold rarely result in hypoxemia, whereas attempts at or below this point virtually guarantee desaturation to hypoxemia. It appears that BVM ventilation would improve oxygenation in many of these patients.

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