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Preoxygenation and apneic oxygenation using Transnasal Humidified Rapid-Insufflation Ventilatory Exchange for emergency intubation☆,☆☆

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ABSTRACT

Purpose: Hypoxia is one of the leading causes of anesthesia-related injury. In response to the limitations of conventional preoxygenation, Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE) has been used as a method of providing both preoxygenation and apneic oxygenation during intubation.
Materials and methods: In this prospective, observational study, THRIVE was introduced in a critical care unit (CCU), operating room (OR), and emergency department (ED) during emergency intubation of patients at high risk of hypoxia. Linear regression analysis tested for correlation between apnea time or body mass index and hemoglobin saturation (Spo_2).
Results: Across 71 sequential patients, the interquartile range for apnea time and decrease in Spo_2 were 60 to 125 seconds and 0% to 3%, respectively. Significant desaturation occurred in 5 (7%) patients. There was no evidence of correlation between apnea time or body mass index and Spo_2 ($R^2 = 0.04$ and 0.08 for CCU/ED and OR and 0.01 and 0.04 CCU/ED and OR, respectively). There were no complications reported from using THRIVE.
Conclusions: This study demonstrated that preoxygenation and apneic oxygenation using THRIVE were associated with a low incidence of desaturation during emergency intubation of patients at high risk of hypoxia in the CCU, OR, and ED. THRIVE has the potential to minimize the risk of hypoxia in these patient groups.

1. Introduction

Hypoxia is one of the leading causes of anesthesia-related injury in the United Kingdom [1]. It is particularly common during the emergency intubation of patients outside the operating theater environment and associated with severe adverse harm in this patient group [2,3]. The techniques of preoxygenation and rapid sequence induction (RSI) have developed to minimize the risk of hypoxia during intubation.

Preoxygenation describes the process of maximizing the amount of oxygen stored in the body before induction of anesthesia. The most important store of oxygen is the functional residual capacity (FRC), the volume of gas present at the end of passive expiration. The amount of oxygen contained in the FRC can be improved by (1) increasing the inspired Fio_2 to denitrogenate the FRC, (2) applying continuous positive airway pressure (CPAP) to minimize airway atelectasis, and (3) positioning the patient in a head up (25°-35°) to increase the available volume of the FRC.

Rapid sequence induction describes the sequential process of (1) preoxygenation, (2) administration of a predetermined dose of induction agent, (3) administration of a predetermined dose of muscle relaxant, (4) avoidance of positive pressure ventilation, and (5) confirmation of tracheal intubation. It is thought that this approach minimizes the duration of time the airway is unprotected and avoids gastric insufflation, thereby reducing the risk of aspiration.

Adequate preoxygenation and RSI have become cornerstones of safe anesthetic practice. These techniques are considered to be particularly useful for patients with high metabolic rates, respiratory pathology, or a reduced FRC, who have either a higher oxygen requirement or a

Abbreviations: THRIVE, Transnasal Humidified Rapid-Insufflation Ventilatory Exchange; CCU, critical care unit; OR, operating room; ED, emergency department; RSI, rapid sequence induction; FRC, functional residual capacity; CPAP, continuous positive airway pressure; BMI, body mass index; Spo_2, hemoglobin saturation; NO-DESAT, nasal oxygen during efforts securing a tube.

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lower oxygen storage capacity and are therefore likely to develop hypoxia (desaturate) more rapidly. However, despite apparent adequate preoxygenation and RSI, desaturation can still occur within 60 seconds in susceptible patients [4]. This limitation of conventional preoxygenation and RSI has led to renewed interest in the use of apneic oxygenation to extend the period of time that a patient maintains adequate oxygenation after induction of anesthesia, but before intubation.

Apneic oxygenation occurs in response to differences in solubility of oxygen and carbon dioxide. After the onset of apnea, oxygen continues to diffuse from the alveolar air space into the blood at a rate of approximately 250 mL/min. At the same time, carbon dioxide continues to diffuse from the blood into the alveolar air space at a rate of approximately 200 mL/min. This results in an initial volume deficit of 50 mL/min in the alveolar air space. In the absence of ventilation, carbon dioxide accumulates in the alveolar air space and approaches equilibrium with carbon dioxide in the blood. As a consequence, carbon dioxide diffusion falls to approximately 10 mL/min after approximately 45 seconds and the difference between the volume of oxygen leaving and the volume of carbon dioxide entering the alveolar air space is approximately 240 mL/min [5]. This discrepancy generates a negative pressure gradient between the alveolus and the upper airway, promoting the flow of gas from the pharynx to the alveolus, provided that the upper airway is patent. If the upper airway is insufflated with 100% oxygen, apneic oxygenation provides a mechanism to replenish the oxygen stored in the FRC at a rate approximately equal to rate oxygen diffuses across the alveolar membrane and so extend the duration of adequate oxygenation during periods of apnea [6,7].

Recently, humidified high-flow nasal oxygenation, known as Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE), has been investigated as a mechanism of providing both preoxygenation and apneic oxygenation in elective surgical patients, and reported to extend oxygen saturations during laryngoscopy and highly specialized airway surgery from a few minutes to more than 1 hour in some cases with relatively modest rises in carbon dioxide [7]. The beneficial effects of THRIVE in maintaining hemoglobin saturation (Spo_2) have also been demonstrated during the emergency intubation of critical care patients [8].

We hypothesized that preoxygenation and apneic oxygenation using THRIVE would be associated with a low incidence of desaturation during the emergency intubation of patients at high risk of hypoxia in our hospital. We report the findings of our pilot study, demonstrating the practicalities and results of implementing a THRIVE protocol in our critical care unit (CCU), operating room (OR), and emergency department (ED).

2. Material and methods

This prospective, observational study was conducted at the Queen Elizabeth Hospital, Norfolk, UK. As the data were collected as part of delivering routine care after a change of practice at the institution for audit, service surveillance, and improvement purposes, and anonymized, formal ethical committee approval was not sought. However, the Chair of the Research Governance Committee and Caldicott Guardian were consulted for approval to report data from routine practice and for publication of anonymized data. All equipment was used according to the manufacturers' instructions. Each patient was more than 18 years of age and required intubation as part of his or her routine care.

The THRIVE protocol was introduced to the CCU, OR, and ED as part of routine care for patients at high risk of hypoxia during intubation. The THRIVE protocol consisted of preoxygenation for 3 minutes using a simplified Optiflow system (Fisher and Paykel, New Zealand), incorporating of a high-flow rotameter, a reusable humidifier, reusable circuit, and a disposable nasal interface. The rotameter was set at 60 L/min during preoxygenation and a disposable bacterial filter was applied between the breathing circuit and nasal interface. Anesthesia and neuromuscular blockade were achieved using either a predetermined dose of thiopental (4-5 mg/kg) and succinylcholine (1-2 mg/kg) (OR and ED) or propofol (1-2 mg/kg) and rocuronium (1 mg/kg) (CCU). Approximately 30 N of cricoid pressure was applied to the cricoid cartilage at the time of loss of consciousness until tracheal intubation had been confirmed, in accordance with established practice in the United Kingdom. A face mask was not used as part of the THRIVE protocol and therefore manual ventilation was absent during the apneic period; however, airway patency was maintained using head tilt, chin lift, and/or jaw thrust. Finally, tracheal intubation was performed with a cuffed endotracheal tube. Patients at high risk of hypoxia during intubation were identified as those requiring intubation on the CCU or ED, or those patients presenting to the OR with a high metabolic rate, acute respiratory disease, predicted difficult airway, body mass index (BMI) >30, patients with chronic respiratory disease, and/or pathology reducing their FRC.

The data collected included the patient age, gender, BMI and known comorbidities, the location and reason for intubation, risk factors for desaturation, the grade of larynx according to the Cormack-Lehane system, the number of attempts at laryngoscopy, the use of difficult intubation equipment (equipment other than a direct laryngoscope and appropriately sized Macintosh blade), pre- and postintubation Spo_2, *apnea time* (defined as time from administration of neuromuscular blockade to confirmed placement of endotracheal tube), and any complications from the use of the THRIVE protocol. *Significant desaturation* was defined as a reduction in Spo_2 >10% after induction of anesthesia. Data were entered into a spreadsheet and analyzed using Excel (Microsoft, CA). Statistical analysis was performed using linear regression analysis to test for correlation between apnea time or BMI and Spo_2.

3. Results

Data were collected from 71 sequential patients. The demographic details and patient comorbidities are shown in Table 1. The location and reason for intubation are shown in Table 2. The risk factors for desaturation are shown in Table 3. The grade at laryngoscopy ranged from 1 to 4 (grade 1, 59%; grade 2, 27%; grade 3, 13%; grade 4, 1%). Thirteen cases required ≥2 attempts at laryngoscopy before successful intubation (3 (23%) of which underwent significant desaturation). Difficult airway equipment was used for 36 patients.

Overall, the median apnea time was 80 seconds (interquartile range [IQR], 60-125 seconds; range, 30-480 seconds) and the median decrease in Spo_2 was 1% (IQR, 0%-3%; range, 0%-33%). Significant desaturation occurred in 5 (7%) patients.

In the CCU/ED, the median apnea time was 115 seconds (IQR, 60-175 seconds; range, 30-480 seconds) and the median decrease in Spo_2 was 1% (IQR, 0%-4%; range, 0%-33%). Seven patients had a preinduction Spo_2 <90% (range, 67%-89%) secondary to acute respiratory failure. In these 7 patients, the median decrease in Spo_2 was 3% (IQR, 1.5%-3.5%;

Table 1
The demographic details and comorbidities of patients at high risk of hypoxia during intubation in CCU, OR, and ED

Variable	CCU/ED (IQR)	OR (IQR)
No. of patients	34	36
Median age	65 (60-70)	56 (44-75)
Gender (male/female)	12/22	16/20
Median BMI	27 (23-32)	31 (26-38)
Asthma	4	4
Chronic obstructive pulmonary disease	6	6
Obstructive sleep apnea	2	1
Hypertension	14	12
Ischaemic heart disease	5	7
Chronic heart failure	4	1
Cerebrovascular disease	3	1
Peripheral vascular disease	4	0
Atrial fibrillation	2	2
Diabetes mellitus	10	6
Chronic liver disease	5	0
Cancer	5	3