Article

Identification of the Optimal Position of a Nasal Oxygen Cannula for Apneic Oxygenation - A Technical Simulation

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Abstract: Background. In a cannot ventilate cannot intubate situation, careful preoxygenation with high FiO_2 allowing subsequent apneic oxygenation can be life-saving. The best position for an oxygen supply line within the human airway at which oxygen insufflation is more effective than standard preoxygenation with a face mask, or comparably effective as intratracheal insufflation, is unknown. **Methods**. In this experimental study, we compared effectiveness of preoxygenation by placing an oxygen cannula at the nose entrance, through the nose at the soft palatine, or at the base of tongue; as control we used ambient air. We connected a fully preoxygenated test lung on one side to an oximeter with a flow rate of 200ml/min simulating oxygen consumption of a normal adult, and on the other side to the trachea of an anatomically correctly shaped airway manikin over a 20 min observation period five times for each cannula placement in random order. **Results.** Oxygen percentage in the test lung dropped from 100% in all groups to 53±1% in the ambient air control group, to 87±2% in the nasal cannula group, to 96±2% in the soft palatine group, while it remained at 99±1% in the base of tongue group ($p=0.003$ for soft palatine vs base of tongue; and $p<0.001$ between all other groups). **Conclusions.** When simulating apneic oxygenation in a preoxygenated manikin, oxygen insufflation at the base of tongue kept oxygen percentage at baseline values of 99% demonstrating a complete block for ambient air flowing into the manikin's airway. Oxygen insufflation at the soft palatine or insufflation via nasal cannula were less effective in regard of this effect.

Keywords: airway manikin; apnoeic oxygenation; denitrogenisation; desaturation; oxygen insufflation; test lung

1. Background

During emergent or planned airway management, either the patient does not breathe sufficiently, or anesthesia drugs have induced apnea. Thus, bag-valve-mask ventilation, followed by insertion of an airway device and subsequent mechanical ventilation has to be performed. If neither ventilation with bag-valve-mask ventilation, tracheal intubation, or placement of a supraglottic airway device (SGA) are successful, a "cannot ventilate cannot intubate"-situation (CVCI) occurs with imminent severe risk of ensuing hypoxia and possibly, death by suffocation. [1]

Following preoxygenation for scheduled induction of anesthesia, oxygen can be absorbed during apnea, thus significantly prolonging the time until hypoxia arises. However, moderate hypoxia often occurs during standard intubation attempts. [2] Recent studies have shown that the time until hypoxia occurs can be prolonged by diligent

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preoxygenation and employing apneic oxygenation, which may be lifesaving. Different strategies to deliver oxygen have been described, such as specifically modified oxygenation laryngoscopes, [3, 4] oxygenation oropharyngeal tubes, or intratracheal oxygen insufflation with a bronchoscope. [5-7] In those studies, the deeper the oxygen was applied, the more effective it was. [6, 7] However, we still do not know the optimum depth, or the turning point in the human airway at which oxygen insufflation is more effective than nasal insufflation, and where it is comparably effective as intratracheal insufflation. While intratracheal oxygen is most effective, it may be technically more difficult and may impair visibility and ease of tracheal tube insertion during intubation attempts, especially in difficult airways.

In order to assess the optimal position of oxygen insufflation in a human airway, we placed an oxygen cannula at several positions into the airway of a manikin in an established technical model of apneic oxygenation, and compared it with standard preoxygenation. The formal hypothesis was that there would be no difference in oxygen percentage decrease between groups.

2. Methods

Ethics approval was waived since this was solely a technical simulation with no participants or patients.

The trachea of a male intubation manikin (AirSim Combo Bronchi X, TruCorp, Lurgan, Northern Ireland) was connected to a test lung (volume 3 L), representing the functional residual capacity of an adult man. An oximeter with a sampling rate of 200 mL/min (Wato Ex 35, Mindray, Shenzen, China) was connected to the test lung. This continued sampling rate equals oxygen uptake of a male adult during apneic oxygenation.[8] At baseline, the airways and the test lung were filled with 100% oxygen. Then, insufflation of oxygen at a rate of 4 L/min was performed using an oxygen cannula (Oxygen cannula, Asid Bonz, Herrenberg, Germany) placed (1) at the nose entrance, (2) through the nose with the tip at the soft palatine, (3) and at the base of the tongue, whereas (4) a control group received no oxygen insufflation. Five experiments for each group were performed in random order, measuring the decrease in oxygen percentage during a period of 20 min. The observer was blinded to the method of oxygen delivery.

Data are reported as mean ± standard deviation. SPSS (IBM SPSS V28; IBM, Armonk, NY, USA) was used for statistical analysis. After Kolmogorov Smirnov analysis, post hoc analysis of variances was performed to determine overall statistical significance between groups. To assess differences between groups, Student Newman Keuls test was performed; $p < 0.05$ was considered being statistically significant.

3. Results

During the 20 min observation period, oxygen percentage in the test lung dropped from 100% at baseline to 53±1% in the control group, to 87±2% in the nasal cannula group, to 96±2% in the soft palatine group, while it remained at 99±1% in the base of tongue group ($p=0.003$ for soft palatine vs base of tongue; and $p<0.001$ between all other groups). The detailed course of oxygen content decline in the test lungs for all groups is depicted in Figure 1.

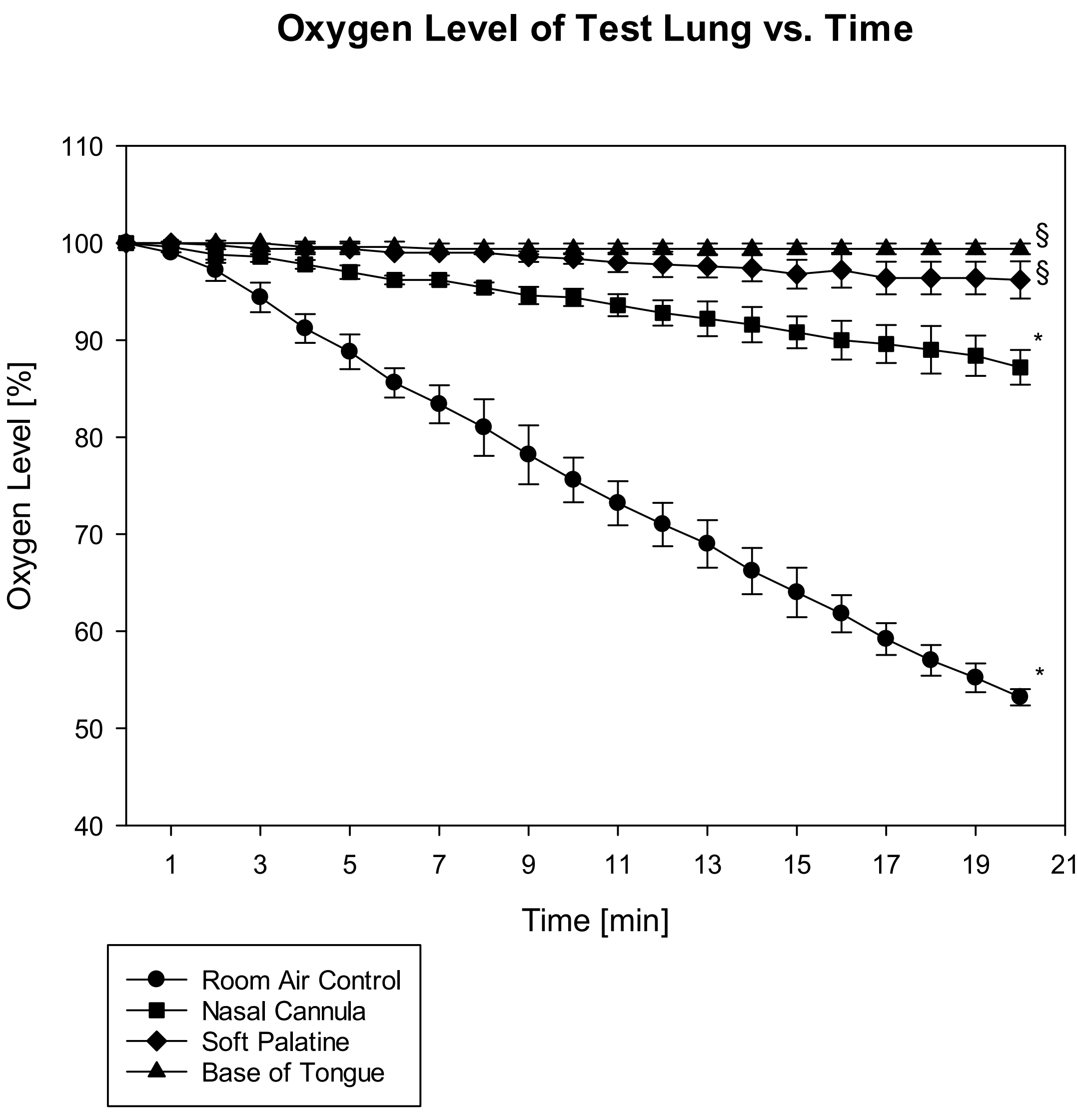

Figure 1. Course of oxygen content in the test lung for the observation period of 20 minutes. (§ p=0.003 for soft palatine vs base of tongue groups and <0.001 to all other groups; and * p<0.001 compared to all other groups).

4. Discussion

In this model of apneic oxygenation, oxygen insufflation at the base of the tongue (and thus distal the oral cavity) was most effective in preventing environmental air to enter the airways and the lungs, and thus maintained apneic oxygenation.

Previous studies have also observed superiority of deep oxygen insufflation, and have attributed this effect to the anatomy of the kinked human airway: oxygen entering via a nasal cannula pours into the upper oral cavity and the upper pharynx, where it is likely to mix with nitrogen from environmental air entering through the manikin's mouth.[7] The Venturi effect may emphasize this phenomenon by suctioning air into the airway, especially when higher oxygen flows are applied.[9] According to our data, this may to a certain degree also apply for oxygen given at the level of the soft palatine. In contrast, insufflating oxygen at the base of the tongue may be close enough to the trachea thus completely preventing environmental air from entering the test lung.

In contrast to other studies favoring to apply very high oxygen rates for apneic oxygenation [10, 11] we were able to show that apneic oxygenation can be maintained with a flow of only 4 L/min when applied distally which is in accordance to a recently published study in humans. [12] An oxygen supply of 4 L/min exceeds the normal oxygen uptake of 200 mL/min being absorbed by the lungs (which is simulated by gas sampling in our model) 20-fold. This may build up a reservoir in the lower pharyngeal cavity, thus generating flow of abundant oxygen back to the oral cavity, which completely prevented ambient air from entering the airway.

A technical simulation is always a limitation by itself. Further, we were not able to simulate carbon dioxide production, or humidification of airway gases. Thus, we were not completely realistic in simulating an apneic oxygenation scenario. However, an important point in this study was the anatomical correct shape of the human airway, and the determination of the turning point from where no mixing with intruding nitrogen is evident. Further, the principle of apneic oxygenation is well known and gas consumption can be calculated [13-15]. The most important precondition is adequate preoxygenation and insufflation of pure oxygen to avoid any renitrogenisation in the test lung. [16] In this regard, our scenario may be realistic to demonstrate anatomically correctly the point in the airway for oxygen insufflation that impairs ambient air flowing into the airway. More realistic scenarios in regard of apneic oxygenation such as animal experiments would have either meant testing in different anatomical airway shapes without a kinked airway which is not possible for the purpose of this study. Studies in non-intubated humans may be unethical. Thus, in our opinion this bench model was the best available method to test our hypothesis. Based on the actual study the base of tongue may be described as turning point for oxygen insufflation in the human airway completely avoiding any ambient air entering the airway. This effect may be reached by different devices that such as an oxygenation laryngoscope, or a special oropharyngeal oxygenation airway device. [3, 4, 17, 18]

In conclusion, when simulating apneic oxygenation in a preoxygenated manikin, oxygen insufflation at the base of tongue kept oxygen percentage at baseline values of 99% demonstrating a complete block for ambient air flowing into the manikin's airway. Oxygen insufflation at the soft palatine or insufflation via nasal cannula were less effective in regard of this effect.

Author Contributions: The study was conceptualized by HH, VW and WAW. SJH, HH and WAW conducted the experiments. HH, DCS and WAW analyzed data and prepared figures. WAW, SJH and HH drafted the manuscript. VW, BWB and DCS revised the manuscript. All authors read and approved the final manuscript.

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Institutional Review Board Statement: Not applicable since this is a completely technical simulation without human data.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data is included in the manuscript. The original datasets analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: There are no competing interests in regard of this study. Bernd W. Böttiger is treasurer of the European Resuscitation Council (ERC), Founder of the ERC Research NET, Chairman of the German Resuscitation Council (GRC), Member of the „Advanced Life Support (ALS) Task Force of the International Liaison Committee on Resuscitation (ILCOR), Member of the Executive Committee of the German Interdisciplinary Association for Intensive Care and Emergency Medicine (DIVI), Founder of the "Deutsche Stiftung Wiederbelebung", Federal Medical Advisor of the German Red Cross (DRK), Member of the Advisory Board of the "Deutsche Herzstiftung", Co-Editor of "Resuscitation", Editor of the Journal "Notfall + Rettungsmedizin", Co-Editor of the Brazilian Journal of Anesthesiology. He received fees for lectures from the following companies: Forum für medizinische Fortbildung (FomF), Baxalta Deutschland GmbH, ZOLL Medical Deutschland GmbH, C.R. Bard GmbH, GS Elektromedizinische Geräte G. Stemple GmbH, Novartis Pharma GmbH, Philips GmbH Market DACH, Bioscience Valuation BSV GmbH. All other authors have no possible conflicts of interest to declare.

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