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APNEIC OXYGENATION

by

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An Independent Study
Submitted to the Graduate Faculty
of the
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in partial fulfillment of the requirements
for the degree of
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PERMISSION

Title	Apneic Oxygenation
Department	Nursing
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Abstract

Airway management and maintaining oxygen saturation is one of the most important components in the anesthesia profession. According to an American Association of Nurse Anesthetists (AANA) closed claims study, the most common negative outcome was due to a respiratory event, accounting for 31.8% of all claims from 2003-2012 (Jordan & Quraishi, 2015). According to the American Society of Anesthesiologists (ASA) Closed Claims database, respiratory events were the second most damaging event due to anesthesia, accounting for 17% of all claims (Metzner, Posner, Lam, & Domino, 2011). Difficult mask ventilation and difficult intubation can pose serious and life threatening risks for our patients, especially when they are not anticipated. Oxygen desaturation (<90%) can occur in as little as 45 seconds following the onset of apnea if the anesthesia provider is unable to successfully ventilate or intubate the patient. The purpose of this Independent Project is to provide a thorough and detailed review of preoxygenation along with a description of Apneic Oxygenation (AO) and how it may give anesthesia providers additional time when attempting to secure an airway. An expansive literature search was done utilizing the University of North Dakota's Harley E. French Library of Health Sciences. The literature review provided information on different methods of preoxygenation and how apneic oxygenation can be utilized. Prolonging a patient's ability to maintain oxygen saturation may allow the anesthesia provider to secure the airway before a serious complication or death occurs.

Keywords: Apneic oxygenation, preoxygenation in anesthesia, airway management, AANA closed claims, negative outcomes in anesthesia

Importance of Oxygenation

Maintaining oxygenation is the primary goal during airway management. Preoxygenation is very important prior to induction because it helps to delay arterial desaturation during the upcoming apneic period of laryngoscopy and is critical to patient safety. If a patient's oxygen saturation drops below 70%, they have reached a critical level and are at an increased risk for dysrhythmias, hemodynamic decompensation, hypoxic brain injury, and death (Weingart & Levitan, 2012). Adequate preoxygenation can increase the oxygen content of the patient's functional residual capacity (FRC) up to 90% (end tidal oxygen concentration of 90%); it also eliminates much of the nitrogen from the FRC (Nagelhout & Plaus, 2014). If preoxygenation is not done or is performed ineffectively, the patient's oxygen reserve in the FRC is minimized and the anesthetist has a limited amount of time to secure the airway before desaturation occurs. The normal oxygen demand is 200-250 mL/minute; effective preoxygenation can allow a healthy patient to have an oxygen reserve of 5-8 minutes (Butterworth, Mackey, & Wasnick, 2013). The time before desaturation occurs during the apneic period can be decreased with conditions that have an increased oxygen demand (i.e. sepsis, pregnancy) or a decreased FRC (i.e. morbid obesity, pregnancy, lung disease) (Butterworth, Mackey, & Wasnick, 2013).

Adequate preoxygenation allows a buffer period during periods of apnea and hypoventilation and prolongs the duration of safe apnea, which is defined as the time until a patient reaches an oxygen saturation level of 88% to 90% (Weingart & Levitan, 2012). According to the steep portion of the oxyhemoglobin dissociation curve, once a patient's saturation reaches this level they can decrease to critical levels of oxygen saturation, less than 70%, very rapidly. How quickly a patient's oxygen saturation decreases depends on how much oxygen is stored compared to how much is being consumed. In the body, oxygen is stored in the lungs, blood and tissues. Adequate oxygenation increases the amount of oxygen stored in the lungs, which increases FRC. Oxygen consumption is determined by metabolic rate and desaturation may occur more rapidly in certain patient populations (obese, pregnant, pediatric, and septic).

Anesthesia providers clearly understand the importance of preoxygenation prior to the induction sequence while the patient is awake and spontaneously breathing, however providers may not understand the role of apneic oxygenation in this process. This independent project investigated the concept of apneic oxygenation as it relates to the induction sequence.

Case Report

The case being explored involved a 59-year old, 98 kg male patient presenting for a bronchoscopy, thoracoscopy, and left lower lobectomy with mediastinal lymph node biopsy for a malignant neoplasm of the left lower lobe. The patient was categorized as an ASA 3 with an allergy to succinylcholine (pseudocholinesterase deficiency). Past medical history included degenerative disk disease, lumbar spondylosis, lumbar radiculopathy, anxiety, depression, gastroesophageal reflux disease, and lung cancer. The patient reported a history of complications with succinylcholine, which included prolonged paralysis. Surgical history included bronchoscopy, mediastinoscopy, back surgery, shoulder arthroscopy, and tonsillectomy. Current medication regimen included lorazapam, naproxen, omeprazole, Percocet, and ambien. A thorough preoperative exam included vital signs, which were as follows: blood pressure 143/96, heart rate 80 bpm, respiratory rate 18, oxygen saturation 96% on room air, and a temperature of 36.8 degrees Celsius. Laboratory data included a complete blood cell count noting hemoglobin of 16.3 g/dl, hematocrit of 47 g/dl, platelet count of 188,000/microliter and a complete metabolic panel that was within normal limits.

The patient presented with a Mallampati II, thyromental distance of 3 fingerbreadths, full neck range of motion, along with some of his teeth chipped and capped. Apneic oxygenation was performed by administering 10 L/minute of oxygen by high flow nasal cannula in the pre-op area and remained in place until the patient was intubated and connected to the breathing circuit. Once in the operating room, preoxygenation was started and the following medications were given: versed 2 mg, fentanyl 150 mcg, propofol 200 mg, lidocaine 50 mg, and cisatracurium 10 mg. A Mac 4 blade was utilized and provided a grade 1 airway. A 39 French left double-lumen endotracheal tube was passed through the vocal cords and placement was confirmed with the presence of an end tidal carbon dioxide waveform and bilateral breath sounds with auscultation. Clamping each lumen and auscultating breath sounds in the appropriate lung along with the absence of breath sounds in the desired lung confirmed correct placement of each lumen of the DLT. The endotracheal tube was taped and the patient was placed on volume control ventilation (VCV) with a tidal volume of 600 mL, respiratory rate of 12, and peak end expiratory pressure (PEEP) of 5 cmH2O. After placing the patient in the right lateral decubitus position, lung sounds were auscultated to ensure the endotracheal tube remained in the appropriate position. The entire induction sequence took approximately 3 minutes, with the patient's oxygen saturation remaining above 96% throughout the induction.

Depth of anesthesia was maintained using Sevoflurane 2 – 2.5% with doses of fentanyl 25 – 50 mcg, cisatracurium 5 – 10 mg, and 1 gram of Ofirmev. During the procedure, the patient also received dexamethasone 8 mg and ondansetron 4 mg for their anti-emetic effects. Muscle relaxation was reversed with neostigmine 4 mg and glycopyrrolate 0.6 mg. The patient also required a few doses of phenylephrine (50 – 100 mcg) throughout the procedure for hypotension. A total of 1,900 mL of intravenous fluids were given and total estimated blood loss for the procedure was 100 mL. An awake extubation was performed in the operating room uneventfully, a non-rebreather mask was placed with a flow of 10 L/minute, and the patient was transported to the post anesthesia care unit (PACU). Upon arrival to the PACU the patient was alert and oriented, reported a tolerable pain level of 2/10, and denied any post-operative nausea or vomiting. The patient was discharged from PACU approximately 45 minutes later and was discharged home 3 days later following a successful hospital stay.

Discussion

Oxygen

Oxygen is vital because all tissues in the human body depend on oxygen to meet their metabolic needs. Oxygen is transported in the blood and carried in two forms: dissolved and bound to hemoglobin (Grossman & Porth, 2014). The majority of oxygen (approximately 98%) is bound to hemoglobin, while the other 2% is transported in the dissolved state. Only the oxygen that is in the dissolved state is able to transfer across the cell membrane, produce a partial pressure (PO2), and make itself readily available for use in cell metabolism (Grossman & Porth, 2014). Once oxygen is in the lung, it moves from the alveoli to the pulmonary capillaries. This movement occurs along a concentration gradient, from the alveoli where the PO2 is approximately 100 mm Hg to the venous end of the pulmonary capillaries where the PO2 is lower (Grossman & Porth, 2014). Once it transfers to the venous capillaries, oxygen relies on hemoglobin for transport because it is somewhat insoluble in plasma. The ability of the blood to transport oxygen depends on the amount of hemoglobin present and the ability of the lungs to oxygenate the hemoglobin (Grossman & Porth, 2014). Oxygen is then released from hemoglobin in the tissue capillaries where the partial pressure of oxygen is lower than in the arterial blood. Hemoglobin's affinity for oxygen is affected by the carbon dioxide content of the blood and its pH temperature and 2,3-DPG, a by-product of glycolysis in RBCs (Grossman & Porth, 2014). When metabolic demand is increased, the PCO2 is increased, which decreases the pH and decreases the binding affinity of hemoglobin. When metabolic demand is decreased the PCO2 is decreased, which increases the pH and increases the affinity of hemoglobin (Grossman & Porth, 2014).

Aerobic vs. Anaerobic Metabolism

Aerobic metabolism occurs in the cell's mitochondria when the carbon compounds from fats, proteins, and carbohydrates are broken down and their electrons combine with molecular oxygen to form carbon dioxide and water as energy is released (Grossman & Porth, 2014). These two end products, carbon dioxide and water, are easily eliminated from the body. Aerobic, or oxidative, metabolism supplies approximately 90% of the body's energy needs (Grossman & Porth, 2014). Under aerobic conditions, ATP is produced through glycolysis, the Krebs cycle, and the electron transport chain. During these reactions, Hydrogen protons combine with oxygen to form water, and large amounts of energy are released and used to add a phosphate bond to convert ADP to ATP (Grossman & Porth, 2014). A total of 36 molecules of ATP are formed from one molecule of glucose during aerobic metabolism.

Anaerobic metabolism occurs in cells that lack mitochondria, it can also be utilized to provide energy when the delivery of oxygen to the cell is delayed or impaired (Grossman & Porth, 2014). Energy in this situation is provided by glycolysis, which involves a sequence of reactions that convert glucose to pyruvate and allows the production of ATP from ADP. Anaerobic metabolism is much less efficient than aerobic metabolism, as the net energy gain from one molecule of glucose is only two ATP molecules (compared to 36 ATP molecules with aerobic metabolism) (Grossman & Porth, 2014). Even though anaerobic metabolism is relatively inefficient it is very important during times of decreased oxygen delivery. Pyruvate is converted to lactic acid during anaerobic periods, such as cardiac arrest or circulatory shock (Grossman & Porth, 2014). This conversion is reversible and once the oxygen supply has been restored, lactic acid is transformed back into pyruvate that can be used for energy or to synthesize glucose (Grossman & Porth, 2014).

Oxygen-Hemoglobin Dissociation Curve

The oxyhemoglobin dissociation curve is used to describe the relationship between oxygen that is being carried by hemoglobin and the PO2 of the blood. The x-axis of the graph represents the PO2 or dissolved oxygen and represents the partial pressure of the oxygen in the lungs (Grossman & Porth, 2014). When a person is breathing room air, the normal PO2 in the lungs is approximately 100 mmHg. The left y-axis represents the amount of oxygen that is carried by the hemoglobin, and the right y-axis represents the total amount of oxygen being carried in the blood (Grossman & Porth, 2014).

The dissociation curve is S-shaped, where a flat top portion represents the binding of oxygen to hemoglobin in the lungs and a steep portion that represents the release of oxygen into the tissue capillaries (Grossman & Porth, 2014). Hemoglobin's affinity for oxygen fluctuates with various conditions in the human body, which means that hemoglobin can more efficiently carry oxygen. In the lung, it is able to bind more oxygen than simple diffusion would allow and it can easily unload that oxygen for delivery in the tissues (Nagelhout & Plaus, 2014). Hemoglobin's changing affinity for O2 allows loading at the pulmonary capillaries and unloading of O2 at the peripheral tissues (Nagelhout & Plaus, 2014). There is a plateau in the dissociation curve at about 100 mmHg PO2, this is where hemoglobin is approximately 98% saturated and increasing the alveolar PO2 above this level does not increase the hemoglobin saturation (Grossman & Porth, 2014). The steep portion of the curve lies between 60 and 40 mm Hg and represents the dissociation of oxygen from the hemoglobin as it moves through the tissue capillaries (Grossman & Porth, 2014). In this portion of the curve, there is a large transfer of oxygen from hemoglobin to the tissues with even a minor decrease in PO2. About 5 mL of oxygen per 100 mL of blood are removed from the tissues under normal circumstances, and the hemoglobin of mixed venous blood is approximately 75% saturated as it returns to the right side of the heart (Grossman & Porth, 2014).

Hemoglobin acts as a buffer system that controls the delivery of oxygen to the tissues. In order to do this, hemoglobin must be able to adjust its affinity for oxygen as the metabolic needs of the tissues change. A shift of the curve to the right or left represents this changing affinity. The dissociation curve is shifted to the left of the normal curve by hypocapnea, a decrease in temperature, alkalosis, and a decrease in 2,3-diphosphoglycerate, which causes an increased affinity of hemoglobin for O2 (Nagelhout & Plaus, 2014). A shift to the right indicates that the tissue PO2 is greater for any level of hemoglobin saturation and indicates a decreased affinity of hemoglobin for oxygen at any PO2 (Grossman & Porth, 2014). A shift to the right curve can be caused by hypercapnia, increased temperature, acidosis, and an increase in 2,3-diphosphoglycerate levels (Nagelhout & Plaus, 2014). The partial pressure of oxygen that is required to obtain a 50% saturation of hemoglobin, or P50, is what determines the degree of the shift (Grossman & Porth, 2014). During normal circumstances, adult human blood has a P50 of approximately 26 to 27 mmHg. When the dissociation curve shifts to the left, the P50 decreases; and when the curve shifts to the right, the P50 increases (Nagelhout & Plaus, 2014).

Hypoxia/Hypoxemia

Hypoxemia is defined as a reduction in arterial blood O2 levels (PaO2 less than 95 mmHg) and can often lead to hypoxia, which is a lowered oxygen level in body tissues (Grossman & Porth, 2014). The effects of hypoxemia are demonstrated through tissue hypoxia and the compensatory mechanisms the body uses to adapt to the lowered oxygen level (Grossman & Porth, 2014). Conditions that may lead to decreased PO2 include hypoventilation, impaired diffusion of gases, inadequate circulation, and ventilation/perfusion mismatch. The brain, lungs, and heart have the greatest oxygen requirements. Mild hypoxemia may lead to recruitment of the sympathetic nervous system (SNS) and lead to an increase in heart rate, peripheral vasoconstriction, diaphoresis, and a minor increase in blood pressure. More severe hypoxemia may lead to confusion, personality changes, restlessness, agitated or combative behavior, uncoordinated muscle movements, impaired judgment, delirium, and eventually stupor and coma (Grossman & Porth, 2014).

Functional Residual Capacity (FRC)

The functional residual capacity (FRC) is the volume of air remaining in the lungs after normal expiration. It is the sum of the residual volume (RV) and expiratory reserve volume (ERV). The RV is the volume of air remaining in the lungs after maximal expiration and the ERV is the maximum volume of air expired from the resting end-expiratory level (Nagelhout & Plaus, 2014).

Oxygenation

Oxygen consumption continues throughout the apneic period, therefore the purpose of preoxygenation is to maintain hemoglobin saturation during that period. The most common adverse event encountered during intubation is oxygen desaturation, which can lead to serious complications such as cardiovascular collapse, anoxic brain injury, and death (Mosier, Hypes, & Sakles, 2016). The likelihood of encountering oxygen desaturation during the apneic period can be minimized by adequately preoxygenating the patient prior to intubation. Patients are able to tolerate longer periods of apnea when optimal preoxygenation is performed, which allows for an increased margin of safety between the time of induction and when the airway is secured. “This extra time may prove particularly valuable if mask ventilation is difficult or contraindicated and if laryngoscopy and tracheal intubation are more difficult than expected” (Tanoubi, Drolet, & Donati, 2009, p. 449).

Physiology of Oxygenation

The main function of the respiratory system is to remove appropriate amounts of CO2 from the blood entering the pulmonary circulation and to add appropriate amounts of O2 to the blood leaving the pulmonary circulation (Grossman & Porth, 2014). O2 moves from the air in the alveoli, which is rich in O2 and low in CO2, to the blood in the pulmonary capillaries. CO2 is transferred from the blood in the pulmonary capillaries, which have low amounts of O2 and high amounts of CO2, to the alveoli to be expired. Adequate circulation of blood through the pulmonary blood vessels (perfusion) and appropriate contact between ventilated alveoli and perfused capillaries (ventilation and perfusion matching) are also important for adequate oxygenation of the blood and removal of CO2 (Grossman & Porth, 2014).

Adequate preoxygenation increases the oxygen content and eliminates much of the nitrogen (denitrogenation) from the FRC and can allow oxygen to be delivered to the blood for up to 12 minutes in a healthy individual (Nagelhout & Plaus, 2014). The concept of preoxygenation has been around since the 1950s. Anesthesia providers realized that by filling the patient’s alveoli with a high fraction of inspired oxygen (FiO2), they could significantly increase the time to desaturation (Weingart & Levitan, 2012). Oxygen consumption in an adult patient at rest with an ideal body weight is roughly 200 – 250 mL/min (Tanoubi et al., 2009). Oxygen stored in the lungs and blood is readily mobilized, and these reserves are quickly used up during periods of apnea. The typical oxygen reserve for a healthy individual breathing room air ranges from 1.0-1.5 L. This amount increases to approximately 3.5 – 4 L in an individual that has been optimally preoxygenated with 100% oxygen (Weingart & Levitan, 2012). The majority of this oxygen is found in red blood cells bound to hemoglobin. “Theoretically, patients should be able to tolerate apnea that lasts up to 5 or 6 minutes; however, oxygen saturations (SpO2) would decrease below 90% after 1-2 min” (Tanoubi et al., 2009, p. 450). Since hemoglobin is almost 100% saturated when a person is breathing room air, preoxygenating with 100% oxygen will only slightly increase the blood oxygen content. Any additional oxygen that is given prior to the apneic period is stored in the lungs and allows for a longer period of safe apneic time because it is used instead of the hemoglobin-bound oxygen. According to the oxyhemoglobin dissociation curve it is very important to maintain an oxygen saturation > 90% because once it drops below 90% the curve is very steep and desaturation occurs rapidly. Therefore, the safe duration of apnea can be viewed as the duration of time between the onset of apnea and the time oxygen saturation reaches 90% or below. In healthy adults, the safe duration of apnea is approximately 6.9 minutes after preoxygenation with 100% oxygen, 5 minutes after inhaling 80% oxygen, 3.5 minutes after inhaling 60%, and 1 minute after breathing room air (Tanoubi et al., 2009).

Apnea

Alveoli continue to take up oxygen during times of apnea even though there is no diaphragmatic movements or lung expansion. Approximately 250 mL/minute of oxygen will move from the alveoli into the bloodstream in a person that is apneic and only 8 – 20 mL/minute of carbon dioxide (CO2) move into the alveoli during periods of apnea (Weingart & Levitan, 2012). The CO2 that does not move into the alveoli remains in the bloodstream. The differences in gas solubility in the blood and the affinity of hemoglobin for oxygen are responsible for this difference in oxygen and CO2 movement across the alveolar membrane (Weingart & Levitan, 2012). This difference in movement across the alveolar membrane causes the pressure in the alveoli to become subatmospheric, which generates a mass flow of gas from pharynx to alveoli (Weingart & Levitan, 2012).

The passive flow of gas from the pharynx to alveoli is known as apneic oxygenation (AO). This phenomenon allows an individual to maintain oxygenation without spontaneous or administered ventilations (Weingart & Levitan, 2012). With AO, a person's arterial oxygen pressure (PaO2) can be kept at greater than 100 mm Hg for up to 100 minutes without a breath, but this lack of ventilation will eventually lead to a buildup of CO2 and respiratory acidosis (Weingart & Levitan, 2012).

CO2 continues to be produced by the body during periods of apnea, but it is not eliminated at the same rate during these periods. About 200 mL of CO2 is produced per minute and its rate of elimination is determined by alveolar ventilation (Pratt & Miller, 2016). During periods of apnea, approximately 90% of the CO2 produced, stays in the circulation and is distributed throughout the body resulting in an uncompensated respiratory acidosis (Pratt & Miller, 2016). Pratt & Miller (2016) looked at multiple studies and found that even though there was an increase in CO2 levels after periods of apnea, the patients fully recovered without experiencing any complications after ventilation was resumed.

Methods of Preoxygenation

Preoxygenation with 100% oxygen is an important step to perform prior to induction of anesthesia, especially under circumstances when mask ventilation is contraindicated. Some of these situations include; if the individual has a presumed full stomach, if difficult mask ventilation is anticipated, when tracheal intubation may take longer than normal, if special airway management techniques will be used (i.e. double lumen tube), and in patients who will likely desaturate quickly (i.e. obese, pregnant, febrile, or pulmonary disease) (Tanoubi et al., 2009).

Three important components of optimal preoxygenation are to use 100% oxygen as the fresh gas, ensure no leak is present, and not to allow rebreathing. There must be a good seal between the mask and the patient's face, and adequate fresh gas flow (approximately 10 – 12 L/min) of oxygen must be delivered in order to prevent rebreathing (Tanoubi et al., 2009). The rate that oxygen replaces air in the lungs depends directly on alveolar minute ventilation and inversely on FRC (Tanoubi et al., 2009). Effective preoxygenation increases the oxygen content and eliminates nitrogen from the FRC. Signs of adequate preoxygenation include the respirator bag moving with each inspiration/expiration, a good end-tidal CO2 waveform, and the fraction of expired oxygen should begin to increase (Nagelhout & Plaus, 2014).

Standard 3 – 5 Minutes

This method of preoxygenation takes the most amount of time, but is the preferred technique with standard induction in a controlled setting. With this technique, the individual breathes normally (tidal volume breathing or TVB) until the end-tidal oxygen fraction (FeO2) is > 90%, which typically takes about 3 minutes (Tanoubi et al., 2009). When using this method, it is more effective to use FeO2 > 90% as the endpoint rather than a set amount of time, such as 3 or 5 minutes. (Tanoubi et al., 2009). A leak should be anticipated if the target FeO2 is not being obtained. Studies have shown that when adequate preoxygenation is performed, the duration of apnea without desaturation (DAWD) can be up to 8 minutes for a healthy individual (Tanoubi et al., 2009).

4 or 8 Deep Breaths Method

This method of preoxygenation takes less time than the standard method, but may not be as effective. Increasing ventilation by having an individual take deep breaths decreases the amount of time necessary to replace the air in the lungs with oxygen. TVB for 3 minutes has proven to be a more effective method of preoxygenation than 4 deep breaths taken over 30 seconds (Tanoubi et al., 2009). TVB for 3 minutes can provide an additional 2 minutes of DAWD when compared to 4 deep breaths taken over 30 seconds (Tanoubi et al., 2009). Another option is to have the individual take 8 deep breaths over 1 minute. This method is similarly effective as the TVB for 3 minutes, but it requires a high fresh gas flow and may lead to mild hypocapnia (Tanoubi et al., 2009).

Application of Positive End-Expiratory Pressure (PEEP)

Utilizing non-invasive pressure support ventilation with PEEP during preoxygenation can limit alveolar collapse and atelectasis formation, both of which can contribute to hypoventilation and low perfusion ventilation ratio (Jaber, Molinari, & De Jong, 2016). Preoxygenating with PEEP and non-invasive positive inspiratory pressure can increase FRC and initial investigations are encouraging, but additional studies need to be performed before this method can be recommended in clinical practice (Tanoubi et al., 2009).

Patient Position

Patient position can also have implications on the effectiveness of pre-oxygenation. FRC is decreased in the supine position due to cephalad movement of the diaphragm. As a result, preoxygenation in the upright position may lead to better oxygen reserves, especially in patients that are obese or pregnant (Tanoubi et al., 2009). The upright position may help with preoxygenation, but it is associated with a risk of hypotension and difficult tracheal intubation. Instead of using an upright or seated position, a slight reverse trendelenberg position may be helpful. This position should relieve some of the pressure on the diaphragm, increase FRC, and actually benefit laryngoscopy and tracheal intubation.

Negative Outcomes

A preoperative airway assessment should be performed on every patient prior to every procedure that will involve the use of anesthesia. However, the prediction of difficulty in airway management is not completely reliable so it is important that the anesthesia provider has a strategy in place before the induction of anesthesia (Frerk et al., 2015). Oxygen desaturation (<90%) can occur in as little as 45 seconds following the onset of apnea if the anesthesia provider is unable to successfully ventilate or intubate the patient. The incidence of difficult mask ventilation is approximately 0.9% - 7.8% and the incidence of failed tracheal intubation is 0.05% - 0.35% (Nagelhout & Plaus, 2014). The likelihood of difficult ventilation and intubation increases significantly in patients with neck or mediastinal pathology, previous surgery, or radiation (Nagelhout & Plaus, 2014). Unfortunately, there is no single predictor of difficult intubation that is very reliable. Norskov, Rosenstack, Wetterslev, Astrup, Afshari, & Lundstrom (2015) found that of 3391 difficult intubations 3154 (93%) of them were unanticipated. Norskov et al (2015) also found that difficult mask ventilation was unanticipated in 808 of 857 (94%) cases. There is a correlation between difficult mask ventilation and difficult tracheal intubation, and it can be life threatening if both of these occur simultaneously (Norskov et al., 2015). The major complications associated with difficult ventilation and intubation are death, brain damage, cardiovascular collapse, emergency surgical airway placement, and unanticipated intensive care unit admission (Nagelhout & Plaus, 2014).

Apneic Oxygenation

Apneic oxygenation (AO) is a concept that has been described in medical literature for more than a century. AO can also be called apneic diffusion oxygenation, diffusion respiration, and mass flow ventilation (Weingart & Levitan, 2012). Oxygen continues to be taken from the lungs into the blood during periods of apnea. This uptake of oxygen is greater than the return of CO2 from the blood to the alveoli, which causes a net loss of volume in the lungs and results in a negative pressure within the lungs (Biffen

& Hughes, 2013). Because of the negative pressure in the lungs, gas continues to be pulled from the upper airway into the alveoli, even without respiratory effort, as long as the airway remains patent. If the gas being drawn into the lungs is mainly oxygen, it provides a reserve for the body and prolongs the period of apnea without desaturation (Tanoubi et al., 2009). The delivery of oxygen for AO can be performed in a variety of techniques. Some of the different techniques available include utilization of a nasal cannula, nasopharyngeal catheter, nasal prongs, and intratracheal catheter.

A study performed by Taha et al. (2006) evaluated the effectiveness of nasopharyngeal oxygen insufflation following preoxygenation using the 4 deep breath technique within 30 seconds and the time to desaturation following the onset of apnea. This study consisted of 30 ASA I or II patients scheduled for elective surgery requiring general endotracheal anesthesia. Half (n=15) of the patients assigned to the study group a received AO via nasopharyngeal catheter at a rate of 5 L/min, and the remaining patients (n=15) were assigned to the control group and did not receive AO. In the control group, SpO2 fell to $\leq$95% at a mean time of 3.65 minutes, and in the study group, SpO2 was maintained in all patients at 100% until the cutoff time of 6 minutes was reached (Taha et al., 2006).

AO in Obese Patients

Obese patients are likely to desaturate more rapidly during apneic periods due to their decreased FRC. A randomized controlled trial performed by Baraka et al. (2007) showed that patients who received nasopharyngeal oxygen supplementation following preoxygenation had a significantly prolonged time to desaturation following apnea when compared to patients who received preoxygenation alone. This study consisted of 34 patients with a body mass index (BMI) above 35 kg/m^2, with 17 patients in each group. The time from onset of apnea until a SpO2 of 95% was recorded, and there was a cutoff time of 4 minutes. In the group that received preoxygenation alone the SpO2 dropped from 100% to 95% in an average of 145 seconds. In the study group that received supplemental nasopharyngeal oxygen following preoxygenation the SpO2 was maintained at 100% until the cutoff time of 4 minutes in 16 of the 17 patients. The patient who desaturated to less than 95% in the study group had a BMI of 65 kg/m^2 and was able to maintain apnea for 153 seconds (Baraka et al., 2007).

Another study performed by Ramachandran, Cosnowski, Shanks, & Turner (2010) involved 30 obese men undergoing general anesthesia. The 15 subjects assigned to the study group received 5 L/min of oxygen through nasal prongs, while the other 15 subjects in the control group did not receive oxygen by the nasal prongs (Ramachandran et al., 2010). Both groups had an average BMI of 31.2 kg/m^2. Both groups received standard preoxygenation with a tightly sealed mask, breathing 100% oxygen at 12 to 15 L/min until their end-tidal O2 was >90%. The study group had a significantly longer period of SpO2 remaining >95% (5.29 minutes) when compared to the control group (3.49 minutes) (Ramachandran et al., 2010). Also, 8 of the subjects in the study group still had a SpO2 >95% at 6 minutes, compared to only 1 in the control group.

AO in Obstetric Patients

Airway management in the obstetric patient population can be difficult due to some of the physical changes that occur during pregnancy. Some of these changes include a more vascular and edematous upper respiratory tract, decreased FRC, and enlarged breasts (Mushambi, Kinsella, Popat, Swales, Ramaswamy, Winton, & Quinn, 2015). There have not been any AO studies conducted in the obstetric population up to this point. However, Mushambi et al. (2015) recommend that the anesthetist should consider administering 5 L/min oxygen flow via nasal cannula before starting preoxygenation in order maintain bulk flow of oxygen during intubation attempts. This is recommended because it has shown to increase the time to desaturation in normal and obese patients.

Nasal Prongs vs. Nasopharyngeal Catheter

AO has already been proven to be an effective way to prolong the safe apnea time. Achar, Pai, & Shenoy (2014) performed a study to determine the effectiveness of administration of oxygen through nasal prongs (NP) and a nasopharyngeal catheter (NC) and the duration of oxygen saturation $\geq$95% during simulated prolonged difficult laryngoscopy. This study consisted of 56 adult patients ASA I and II undergoing elective surgical procedures requiring general endotracheal anesthesia. All patients were preoxygenated until a FeO2 of >90% was reached. Induction was then performed, the ability to mask ventilate was confirmed, followed by paralysis with rocuronium. 28 of the patients received AO via NP and the other 28 patients received AO through a NC, both at a rate of 5 L/min of O2. Apnea was held until SpO2 dropped to <95% or until the cutoff time of 10 minutes. Achar et al. (2014) found that in the NP group 9 patients desaturated compared to none in the NC group (P=0.001). Achar et al. (2014) attribute this to the fact that the NC is placed more nearer to the trachea than the NP and therefore oxygen is delivered more effectively. Even though the NC is more effective than NP at prolonging the safe apnea time, there are other things to take into consideration. First, administration of oxygen via NP significantly increases the duration of time of SpO2 ≥95%. Second, the administration of oxygen via NC is more invasive and increases the risk of epistaxis related to nasal trauma (Ramachandran et al., 2010).

Conclusion

AO has been proven in numerous studies to prolong the safe apneic period without desaturation. The research and literature reviewed provided significant results and showed that by utilizing AO it may be able to give the anesthesia provider valuable time while attempting to secure a patient’s airway. This may be even more beneficial in patients that are at an increased risk of rapid desaturation, such as obese and obstetric patients. Two main methods of administering supplemental oxygen were studied, which included the use of a nasal cannula and nasal prongs. Both of these are easy to implement into practice and the benefits definitely outweigh the risks. The information provided in this Independent Project will allow anesthesia professionals to become familiar with the concept of AO so that they can implement AO into their practice if they desire.

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Appendix

The following PowerPoint presentation was presented at the fall North Dakota Association of Nurse Anesthetists meeting in Bismarck, North Dakota on 2017.

Apneic Oxygenation
Scott Honkola, SRNA

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Oxygen

- Oxygen is vital because all tissues in the human body depend on oxygen to meet their metabolic needs
- According to an American Association of Nurse Anesthetists (AANA) closed claims study, the most common negative outcome was due to a respiratory event, accounting for 31.8% of all claims from 2003-2012
- Oxygen desaturation (<90%) can occur in as little as 45 seconds following the onset of apnea if the anesthesia provider is unable to successfully ventilate or intubate the patient

Jordan & Quraishi, 2015

Oxygen

- The normal oxygen demand is 200-250 mL/minute; effective preoxygenation can allow a healthy patient to have an oxygen reserve of 5-8 minutes
- Adequate preoxygenation allows a buffer period during periods of apnea and hypoventilation and prolongs the duration of safe apnea, which is defined as the time until a patient reaches a SpO2 of 88% to 90%
- According to the steep portion of the oxyhemoglobin dissociation curve, once a patient's SpO2 reaches this level they can decrease to critical levels of SpO2, less than 70%, very rapidly

Butterworth, Mackey, & Wasnick, 2013, Weingart & Levitan, 2012

Review of Literature

- A review of literature was conducted using the Harley E. French Library to determine current recommendations on the following topic:
- Anesthesia providers clearly understand the importance of preoxygenation prior to the induction sequence while the patient is awake and spontaneously breathing, however providers may not understand the role of apneic oxygenation in this process. Can apneic oxygenation allow the anesthesia provider a longer safe apneic period while attempting to secure an airway?

Case Information

- Surgical Procedure: Bronchoscopy, thoracoscopy, and left lower lobectomy with mediastinal lymph node biopsy
- Age: 59-year old
- Weight/Height/BMI: 98 kg, 180 cm, 30.2 kg/m^2
- Gender: Male
- Allergies: Succinylcholine (pseudocholinesterase deficiency)
- ASA: 3

Pre-operative Evaluation

- Past Medical History: Degenerative disk disease, lumbar spondylosis, anxiety, depression, GERD, lung cancer, prolonged paralysis following succinylcholine
- Surgical History: Bronchoscopy, mediastinoscopy, back surgery, shoulder arthroscopy, and tonsillectomy
- Home Medications: Lorazapam, naproxen, omeprazole, and zolpidem.
- Pre-op VS: BP 143/96, HR 80, RR18, SpO2 96%
- Airway Evaluation: M II, TM distance >3 FB, mouth opening >3 FB, full neck ROM, and chipped/capped teeth

Pre-operative Evaluation

- Laboratory Data:
  - Na 140 mEq/L
  - K 3.9 mEq/L
  - Glucose 101 mg/dL
  - Cl 110 mmol/L
  - Ca 8.5 mg/dL
  - Mg 2.4 mEq/L
  - Creatinine 0.8 mg/dL
  - BUN 12 mg/dL
  - pH 7.41
  - pCO2 36
  - HCO3 26
  - Hgb 16.3 g/dL
  - Hct 47%
  - Plts 188

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Anesthetic Course

- GETA:
  - Midazolam 2 mg
  - Fentanyl 150 mcg
  - Lidocaine 50 mg
  - Propofol 200 mg
  - Cisatracurium 10 mg
  - 39 French left DLETT via Mac 4 blade
  - Sevoflurane 2 – 2.5%
  - Arterial line placed
- Additional Medications:
  - Ancef 2 g
  - Fentanyl
  - Cisatracurium
  - Phenylephrine
  - Ondansetron 4 mg
  - Dexamethasone 8 mg
  - Glycopyrrolate 0.6 mg
  - Neostigmine 4 mg

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Intraoperative Issues

- Tachycardia – IV fluids and prn fentanyl
- Hypotension – IV fluids and prn phenylephrine (50 – 100 mcg)
- Decreased SpO2 – 100 % O2 (SpO2 increased to low/mid 90s)

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Postoperative

- Awake extubation perfomed uneventfully
- Transferred to PACU with non-rebreather mask 10 L/min
- Alert and oriented, tolerable pain level of 2/10 in PACU
- Transferred to med/surg floor
- Discharged home on post-operative day 3

- Case Totals:
  - Urine output 450 mL
  - EBL: 100 mL
  - LR: 1,900 mL
  - Case duration: 2.3 hours

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Physiology of Oxygenation

- O2 is transported in the blood and carried in two forms: dissolved and bound to hemoglobin
- Majority of O2 (approximately 98%) is bound to hemoglobin, while the other 2% is transported in the dissolved state
- Only O2 that is in the dissolved state is able to transfer across the cell membrane, produce a partial pressure (PO2), and make itself readily available for use in cell metabolism

Grossman & Porth, 2014

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Physiology of Oxygenation

- O2 moves from the air in the alveoli, which is rich in O2 and low in CO2, to the blood in the pulmonary capillaries
- Adequate circulation of blood through the pulmonary blood vessels (perfusion) and appropriate contact between ventilated alveoli and perfused capillaries (ventilation and perfusion matching) are also important for adequate oxygenation of the blood and removal of CO2
- Adequate preoxygenation increases the O2 content and eliminates much of the nitrogen (denitrogenation) from the FRC and can allow O2 to be delivered to the blood for up to 12 minutes in a healthy individual

Nagelhout & Plaus, 2014, Grossman & Porth, 2014

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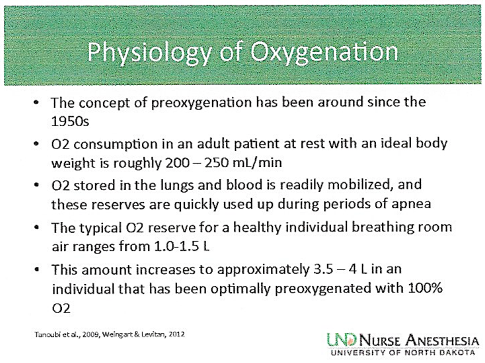

Physiology of Oxygenation

- The concept of preoxygenation has been around since the 1950s
- O2 consumption in an adult patient at rest with an ideal body weight is roughly 200 – 250 mL/min
- O2 stored in the lungs and blood is readily mobilized, and these reserves are quickly used up during periods of apnea
- The typical O2 reserve for a healthy individual breathing room air ranges from 1.0-1.5 L
- This amount increases to approximately 3.5 – 4 L in an individual that has been optimally preoxygenated with 100% O2

Tanoubi et al., 2009, Weingart & Levitan, 2012

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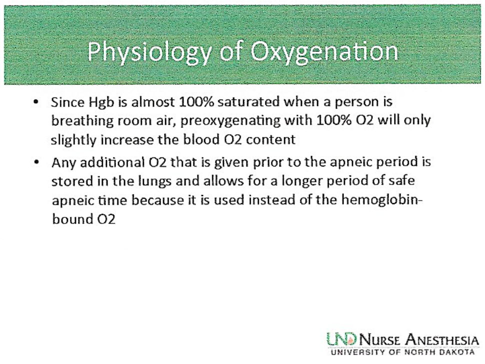

Physiology of Oxygenation

- Since Hgb is almost 100% saturated when a person is breathing room air, preoxygenating with 100% O2 will only slightly increase the blood O2 content
- Any additional O2 that is given prior to the apneic period is stored in the lungs and allows for a longer period of safe apneic time because it is used instead of the hemoglobin-bound O2

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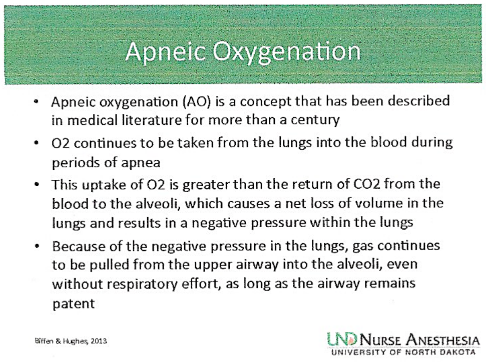

Apneic Oxygenation

- Apneic oxygenation (AO) is a concept that has been described in medical literature for more than a century
- O2 continues to be taken from the lungs into the blood during periods of apnea
- This uptake of O2 is greater than the return of CO2 from the blood to the alveoli, which causes a net loss of volume in the lungs and results in a negative pressure within the lungs
- Because of the negative pressure in the lungs, gas continues to be pulled from the upper airway into the alveoli, even without respiratory effort, as long as the airway remains patent

Biffen & Hughes, 2013

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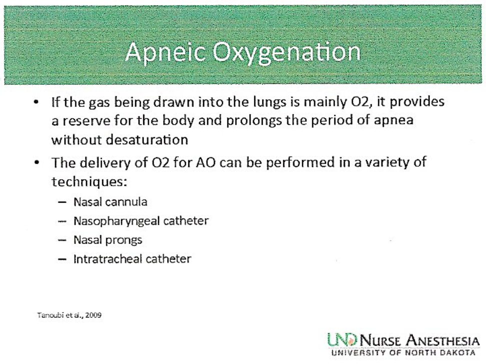

Apneic Oxygenation

- If the gas being drawn into the lungs is mainly O2, it provides a reserve for the body and prolongs the period of apnea without desaturation
- The delivery of O2 for AO can be performed in a variety of techniques:
  - Nasal cannula
  - Nasopharyngeal catheter
  - Nasal prongs
  - Intratracheal catheter

Tanoubi et al., 2009

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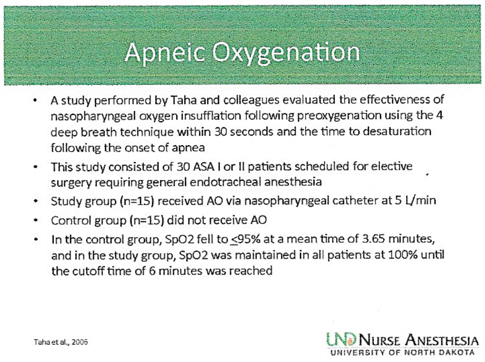

Apneic Oxygenation

- A study performed by Taha and colleagues evaluated the effectiveness of nasopharyngeal oxygen insufflation following preoxygenation using the 4 deep breath technique within 30 seconds and the time to desaturation following the onset of apnea
- This study consisted of 30 ASA I or II patients scheduled for elective surgery requiring general endotracheal anesthesia
- Study group (n=15) received AO via nasopharyngeal catheter at 5 L/min
- Control group (n=15) did not receive AO
- In the control group, SpO2 fell to $\le$95% at a mean time of 3.65 minutes, and in the study group, SpO2 was maintained in all patients at 100% until the cutoff time of 6 minutes was reached

Taha et al., 2006

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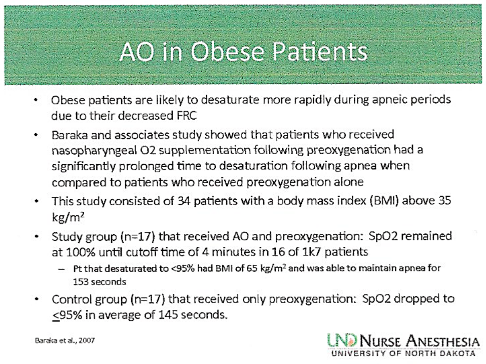

AO in Obese Patients

- Obese patients are likely to desaturate more rapidly during apneic periods due to their decreased FRC
- Baraka and associates study showed that patients who received nasopharyngeal O2 supplementation following preoxygenation had a significantly prolonged time to desaturation following apnea when compared to patients who received preoxygenation alone
- This study consisted of 34 patients with a body mass index (BMI) above 35 kg/m^2
- Study group (n=17) that received AO and preoxygenation: SpO2 remained at 100% until cutoff time of 4 minutes in 16 of 1k7 patients
  - Pt that desaturated to <95% had BMI of 65 kg/m^2 and was able to maintain apnea for 153 seconds
- Control group (n=17) that received only preoxygenation: SpO2 dropped to $\le$95% in average of 145 seconds.

Baraka et al., 2007

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AO in Obese Patients

- Study by Ramachandran and colleagues involved 30 obese men undergoing general anesthesia
- Both groups had an average BMI of 31.2 kg/m^2
- Both groups received standard preoxygenation with a tightly sealed mask, breathing 100% O2 at 12 to 15 L/min until their end-tidal O2 was >90%
- Study group (n=15) received AO via nasal prongs at 5 L/min
- Control group (n=15) did not receive AO
- Study group had a significantly longer period of SpO2 remaining >95% (5.29 minutes) when compared to the control group (3.49 minutes)
- Also, 8 of the subjects in the study group still had a SpO2 >95% at 6 minutes, compared to only 1 in the control group

Ramachandran et al., 2010

Nasal Prongs vs Nasopharyngeal Catheter

- Achar and colleagues study: Determine the effectiveness of administration of O2 through nasal prongs (NP) and nasopharyngeal catheter (NC) and the duration of SpO2 ≥95%
- Consisted of 56 adult ASA I and II requiring GETA
- All patients were preoxygenated until a FeO2 of >90% was reached. Induction was then performed, the ability to mask ventilate was confirmed, followed by paralysis with rocuronium
- Half received AO via NP and half received AO via NC (both at 5 L/min)
- Apnea held until SpO2 dropped ≤95% or cutoff time of 10 min
- Results: 9 patients in NP group desaturated compared to none in NC group (P=0.001)

Achar et al., 2014

Recommendations

- Multiple AO techniques are available, and all effectively prolong the safe apneic period
- Most of the studies include small samples and patient populations
- Most studies include low risk, ASA I or II patients
- Larger studies involving higher risk patients are needed
- Several studies suggest the use of AO given the benefits outweigh the risks

Conclusion

- Additional large, randomized controlled studies involving higher risk patients are needed
- The research and literature reviewed provided significant results and showed that by utilizing AO it may be able to give the anesthesia provider valuable time while attempting to secure a patient's airway
- This may be even more beneficial in patients that are at an increased risk of rapid desaturation, such as obese and obstetric patients
- AO is easy to implement into practice and the benefits definitely outweigh the risks

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Thank You
Are There Any Questions?

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