Apneic Oxygenation: A Method to Prolong the Period of Safe Apnea

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A difficult intubation poses one of the most challenging tasks for anesthesia professionals, representing 27% of all adverse respiratory events, 93% of which are unanticipated. Unanticipated difficult mask ventilation and intubation may result in serious complications. Safe airway management requires a proper and thorough preoperative airway evaluation and a plan to secure the airway, with alternate plans available when the initial plan fails. Pediatric, obese, and obstetric patients undergoing general anesthesia with endotracheal intubation are considered to be at risk of rapid desaturation. As an adjunct to conventional preoxygenation techniques, continuous oxygen administration during the apneic period, termed apneic oxygenation, assists in the maintenance of oxygenation when tracheal intubation is attempted. Nine articles were selected for appraisal in this literature review: 6 randomized control trials, 2 prospective studies, and 1 retrospective study. Multiple apneic oxygenation techniques, including nasopharyngeal catheter, nasal prongs, endotracheal tube, intratracheal catheter, and high-flow transnasal humidified oxygen, demonstrated effectiveness at delaying the onset of hypoxemia during the apnea period. Prolonging the apneic window changes the nature of airway management in patients at high risk of desaturation and when an unanticipated difficult airway arises.

Keywords: Apneic oxygenation, aventilatory mass flow, difficult airway, high-flow nasal cannula, nasopharyngeal oxygen insufflation.

Maintenance of oxygenation during airway management is of utmost concern for anesthesia providers. Adverse respiratory events accounted for 17% of the most damaging events in the American Society of Anesthesiologists (ASA) closed-claims database from 1990 to 2007, and 31.8% of the claims in the American Association of Nurse Anesthetists (AANA) database from 2003 to 2012. Damaging events are defined as adverse outcomes that result in malpractice claims. Even with advances in respiratory monitoring technology and practice guidelines for managing the difficult airway, difficult airway management accounted for 27% of all adverse respiratory events in the ASA closed-claims database: 67% on induction and 12% on extubation.[1,2]

A preoperative evaluation of the patient's airway history and physical examination of anatomical variables may be predictive of a difficult intubation. The ability to predict and prepare for management of a difficult airway may further reduce the adverse consequences encountered at the time of induction; these include but are not limited to neurologic injury, airway trauma, unnecessary surgical airway, and death. A cohort study conducted by Nørskov et al[3] appraised 188,064 cases that were recorded in the Danish Anesthesia Database, evaluating the diagnostic accuracy in predicting the difficult intubation. There were 3,391 difficult intubations; among these, 93% were not predicted to be difficult ($P < .05$). The ASA recommendations for evaluation of the airway were employed, and the authors concluded there is no single predictor of a difficult intubation.[3]

In 2013, the Canadian Airway Focus Group[4] updated its recommendations for management of the anticipated difficult airway. Included was the endorsement of continuous oxygen (O_2) administration during the apneic period, termed apneic oxygenation (AO), when tracheal intubation is attempted.[4] Research demonstrates that AO can safely prolong the duration of apnea without desaturation, maintaining an oxygen saturation measured by pulse oximetry (SpO_2) at or above 90%.[5-14] The Difficult Airway Society and the Obstetric Anaesthetists' Association, located in the United Kingdom, released new guidelines for management of the unanticipated difficult airway and management of the difficult airway in obstetrics. Emphasis was placed on AO in patients who are considered at high risk of desaturation after the induction of anesthesia.[15,16] More recently, an analysis was conducted on the Pediatric Difficult Intubation (PeDI) registry in the United States; hypoxemia was the most common complication related to tracheal intubation. Based on adult studies and anecdotal reports, PeDI investigators speculate that AO would delay the onset of hypoxemia in children and reduce the number of tracheal intubation attempts.[17] Currently, the application of AO is not standard practice in the United States.

Pediatric, obese, and obstetric patients undergoing general anesthesia are considered at high risk of rapid desaturation. Increased O_2 consumption and reduced

functional residual capacity (FRC) hastens the development of hypoxemia in the obstetric and obese populations.[16,18,19] Compared with adults, pediatric patients desaturate more quickly because they have a higher metabolic rate and greater O_2 consumption.[12,17] Multiple attempts with direct laryngoscopy increase the risk of pharyngeal and laryngeal trauma. Subsequently, the resulting trauma may increase the difficulty of successful face-mask ventilation and successful intubation via repeated laryngoscopy.

As evidenced by clinical research, AO provides acceptable O_2 saturations. Frumin et al[9] and Cook et al[12] suggest saturations greater than 95% for 45 minutes in the nonobese adult patient and 10 minutes in the pediatric patient, respectively. Extending the safe apnea period, which is defined as the time between the onset of apnea and when the Spo_2 concentration reaches 90% or less, increases the margin of safety with tracheal intubation.[19] This may alleviate a high-stress start-stop scenario during laryngoscopy and help avoid a "cannot intubate, cannot ventilate" scenario.[6] Conventional preoxygenation techniques may not be adequate in providing a safe apnea period in all populations. This literature review evaluates a proposed alternative, which is the use of AO as an adjunct to traditional preoxygenation techniques.[4-18]

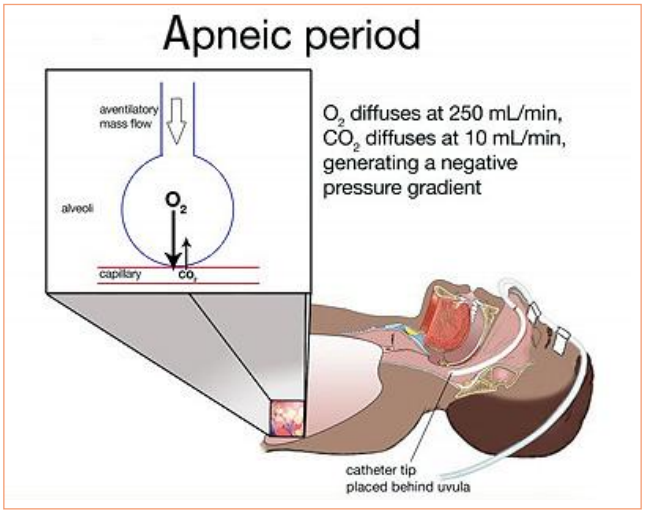

Figure 1. Mechanics of Apneic Oxygenation
Pressure difference between oxygen (O_2) diffusion from the alveoli and carbon dioxide (CO_2) excretion from the capillary produces a negative pressure gradient, resulting in aventilatory mass flow (AVMF) of gases into the lungs.[8,20] Insufflation of O_2 into the pharynx via nasopharyngeal catheter allows for AVMF of O_2 into the lungs.

Physiology of Apneic Oxygenation

Ensuring adequate oxygenation and ventilation is the primary objective of airway management; thus, before the induction of anesthesia, patients are preoxygenated with 100% O_2 via face mask. Preoxygenation denitrogenates the lungs, creating an alveolar O_2 reservoir, which helps reduce the frequency and severity of desaturation. In a nonobese adult patient without pulmonary disease, conventional preoxygenation techniques provide 4 to 8 minutes of safe apnea.[19] Metabolic O_2 consumption and carbon dioxide (CO_2) production of the adult human body weighing approximately 70 kg is approximately 250 mL/min and 200 mL/min, respectively. Following denitrogenation of the FRC, O_2 diffuses from the alveolus into the bloodstream at a rate of about 250 mL/min.[19,20] During apnea, CO_2 production remains unchanged; however, the elimination of CO_2 is almost completely halted and diffuses into the alveolar space at a rate of approximately 10 mL/min. The pressure difference results in a net gas flow of 240 mL/min from the alveoli into the blood, generating a negative pressure gradient. Negative pressure that is created from the diffusion of O_2 causes entrainment of ambient gases into the lungs and describes the physiological phenomenon of aventilatory mass flow (AVMF). Normally, room air gases (79% nitrogen and 21% O_2) are entrained into the lungs, and as nitrogen accumulates, desaturation occurs. Provided that a patent air passage exists from the lungs to the pharynx, the insufflation of O_2 into the pharynx extends the reservoir, allowing AVMF of O_2 (Figure 1).[20] The clinical use of this procedure, regarded as AO, allows for persistent oxygenation without ventilations.

Carbon Dioxide Physiology During Apneic Oxygenation

The human body produces approximately 200 mL of CO_2 every minute. Carbon dioxide is highly soluble and elimination is dependent on alveolar ventilation. Holmdahl[20] estimated that during AO, 90% of the CO_2 produced stays in circulation and is distributed throughout the body, whereas only 10% enters the alveoli, resulting in an uncompensated respiratory acidosis. Five studies[5,6,8,12,14] evaluated the rate of rise in CO_2, and none of the studies reported uncontrolled cardiovascular complications or other complications suggestive of CO_2 toxicity: seizures, arrhythmias, and cardiovascular collapse. Studies[5,6,8,14] in adult patients reported average increases in CO_2 ranging from 1.12 mm Hg/min to 2.4 mm Hg/min. In 2 studies,[6,8] several patients underwent procedures and were apneic for 45 minutes and 65 minutes; the highest CO_2 measurements recorded were 89 mm Hg and 112 mm Hg, respectively. All studies reported results after ventilation was resumed, and patients fully recovered without experiencing any complications.

Compared with adults, CO_2 levels increase faster in pediatric patients because they have a higher metabolic rate. A study in pediatric patients reported that during the first minute of apnea the mean increase in $PaCO_2$ was 12.2 mm Hg, followed by 4.2 mm Hg/min over the next 4 minutes.[12] Frumin et al[9] suggests that hypercarbia produced by apnea periods of even 30 minutes may be tolerable in an anesthetized nonobese adult patient, with complete recovery. However, it is important for the

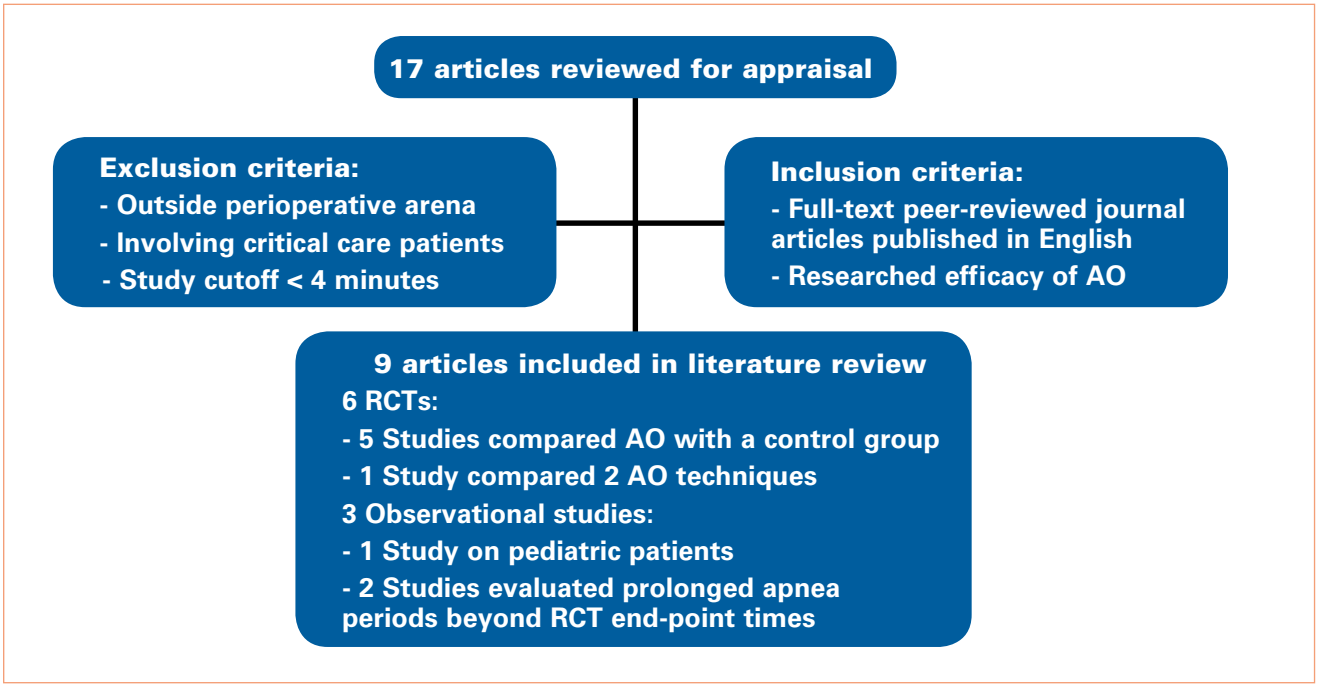

Figure 2. Flowchart of Literature Search
Abbreviations: AO, apneic oxygenation; RCT, randomized control trial.

clinician to understand that AO provides little relevant clearance of CO_2 and progresses to eventual respiratory acidosis, which may be severe.

History and Review of the Literature

Apneic oxygenation has been explored for more than a century.[6,8,9,18] Although the physiological nomenclature of AO has changed several times, the physiological phenomenon remains unchanged.[6,18] Holmdahl[20] first described the concept of apneic diffusion oxygenation in humans in 1956. The technique was used to prevent desaturation during bronchoscopies while allowing the endoscopist to work without the need for ventilations.[20] Most recently, AO has been studied and used clinically to prevent desaturation during panendoscopies, otolaryngeal procedures, brain death testing, and laryngoscopy.[6,8,18] In 2011, Weingart and Levitan[18] recommended Nasal Oxygen During Efforts Securing A Tube (NO DESAT), which describes the use of AO in efforts to prevent desaturation during emergency airway management. Their recommendations consist of using a nasal cannula to deliver O_2 at 15 L/min during the apneic period.[18] The Canadian Airway Focus Group[4] and the Difficult Airway Society[15] have evaluated recommendations for and the empirical evidence of AO, suggesting its use in patients who are considered at high risk of desaturation. Additionally, the recommendations have been adopted by the Obstetric Anaesthetists' Association[16] and employed in guidelines for management of the difficult and failed tracheal intubation in obstetrics.

An electronic database search was conducted using The Cochrane Library, Cumulative Index to Nursing & Allied Health Literature, PubMed, Springer Link, Google Scholar, and Wolters Kluwer. The search also included the following professional organizations' websites: ASA, AANA, and Difficult Airway Society. The following search terms were used alone and in combination: *apneic oxygenation, difficult airway, aventilatory mass flow, nasopharyngeal oxygen insufflation, and high flow nasal cannula*. Evidence sources were also examined to determine if they evaluated the use of AO. Results of the search are displayed in Figure 2.

• ***Apneic Oxygenation in Adults.*** The empirical evidence of AO has been studied using several different techniques, which all support prolonging the period of safe apnea by extending the time to desaturation. Techniques examined include insufflation of O_2 using a nasopharyngeal catheter, nasal prongs, intratracheal catheter, and high-flow transnasal humidified O_2.[5-14] The sample demographics, preoxygenation techniques, AO intervention and comparator, and associated findings are summarized in the Table.

Apneic oxygenation necessitates a patent airway to allow for the delivery and entrainment of O_2 from the pharynx to the lungs. Placement of a nasopharyngeal catheter effectively delivers O_2 to the pharynx, providing an extension of the O_2 reservoir during apnea. Nasopharyngeal oxygenation is achieved by placing an O_2 catheter in the naris to the depth of the nasopharynx. Catheter depth is determined by measuring from the base of the nose to the tragus.[21] Four studies[5,7,10,14] examined the efficacy of AO using a nasopharyngeal catheter and

Evidence source	Sample/evidence level	Preoxygenation technique	Intervention/comparator	Findings
Teller et al,[10] 1988	• N = 12 • RCT • ASA 1 or 2 • Scheduled to undergo general anesthesia	3 min of normal tidal breathing of 100% O_2 via face mask	NC placed, insufflated O_2 at 3 L/min vs no O_2 in control group	• AO group tolerated 10 min of apnea and maintained $SpO_2 \geq 98\%$ • Control group desaturated to SpO_2 of 92%, with mean apnea time of 6.8 min
Taha et al,[5] 2006	• N = 30 • RCT • ASA 1 or 2 • Mean subject height of 165.5 cm and weight of 66.5 kg • Elective procedure undergoing general anesthesia	4 deep breaths in 30 seconds of 100% O_2 via face mask	NC placed, insufflated O_2 at 5 L/min vs no O_2 in control group	• AO group tolerated 6 min of apnea • Control group desaturated to SpO_2 of 95% and had mean apnea time of 3.65 min
Jain et al,[14] 2009	• N = 40 • RCT • ASA 1 or 2 • Mean subject weight: 50.7 kg • Elective procedure undergoing general anesthesia	4 deep breaths in 30 seconds of 100% O_2 via face mask	NC placed, insufflated O_2 at 5 L/min vs no O_2 in control group	• AO group tolerated 6 min of apnea, maintaining $SpO_2 > 95\%$ • Control group desaturated to SpO_2 of 95%, and mean apnea time was 4.04 min
Baraka et al,[7] 2007	• N = 34 • RCT • ASA 1 or 2 • Morbidly obese patients: mean BMI of 42 kg/m^2 • Undergoing gastric bypass surgery	3 min of normal tidal breathing of 100% O_2 via face mask	NC placed, insufflated O_2 at 5 L/min vs no O_2 in control group	• AO group: 16 of 17 patients maintained SpO_2 of 100% and tolerated 4 min of apnea • Control group desaturated to $SpO_2 < 95\%$, and mean apnea time was 145 s
Ramachandran et al,[11] 2010	• N = 30 • RCT • ASA 1 or 2 • Obese patients: mean BMI of 31 kg/m^2 • Elective procedure undergoing general anesthesia	8 VC breaths or normal tidal breathing of 100% O_2 via face mask until ETO_2 of 90%	Nasal prongs placed, insufflated O_2 at 5 L/min vs no O_2 in control group	• AO group: 53% of patients maintained $SpO_2 \geq 95\%$, and mean apnea time was 5.29 min • Control group: 1 patient maintained $SpO_2 \geq 95\%$, and mean apnea time was 3.49 min • Mean SpO_2 significantly higher in AO group, 94.3 ± 4.4% vs 87.7 ± 9.3% in control group
Achar et al,[13] 2014	• N = 56 • RCT • ASA 1 or 2 • Mean BMI: 23 kg/m^2 • Elective procedure undergoing general anesthesia	Deep breathing of 100% O_2 via face mask until ETO_2 of 90%	Insufflated O_2 at 5 L/min via NC or nasal prongs	• NC group: all patients tolerated 10 min of apnea without desaturation • Nasal prong group: 9 patients desaturated to $SpO_2 < 95\%$
Rudlof & Hohenhorst,[8] 2013	• N = 47 • Retrospective study • ASA 2 or 3 • Range of subject weight of 44-156 kg and mean height of 171.5 cm • Undergoing panendoscopy	3 min of normal tidal breathing of 100% O_2 via face mask, desired ETO_2 of 90%	Insufflated O_2 at 0.5 L/min via intratracheal catheter	• Apnea was maintained throughout procedure for 44 of 47 patients, and mean apnea time was 24.7 min • Maximum apnea time of 45 min and minimum apnea time of 1 min

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Patel & Nouraei,[6] 2015	• N = 25 • Prospective study • ASA 1-4 • BMI range: 18-52 kg/m^2 • Documented or suspected difficult airways • Undergoing general anesthesia for hypopharyngeal or laryngotracheal surgery	Delivered transnasal humidified O_2 at 70 L/min for 10 min before induction	Continued delivery of O_2 at 70 L/min until definitive airway was established	• All patients maintained SpO_2 > 90%, mean apnea time was 17 min, and apnea times ranged from 5 to 65 min
Cook et al,[12] 1998	• N = 26 • Prospective study • ASA 1 or 2 • Pediatric patients: age range of 1 mo to 11 y • Subjects' weight range: 3.7-48.6 kg • Undergoing cardiac catheterization	Before end of the procedure, patients were ventilated with 100% O_2 until $ETCO_2$ of 25 mm Hg	Endotracheal insufflation of O_2 via T-piece at 1 L/min	• Mean PaO_2 started at 561 mm Hg and decreased to 366 mm Hg after 5 min of apnea • Serial ABGs were performed every minute during apnea for 5 min. During first minute of apnea, mean decrease in PaO_2 was 105 mm Hg, followed by decrease of 31 mm Hg/min over next 4 min

Table. Matrix of Randomized Controlled Trials and Observational Studies Reviewed

Abbreviations: ABG, arterial blood-gas analysis; AO, apneic oxygenation; BMI, body mass index; $ETCO_2$, end-tidal carbon dioxide; ETO_2, end-tidal oxygen concentration; NC, nasopharyngeal catheter; O_2, oxygen; PaO_2, arterial partial pressure of oxygen; RCT, randomized controlled trial; SpO_2, oxyhemoglobin saturation; VC, vital capacity.

found it was more efficacious in prolonging the apneic period compared with preoxygenation alone. After preoxygenation and induction, a nasopharyngeal catheter was placed and O_2 was insufflated at 3 L/min or 5 L/min. Study end-point times were 6 minutes and 10 minutes or until the SpO_2 concentration fell to 92% or 95%, whichever occurred first.[5,7,10,14] In 3 studies[5,10,14] all patients in the AO groups maintained their SpO_2 concentration at 97% or higher for the duration of the apneic period. Conversely, all patients in the control groups desaturated to 92% or 95% before the study cutoff time; mean apnea times were 3.65 minutes,[5] 4.04 minutes,[14] and 6.8 minutes.[10]

Baraka et al[7] researched the effectiveness of AO using a nasopharyngeal catheter in obese patients with a body mass index (BMI) above 35 kg/m^2. All but 1 patient in the treatment group tolerated 4 minutes of apnea. The patient who desaturated to a concentration less than 95% had a BMI of 65 kg/m^2 and maintained 153 seconds of apnea.[7] All 4 studies[5,7,10,14] evaluating the efficacy of nasopharyngeal O_2 therapy validate its ability to significantly delay the onset of desaturation.

The Difficult Airway Society[15] and the Obstetric Anaesthetists' Association[16] recommend the use of nasal prongs to insufflate O_2 at flows of 5 L/min to 15 L/min during the apneic period. Nasal prongs require nasopharyngeal patency to allow for the delivery of O_2 to the pharynx. Induction may compromise nasopharyngeal airway patency in a number of patients, including but not limited to edentulous patients, obstetric patients, obese patients, and patients with obstructive sleep apnea. This technique was evaluated in 2 different studies. One study[11] employed AO via nasal prongs during a simulated difficult laryngoscopy with obese patients. Induction was performed and O_2 was administered to the study group at flows of 5 L/min vs no O_2 via nasal prongs to the control group. The AO group had a significantly longer time until desaturation of less than 95%: 5.29 minutes compared with 3.49 minutes in the control group (P = .001). The mean SpO_2 concentration was also higher in the AO group, 94.3 ± 4.4% vs 87.7 ± 9.3% in the control group (P = .001). Among studies[7,11] examining the obese population, the time until the SpO_2 concentration decreased to less than 95% was significant between the control groups and AO groups. Obese patients have a reduced FRC, which makes extrapolation of these results more significant, suggesting that AO may also improve the safety of airway management in obstetric patients.

A more recent study, conducted by Achar et al,[13] compared the effectiveness of nasal prongs vs a nasopharyngeal catheter in 56 patients. After preoxygenation and induction, O_2 was insufflated with either a nasopharyngeal catheter or nasal prongs at flows of 5 L/min. The period of apnea was held for 10 minutes or until the SpO_2 concentration fell below 95%, whichever

occurred first. No patients in the nasopharyngeal catheter group desaturated compared with 32% in the nasal prongs group (P = .001).[13] These studies suggest that AO is better achieved with a nasopharyngeal catheter rather than nasal prongs. Insufflation of O_2 via nasopharyngeal catheter distributes O_2 close to the trachea, thus circumventing potential problems associated with nasal prongs when airway patency is not maintained. Ramachandran and colleagues[11] suggested that O_2 flows above 5 L/min may enhance nasal patency, improving the delivery of O_2 to the pharynx. Additional proposals for maintaining a patent airway consist of performing a jaw thrust for the duration of the procedure, inserting a nasal trumpet when using nasal prongs, and aligning the horizontal plane of the patient's external auditory meatus and sternal notch.[7,13,18]

Rudlof and Hohenhorst[8] investigated the clinical efficacy of AO in adult patients undergoing panendoscopy. Following induction, direct laryngoscopy was performed, an 8-French catheter was placed in the trachea, and O_2 was insufflated at 0.5 L/min. Among the 47 patients included in the study, 44 tolerated the procedure, maintaining a mean SpO_2 concentration of 98%, a mean apnea time of 24.7 minutes, and a maximum apnea time of 45 minutes.[8]

Patel and Nouraei[6] researched the use of transnasal high-flow humidified O_2 in patients with a difficult airway. Patients were preoxygenated using the Optiflow nasal cannula (Fisher & Paykel Healthcare Ltd), which provided O_2 at a rate of 70 L/min for 10 minutes. After induction, the nasal cannula (Optiflow) continued to deliver O_2 until a definitive airway was achieved. All patients maintained their SpO_2 concentrations above 90%, and apnea times ranged from 5 to 65 minutes, with a mean apnea time of 17 minutes.[6] Although high-flow nasal cannulas are not readily available in the operating suite, this device was effective at prolonging the apnea time without desaturation in patients with a difficult airway and reduced FRC. Both this study and the one by Rudlof and Hohenhorst demonstrated that AO was able to prolong the apneic period, up to 45 minutes[8] and 65 minutes,[6] signifying it may provide crucial laryngoscopy time during a rapid-sequence intubation or when an unanticipated difficult airway arises.

The empirical evidence supports the efficacy of AO in delaying desaturation and prolonging the safe apnea period in adults. Another technique for providing AO is with a dual-use laryngoscope blade. The Miller Port American Profile Conventional Blade (SunMed LLC) has an internal lumen built inside the blade and allows for the noninvasive insufflation of O_2 when laryngoscopy is performed (Figure 3). The Naso-Flo nasopharyngeal airway (Medis Medical Co Ltd) is another alternative, which features an O_2 port and allows for O_2 delivery directly to the pharynx (Figure 4).

Figure 3. Dual-Use Laryngoscope Blade
Arrows indicate inflow and outflow of oxygen through the Miller Port American Profile Conventional Blade (SunMed LLC). (Image courtesy of SunMed LLC.)

Figure 4. Nasopharyngeal Airway Device
Arrow indicates oxygen insufflation port of Naso-Flo (Medis Medical Co Ltd). (Image courtesy of Medis Medical.)

The Canadian Airway Focus Group, Difficult Airway Society, and Obstetric Anaesthetists' Association recommend the application of AO in high-risk patients. Considering that 93% of difficult intubations are unanticipated, AO should be considered in all patients undergoing general anesthesia. Prolonging the safe apnea period changes the nature of managing an airway in patients at high risk of rapid desaturation or when an unanticipated difficult airway arises.

• ***Apneic Oxygenation in Children.*** Cook et al[12] examined changes in blood-gas tensions during AO in 26 pediatric patients aged from 1 month to 11 years, 5 of whom were infants. In all patients, the trachea was intubated and respiration was controlled by mechanical ventilation. After completion of the procedure, the patients were mechanically ventilated to a stable end-tidal carbon dioxide concentration of 25 mm Hg. Neuromuscular blockade was administered, and O_2 was delivered via T-piece at a rate of 1 L/min. Serial arterial blood-gas samples were taken every minute during apnea, over the course of 5 minutes. The starting mean PaO_2 was 561 mm Hg and decreased to 366 mm Hg after 5 minutes of apnea (P < .05). During the first minute of apnea, the mean decrease in PaO_2 was 105 mm Hg, followed by a decrease of 31 mm Hg/min over the next 4 minutes (P < .05). Investigators suggested that AO can safely delay desaturation for 5 minutes, with an upper limit of at least 10 minutes.[12]

The PeDI investigation group emphasized the concern of hypoxemia during management of the pedi-

atric airway.[17] Considering that pediatric patients have a smaller apneic period for establishing a definitive airway, anesthesia providers should incorporate AO into their airway management plan. Minimal data are available to compare the safe limits of AO in children. A search of ClinicalTrials.gov,[22] a database with public and private clinical studies involving human participants around the world, revealed 8 active or recently completed clinical studies on AO, and 3 are focused on the efficacy of AO in the pediatric population. As research evolves in the area of AO, these techniques provide a potentially lifesaving tool to be used by anesthesia professionals when critical time is needed to establish a definitive airway.

• ***Strengths and Limitations.*** Strengths of the literature review demonstrate that multiple AO techniques are clinically available, and all are shown to be more effective at prolonging the safe apnea period compared with preoxygenation alone. Limitations of this literature appraisal include small samples and patient populations with a relatively low risk, classified as ASA class 1 or 2. Further investigations should incorporate large-scale multicenter trials concentrating on patient populations prone to rapid desaturation.

Although there are currently no available consensus guidelines for the clinical use of AO, clinicians should consider the potential patient safety applications of the technique. Given the vital nature of ensuring oxygenation and ventilation in rendering safe patient care, AO, although often unconsidered, may provide a potentially valuable clinical technique in selected patient scenarios.

REFERENCES

1. Metzner J, Posner KL, Lam MS, Domino KB. Closed claims' analysis. *Best Pract Res Clin Anaesthesiol.* 2011;25(2):263-276.
2. Jordan LM, Quraishi JA; AANA Foundation Closed Claims Researchers. The AANA Foundation Malpractice Closed Claims Study: a descriptive analysis. *AANA J.* 2015;83(5):318-323.
3. Nørskov AK, Rosenstock CV, Wetterslev J, Astrup G, Afshari A, Lundstrøm LH. Diagnostic accuracy of anaesthesiologists' prediction of difficult airway management in daily clinical practice: a cohort study of 188 064 patients registered in the Danish Anaesthesia Database. *Anaesthesia.* 2015;70(3):272-281.
4. Law JA, Broemling N, Cooper RM, et al; Canadian Airway Focus Group. The difficult airway with recommendations for management—part 2—the anticipated difficult airway. *Can J Anesth.* 2013;60(11):1119-1138.
5. Taha SK, Siddik-Sayyid SM, El-Khatib MF, Dagher CM, Hakki MA, Baraka AS. Nasopharyngeal oxygen insufflation following pre-oxygenation using the four deep breath technique. *Anaesthesia.* 2006;61(5):427-430.
6. Patel A, Nouraei SA. Transnasal humidified rapid-insufflation ventilatory exchange (THRIVE): a physiological method of increasing apnoea time in patients with difficult airways. *Anaesthesia.* 2015;70(3):323-329.
7. Baraka AS, Taha SK, Siddik-Sayyid SM, et al. Supplementation of preoxygenation in morbidly obese patients using nasopharyngeal oxygen insufflation. *Anaesthesia.* 2007;62(8):769-773.
8. Rudlof B, Hohenhorst W. Use of apneic oxygenation for the performance of pan-endoscopy. *Otolaryngol Head Neck Surg.* 2013;149(2):235-239.
9. Frumin MJ, Epstein RM, Cohen G. Apneic oxygenation in man. *Anesthesiology.* 1959;20(6):789-798.
10. Teller LE, Alexander CM, Gross JB, Frumin MJ. Nasopharyngeal insufflation of oxygen prevents hypoxia in apneic patients [abstract]. *Anesthesiology.* 1988;69(3):729A.
11. Ramachandran SK, Cosnowski A, Shanks A, Turner CR. Apneic oxygenation during prolonged laryngoscopy in obese patients: a randomized, controlled trial of nasal oxygen administration. *J Clin Anesth.* 2010;22(3):164-168.
12. Cook TM, Wolf AR, Henderson AJ. Changes in blood-gas tensions during apnoeic oxygenation in paediatric patients. *Br J Anaesth.* 1998;81(3):338-342.
13. Achar SK, Pai AJ, Shenoy UK. Apneic oxygenation during simulated prolonged difficult laryngoscopy: comparison of nasal prongs versus nasopharyngeal catheter: a prospective randomized controlled study. *Anesth Essays Res.* 2014;8(1):63-67.
14. Jain S, Agarawa M, Dali JS. Role of nasopharyngeal oxygen insufflation on haemoglobin desaturation following preoxygenation. *J Anaesthesiol Clin Pharmacol.* 2009;25(4):454-458.
15. Frerk C, Mitchell VS, McNarry AF, et al; Difficult Airway Society Intubation Guidelines Working Group. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. *Br J Anaesth.* 2015;115(6):827-848.
16. Mushambi MC, Kinsella SM, Popat M, et al; Obstetric Anaesthetists' Association; Difficult Airway Society. Obstetric Anaesthetists' Association and Difficult Airway Society guidelines for the management of difficult and failed tracheal intubation in obstetrics. *Anaesthesia.* 2015;70(11):1286-1306.
17. Fiadjoe JE, Nishisaki A, Jagannathan N, et al. Airway management complications in children with difficult tracheal intubation from the Pediatric Difficult Intubation (PeDI) registry: a prospective cohort analysis. *Lancet Respir Med.* 2016;4(1):37-48.
18. Weingart SD, Levitan RM. Preoxygenation and prevention of desaturation during emergency airway management. *Ann Emerg Med.* 2012;59(3):165-175.
19. Tanoubi I, Drolet P, Donati F. Optimizing preoxygenation in adults. *Can J Anesth.* 2009;56(6):449-466.
20. Holmdahl MH. Pulmonary uptake of oxygen, acid-base metabolism, and circulation during apnoea. *Acta Chir Scand Suppl.* 1956;212:1-128.
21. Eastwood GM, Dennis MJ. Nasopharyngeal oxygen (NPO) as a safe and comfortable alternative to face mask oxygen therapy. *Aust Crit Care.* 2006;19(1):22-24.
22. US National Institutes of Health. ClinicalTrals.gov. https://clinicaltrials.gov/ct2/results?term=apneic+oxygenation&Search=Search. Accessed April 4, 2016.

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