Absorption Atelectasis: Incidence and Clinical Implications

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General anesthesia is known to cause pulmonary atelectasis; in turn, atelectasis increases shunt, decreases compliance, and may lead to perioperative hypoxemia. One mechanism for the formation of atelectasis intraoperatively is ventilation with 100% oxygen. The goal of this review is to determine if research suggests that intraoperative ventilation with 100% oxygen leads to clinically significant pulmonary side effects. An initial literature search included electronic databases (Cumulative Index to Nursing & Allied Health Literature [CINAHL], PubMed, MEDLINE, Embase, and The Cochrane Library) using the following search terms: oxygen (administration and dosage), atelectasis, pulmonary complications, and anesthesia. Results were limited to research studies, human subjects, and English-language publications between 1965 and 2011. From this body of research, it appears that absorption atelectasis does occur in healthy anesthetized adults breathing 100% oxygen. Data reviewed suggest that absorption atelectasis does not have significant clinical implications in healthy adults. However, further research is warranted in populations at increased risk of postoperative hypoxemia, including obese or elderly patients and those with preexisting cardiopulmonary disease.

Keywords: Atelectasis, oxygen, ventilation.

General anesthesia is known to cause pulmonary atelectasis; in turn, atelectasis increases shunt, decreases compliance, and may lead to perioperative hypoxemia.[1-3] One mechanism for the formation of atelectasis intraoperatively is ventilation with 100% oxygen.[4-7] Preoxygenation with 100% oxygen has become the standard of care before induction of anesthesia because it prolongs the period between onset of apnea and oxyhemoglobin desaturation.[4,7] Research has also posited that continued use of high fractions of inspired oxygen beyond the induction phase may decrease the incidence of postoperative wound infection and postoperative nausea and vomiting.[8,9] These multiple effects of high oxygen concentration raise the question, does atelectasis formation have a significant enough clinical effect on patient outcomes to outweigh possible benefits of 100% oxygen delivery?[10]

The incidence of pulmonary atelectasis in healthy adults undergoing general anesthesia with muscle relaxation has been reported to be as high as 90% and to persist for at least 24 hours following surgery.[7] Causes of intraoperative atelectasis are related to 3 mechanisms: airway closure resulting from reduced functional residual capacity (FRC), mechanical lung tissue compression, and absorption atelectasis.[7] During 100% oxygen delivery, nitrogen in alveoli is washed out and replaced by oxygen. In contrast to nitrogen, oxygen is extremely soluble in blood and diffuses very quickly into the pulmonary vasculature. So quickly, in fact, that not enough gas is left in the alveoli to maintain patency, and the alveolus collapses; this is known as absorption atelectasis.[7]

A widely accepted method for identifying atelectasis in the surgical patient is a computed tomography (CT) scan of the chest just above the right dome of the diaphragm, and the atelectasis is expressed as a percentage of the total scanned lung volume.[7] The most important clinical implications of intraoperative atelectasis include acute hypoxemia refractory to increased inspired oxygen concentration, increased alveolar-arterial (A-a) oxygen gradient, decreased pulmonary compliance, increased pulmonary vascular resistance, and lung injury.[7,11,12]

Methods to reexpand atelectatic lung units have been well researched, and include recruitment maneuvers and use of positive end-expiratory pressure. Recruitment maneuvers involve delivering a series of 3 breaths to a peak inspiratory pressure of 30 cm H_2O for 15 seconds each with 1 to 2 minutes of normal tidal volume ventilation in between, followed by a final breath to 40 cm H_2O.[7] However, these methods are not without their own risks and do not fully reverse atelectasis.[7] Thus, it is important for anesthesia providers to prevent the formation of atelectasis as much as possible, perhaps by ventilation with lower fractions of inspired oxygen.

Initial literature search for this review included electronic databases (Cumulative Index to Nursing & Allied Health Literature [CINAHL], PubMed, MEDLINE, Embase, and The Cochrane Library) using the following search terms: *oxygen (administration and dosage)*, *atelectasis*, *pulmonary complications*, and *anesthesia*. Results were limited to research studies, human subjects, and English-language publications. Publication dates were not specified, because the historical evolution of data on the topic was of interest to the reviewer. Inclusion criteria included research on adults undergoing anesthesia and surgery,

with independent variables of varying fractions of inspired oxygen, and a primary or secondary outcome being formation of atelectasis or postoperative pulmonary complications. Because of the limited volume of research on this topic, limits were not placed on surgical procedure, inhalational vs intravenous anesthetic, or comorbidities, because consideration of these variables will yield implications for future research. Twelve studies were included for review published between 1965 and 2011.

In this discussion, ventilation with 100% oxygen refers specifically to fresh gas flow. It should be noted that ventilation with 100% oxygen fresh gas flow during inhalational anesthesia is inherently less than 100% oxygen because of the introduction of a volatile anesthetic agent, but the degree that the oxygen fraction decreases is negligible.

History and Review of Literature

Early Research. Déry et al[1] were among the first researchers to study the effects of the fraction of inspired oxygen on postoperative lung volumes of anesthetized patients with a comparative experimental research design. These investigators used the gas dilution technique for measurement of FRC in 12 healthy anesthetized patients undergoing extremity surgery with inhalational anesthetics and a standardized anesthetic regimen. The researchers were able to identify a statistically significant difference in atelectasis formation between patients ventilated with 100% oxygen vs 50% oxygen in 50% nitrogen. Furthermore, they replicated these measurements in a control group of awake subjects breathing 100% and 50% oxygen; data were replicated with a very strong confidence interval. Limitations of this research include small sample size, lack of randomization, and measurement error related to technological limitations of the gas dilution technique at that time.[1] However, these early data have led other investigators to research the clinical implications of absorption atelectasis.

Incidence of Absorption Atelectasis. The literature was reviewed to determine the incidence of absorption atelectasis during induction and maintenance of anesthesia as well as the effect of attempts at reversal of anesthesia-related atelectasis.

Preoxygenation During Induction of Anesthesia. Three studies measured the amount of atelectasis formed after induction of anesthesia with 100% oxygen compared with induction with lower fractions of inspired oxygen; in all 3 studies, patients ventilated with 100% oxygen showed greater amounts of atelectasis by CT scan than did their cohorts.[3,4,13] In addition to disparate amounts of atelectasis after induction with 30% vs 100% oxygen, Rothen et al[2] found that alteration of ventilation-perfusion distribution was unrelated to inspired oxygen concentration, but that maintenance with 30% oxygen resulted in decreased ventilation-perfusion mismatch over time, presumably by hypoxic pulmonary vasoconstriction. However, a major limitation of this study is lack of randomization to treatment groups and sampling bias.[3] Edmark et al[4] found that preoxygenation with 100% oxygen resulted in nearly 10 times the amount of atelectasis than preoxygenation with 80% oxygen. However, these researchers concurrently studied duration of safe apnea between groups, causing the 100% oxygen group to be apneic for longer than the other groups; this is a major confounding variable and disallows the researchers to attribute the atelectasis solely to ventilation with 100% oxygen.[4]

Clinical application of research surrounding preoxygenation with 100% oxygen is somewhat limited, because prolonging the duration of safe apnea is necessary and warranted despite risks of absorption atelectasis. Even these researchers noticed substantial oxyhemoglobin desaturation during apnea in patients preoxygenated with less than 100% oxygen.[3,4,13] This research finding does indicate, however, that absorption atelectasis may occur during the initial preoxygenation period, and it supports the argument that intraoperative recruitment maneuvers are indicated even during maintenance with lower fractions of inspired oxygen.

Hyperoxygenation During Maintenance of Anesthesia. Two studies addressed the degree of atelectasis formation with maintenance ventilation with varying fractions of inspired oxygen. Edmark et al[5] performed an observational study with a historical cohort using data from their 2003 research.[4] They found that preoxygenation and maintenance with 80% oxygen resulted in a slower onset, but eventually equal degree of atelectasis formation over time compared with preoxygenation with 100% oxygen.[5] The researchers drew this conclusion by comparing ventilation with 80% oxygen for 45 minutes and ventilation with 100% oxygen for 14 minutes. These conclusions are called into question, however, because it is impossible to know if atelectasis would have remained at a constant low level in the 100% oxygen group, resulting in equivalent outcomes. The conclusions would be strengthened by replication of the study with each group being studied for equal times.

Agarwal et al[6] performed a more rigorous research study using a comparative experimental design and including 27 subjects. They found that maintenance ventilation with 40% oxygen resulted in significantly lower A-a gradient than maintenance with 100% oxygen (with a standardized induction technique). Limitations of the study by Agarwal et al[6] include small sample size and consideration that A-a may be affected by factors other than pulmonary atelectasis. Because some recent study findings suggest that maintenance ventilation with 100% oxygen may prevent postoperative complications such as wound infection, the data from this study are relevant to situations where practitioners may want to employ such practices.[8,9] A patient-specific plan is imperative to

ensure that prevention of complications such as infection does not put the patient at undue risk of pulmonary complications.

Recruitment Maneuvers. Application of a recruitment maneuver has long been established as an effective method of reversal of anesthesia-related atelectasis.[7] Rothen et al[2] sought to determine if ventilation with 100% oxygen affects atelectasis formation following recruitment maneuver, as is routinely done before emergence and extubation. They found the following: (1) regardless of inspired oxygen, the recruitment maneuver eliminated atelectasis; (2) atelectasis recurred only minimally during ventilation with 40% oxygen; and (3) atelectasis returned to prerecruitment values after 5 minutes of 100% oxygen delivery.[2] Atelectasis was measured in the standard method with CT scans at the dome of the diaphragm at end-expiration.

Benoît et al[14] performed a similar randomized controlled trial with 30 subjects and confirmed the conclusions made by Rothen et al,[2] finding that ventilation with 40% oxygen after recruitment maneuver results in significantly less atelectasis formation than ventilation with 100% oxygen. These authors, however, performed CT scans at the interventricular septum, which is not the standard location for assessment of atelectasis formation.[7]

Rothen et al[2] and Benoît et al[14] studied only patients who were free from cardiac or pulmonary disease and were under total intravenous anesthesia. These strict inclusion criteria limit application of these findings to other populations but strengthen the reliability of the conclusions. Also, Rothen et al[2] used convenience sampling, which introduces bias. Still, based on the results of these 2 investigations, recruitment maneuvers were effective at reducing atelectasis, but the positive effects could be reversed by subsequently breathing 100% oxygen.[2,14]

Effect on Postoperative Pulmonary Outcomes. Three studies examined the effects of differing fractions of inspired oxygen on postoperative lung volumes and capacities, including FRC, residual volume (RV), vital capacity (VC), total lung capacity (TLC), forced expiratory volumes (FEV), and forced vital capacity (FVC).[15-18] Joyce and Baker[19] used the helium dilution technique to measure VC and tidal volume, and from them calculated TLC and RV. Joyce and Baker[19] found no differences in postoperative lung volumes between patients receiving 100% and 30% oxygen with inhalational anesthesia. Akça et al[17] found no difference in postoperative spirometric values or atelectasis formation on CT scan between groups receiving inhalational anesthesia with 30% and 80% oxygen. Major design flaws of this study are lack of a group receiving 100% oxygen, and delivery of the assigned fraction of inspired oxygen for several hours after surgery, which is not standard practice and limits application of these findings to the general population. However, the findings of Akça et al[17] support those of Edmark et al,[4] that there are no significant differences among groups receiving 80% oxygen or less. This may be important to future researchers because it suggests a threshold for clinical effect, which may be helpful to guide study design.

Zoremba et al[16] took spirometric measurements using the best of 3 separate measurements, as is the standard, to measure VC, FVC, FEV, and expiratory flow rates.[16] They found that in moderately obese adults under total intravenous anesthesia, delivery of 80% oxygen preserved spirometric lung volumes better than ventilation with 100% oxygen. Although the anesthetic techniques and methods of measurement studied by Zoremba et al[16] differ from those of Akça et al[17] and Edmark et al,[4] their contradictory results are important to note. Zoremba et al[16] studied patients with compromised pulmonary function related to moderate obesity; this is in contrast to all other studies in this review, which included only healthy subjects free of pulmonary disease. These results suggest that further research is warranted in subjects at increased risk of postoperative pulmonary complications, on whom ventilation with high fractions of inspired oxygen may have more profound effects.

Discussion of State of the Art

The most striking weakness of this body of research is the homogeneity of study subjects, which limits application of results to a broader population. All studies except one include only young, healthy patients undergoing elective procedures. This, in turn, increases the reliability of the research conclusions. Although this body of research does not support the assertion that absorption atelectasis has a statistically significant effect on clinical outcomes, it is not possible to conclude that it does *not*; even the earliest researchers recognized that a 25% decrease in functional residual capacity did not result in hypoxemia in a young healthy population.[1] In fact, the results of Zoremba et al[16] suggest that absorption atelectasis may have significant implications for even the moderately obese patient. Other patient populations who may also be greatly adversely affected by absorption atelectasis and who warrant further research in this field include patients with existing lung or cardiovascular disease, elderly or obese patients, and any patient at increased risk of perioperative hypoxemia.

Most of the research discussed above used a standard anesthetic technique of total intravenous anesthesia; this increases control by eliminating confounding effects of inhalational anesthetics on pulmonary physiology, but also limits application of conclusions to patients undergoing inhalational anesthesia. Agarwal et al[6] were the only researchers to study the degree of atelectasis formation with the patient under inhalational anesthesia, and their results were similar to studies using total intravenous anesthesia. However, inhibition of hypoxic

pulmonary vasoconstriction by inhalational anesthetics may increase ventilation-perfusion mismatch in the patient experiencing absorption atelectasis and enhance unwanted pulmonary effects; this phenomenon warrants further research.

Studies addressing postoperative outcomes mostly measured pulmonary spirometry.[16-19] Other pertinent measurements may include oxyhemoglobin saturation and incidence of pneumonia, myocardial infarction, and death. Further research is warranted to identify long-term clinical implications of 100% oxygen delivery.

Finally, few studies included sample sizes greater than 40 participants. Replication with larger sample sizes may strengthen existing data by enhancing application of findings to a broader population.

Summary

This body of research strongly suggests that absorption atelectasis does occur during 100% oxygen delivery in healthy anesthetized adults.[1,3,13] Recruitment maneuvers effectively reverse absorption atelectasis, but their benefit is short-lived if denitrogenation subsequently recurs by again breathing 100% oxygen.[2,14] There are no current data to suggest that absorption atelectasis has a major effect on postoperative pulmonary function in healthy adults, but postoperative outcomes may be affected by absorption atelectasis in patients at risk of perioperative hypoxemia.[10,16,19] Finally, absorption atelectasis does not appear to occur in patients ventilated with 80% oxygen or less.[4,10,17]

Anesthetists may apply these findings to practice in cases where concern over postoperative pulmonary complications is high, using less than 80% oxygen to minimize absorption atelectasis. When patients are not at increased risk of postoperative pulmonary complications, anesthetists may feel comfortable delivering 100% oxygen in hopes of achieving improved outcomes in areas such as postoperative nausea and vomiting and wound infection. Further research is warranted in this area, specifically with larger sample sizes and in populations at increased risk of postoperative pulmonary complications.

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