Implications of Inspired Carbon Dioxide During Ophthalmic Surgery Performed Using Monitored Anesthesia Care

Thomas A. McHugh, MN, CRNA

Inspired concentration of carbon dioxide ($FICO_2$) in ophthalmic surgery performed under monitored anesthesia care (MAC) has been largely ignored in the recommended monitoring standards of professional anesthesia societies. Most ophthalmic procedures are performed using MAC with facial draping that has been shown to retain carbon dioxide in the ambient air surrounding the patient. The administration of supplemental oxygen has been shown to prevent hypoxia but not hypercapnia. Hypercapnia can lead to physiologic changes, including tachypnea, tachycardia, and increased intraocular pressure. Several closed-claim analyses have described adverse outcomes related to ventilation and oxygenation of patients during MAC.

A literature search using the keywords of ophthalmic surgery, monitored anesthesia care, and inspired carbon dioxide was conducted, and relevant articles dealing with possible complications, methods of measurement, and abatement strategies were examined. No procedure has gained widespread acceptance, yet practitioners employ a variety of methods to decrease $FICO_2$, a parameter not mentioned in the anesthetic record although it is measured by current anesthesia workstations. The goal of this review is to encourage investigation of this underreported parameter.

Keywords: Inspired carbon dioxide, monitored anesthesia care, ophthalmic surgery.

The review will discuss the observation of increased levels of inspired carbon dioxide ($FICO_2$) during ophthalmic procedures performed under monitored anesthesia care (MAC), the most commonly used technique in the United States.[1] Monitored anesthesia care more accurately describes a billing term and is being replaced in practice by the more accurate description of sedation. Throughout this article, MAC will be used to align with the description used in previous publications, to minimize confusion. Increased levels of $FICO_2$ with this technique were described by Kobel et al,[2] with further articles by Schlager and Luger[3] and Inan and colleagues.[4] Physiologic consequences of breathing an atmosphere enriched with carbon dioxide (CO_2) include hypercapnia leading to tachypnea, hypertension, confusion, and increased blood flow to organs including the brain and globe of the eye.[3-5] Several solutions have been proposed, including supplemental oxygen and suction placed under the drapes,[4,6,7] but there is no standardization or inducement to implement them. This has not been discussed in US literature, to the author's knowledge, and standards of care from professional societies are silent on monitoring $FICO_2$ in this setting.[8-10]

Monitored anesthesia care accounted for 10% of closed claims for anesthesia injuries from 1990 to 2007.[11] Respiratory events related to sedation were the most commonly reported adverse outcome under MAC, resulting in death or brain damage in 84% of 25 claims.[11,12] Between 1990 and 2007, fully 38% of surgical claims related to MAC anesthesia were due to patient death. Analyses of closed claims revealed that almost half were thought to have been preventable by improved monitoring, even though pulse oximetry was in use and was combined with capnography for end-tidal carbon dioxide ($ETCO_2$) in some cases.[11,12] There is no indication that high levels of $FICO_2$ were responsible or that measures were employed to reduce $FICO_2$ in cases in which adverse events occurred.

Methods of the Literature Search

The literature search was conducted electronically in October 2017 using PubMed, Cumulative Index to Nursing & Allied Health Literature (CINAHL), MEDLINE, and Google Scholar for journals in English based on keyword combinations of *ophthalmic surgery*, *monitored anesthesia care,* and *inspired carbon dioxide*. Reference lists of selected articles were reviewed for additional sources. Twenty-one citations were returned, 13 of which were relevant to the subject; also included were 2 analyses of closed claims. Articles selected for inclusion included full text articles in English available for download through either PubMed or OpenAthens; 1 exception was made for an English abstract of a French article[2] that had been cited by multiple articles. The timeframe for the search was 1984 to 2017.

Articles were grouped into 2 broad categories: hypercapnia/hypoxia and preventive strategies. Additionally,

Source	Hypercapnia/ hypoxia	Preventive strategy	Type (no. of subjects)
Ramanathan et al, 1978[24]	X		Pilot, nonrandomized, 4 sets of experiments (N = 30)
De Oliveira et al, 2010[19]	X		Prospective, blind (N = 40)
Sukcharanjit et al, 2015[22]		X	Randomized clinical trial (N = 40)
Zeitlin et al, 1989[20]	X	X	Randomized and bench trial
Ebert et al, 2015[17]		X	Randomized, 4-block crossover (N = 45)
Kobel et al, 1984[2]	X		Report
Risdell & Geraghty, 1997[6]	X	X	4-tailed trial: unsupplemented air and 3 types of oxygen supplementation (N = 30)
Schlager & Luger, 2000[3]	X	X	Randomized, single-blind (N = 40)
Schlager, 1999[5]	X	X	Prospective, randomized, single-blind (N = 60)
Schlager & Staud, 1999[7]	X	X	Randomized single-blind (N = 50)
Inan et al, 2003[4]	X	X	Randomized single-blind (N = 160)

Table. Articles Selected for Inclusion

practice standards regarding intraoperative monitoring of the American Society of Anesthesiologists, the American Association of Nurse Anesthetists, and the Association of Anaesthetists of Great Britain and Ireland were reviewed for guidance in monitoring $FICO_2$. A Google search using the keywords *ophthalmic drape support, insufflation drape support*, and *patent* was conducted to determine what designs had been proposed over the years.

Literature Review

The advent of pulse oximetry and $ETCO_2$ capnography and its adoption as a standard of care for general anesthesia in the mid-1980s has made detection of hypoxia and hypercapnia routine (Table). The standard was eventually applied to all anesthetic administration; however, detection of hypoxia and hypercapnia in the spontaneously breathing patient under MAC remains problematic.[13] Combined with a patient airway that is under surgical drapes—remote from the anesthesia provider—and provision of supplemental oxygen based on individual provider experience, respiratory events represent the largest portion of claims filed for adverse events during MAC.[11,12]

• ***Hypoxia and Hypercapnia.*** Hypoxia is a result of insufficient ventilation and can be traced to airway obstruction, a defect in alveolar diffusion, or the respiratory depression effect of anesthetic agents commonly used in MAC. Detection is aided by the use of pulse oximetry for the measurement of oxygenation; however, it is incapable of detecting changes in ventilation, and in the presence of supplemental oxygen, detection of hypoventilation may be delayed.[13] Hypoxemia leads to a compensatory increase in minute ventilation as the oxygen saturation measured by pulse oximetry (SpO_2) falls, and the patient may become agitated and progress to being unresponsive.[4] Hypercapnia occurs with excess CO_2 in body fluids and may be caused by respiratory depression or the inhalation of an atmosphere rich in CO_2. Carbon dioxide is a potent stimulator of increased respiratory rate and minute volume. Both hypoxia and hypercapnia may lead to tachycardia and hypertension[3,14] Hypercapnia is known to increase blood flow to the brain, leading to an increase in intracerebral pressure. A similar increase in blood flow to the eye may increase intraocular pressure. An editorial by Tempelhoff,[15] in response to a study by Lee et al,[16] discussed the complexity of the blood supply of the eye and its responsiveness to CO_2.

• ***Measurement.*** Measurement of $ETCO_2$ during administration of a general endotracheal anesthetic is easily accomplished by direct sampling capnometry of the closed system. Sampling of $ETCO_2$ of the spontaneously breathing patient during procedural sedation or MAC is complicated by many factors, including whether sampling is by nasal cannula or face mask, fresh gas flow (FGF), dilution by room air, dead space, water vapor, and nasal breathing vs mouth breathing.[17,18] Even the design of nasal cannulas can influence measurement. The most accurate design was found to be one that delivered oxygen via one naris and sampled $ETCO_2$ in the other naris.[17] A well-positioned nasal cannula can provide an $ETCO_2$ sample, if not diluted by room air or excessive oxygen flow, that can approximate $PaCO_2$.[17] Unfortunately, nasal cannulas for measurement of $ETCO_2$ are not standardized. Some deliver oxygen and sample CO_2 through a common channel, whereas others provide a cloud of oxygen by means of multiple orifices under the nose, potentially leading to a dilution of expired CO_2.[17] The advantage of $ETCO_2$ capnography is clinician analysis of the visual waveform, which allows for rapid detection of apnea or obstruction, but it is not a reliable predictor of hypoventilation.[19]

Spontaneously breathing patients may also be assessed by transcutaneous capnometry using a heated skin sensor to arterialize the capillary bed to measure CO_2 in tissue.[19] This technique may overestimate the $PaCO_2$, but it does correlate more closely than $ETCO_2$ levels obtained by nasal cannula in deeply sedated, spontaneously breathing patients. The disadvantages of transcutaneous monitoring are the time limitation imposed due to concerns of tissue damage from the heated probe, improper application of the probe, and the inability to detect apnea.

• ***Draping.*** Draping of ophthalmic surgical patients can vary widely and may include full body draping or surgical drapes covering only the head and upper torso.[5,20] Draping may be composed of several layers and materials, including cloth, paper, and plastic, with proximity to the face dictated by the preference of the surgeon for access to the surgical field. The permeability of draping material influences the accumulation of CO_2 and water vapor surrounding the patient.[5] Once the patient is draped, CO_2 accumulates in the draped space within 5 minutes, even with an FGF of 10 L/min insufflated under the drapes.[20] Failure to wash out the CO_2, either with a high FGF or suction, or a combination of both, leads to a rapid increase in CO_2 concentration under the drapes over 30 minutes.[7] The patient's physiologic response to increased CO_2 is an increase in respiratory rate and minute volume that does not decrease $PaCO_2$ until the drapes are removed.[5] In contrast, in a spontaneously breathing intubated patient, small increases in minute ventilation markedly decreased $ETCO_2$ compared with large increases in minute ventilation required to alter $ETCO_2$ in patients under MAC.[21]

Preventive Strategies

Practitioners have attacked the problem of high inspired CO_2 levels under drapes on 5 fronts. These include (1) supports to keep drapes away from the airway, (2) oxygen administration by nasal cannula, (3) dilution of the local atmosphere by insufflation of either oxygen or air, (4) suction under the drapes to encourage air exchange, and (5) a combination of strategies. Many commercial products have been developed, as evidenced by publications and results of a Google search for patent applications for drape support for ophthalmic surgery.[4,6,7,22]

• ***Drape Support.*** The function of a drape support is to prevent the drapes from coming into close proximity with the mouth and nose, and to enhance respiration and patient comfort while allowing the surgeon to have unimpeded access to the surgical field.[20] Supports may be as simple as an ether screen or a flexible arm connected to the stretcher or as complex as custom-made multipurpose hoops or arms with orifices that allow for insufflation of oxygen or application of suction to increase air circulation under the drapes and prevent the accumulation of CO_2.[3,7,20] The ideal support would allow easy airway access for the anesthesia provider, should an intervention be required, without disrupting the surgical field.

• ***Oxygen Insufflation.*** Oxygen administration by nasal cannula is the most common method of providing supplemental oxygen in ophthalmic surgery. Use of a nasal cannula with an FGF of 2 L/min of oxygen has been found to increase arterial oxygen saturation (SaO_2) and prevent hypoxia, but results regarding retention of CO_2 have been mixed.[3,6,20] Insufflation by other means include an anesthetic circuit with high FGF placed on the patient's chest under the drape and several drape holders that have been designed to permit oxygen flow through multiple orifices. These devices have required an FGF of 10 L/min or the addition of a suction apparatus to prevent increases in CO_2 levels.[3,4,7,20] The insufflation of oxygen under drapes increases the potential for an oxygen-enriched atmosphere that could support combustion with the use of electrocautery.[23]

• ***Air Insufflation.*** Insufflation with air from the end of an anesthesia circuit placed on the patient's chest under the drapes is another option that dilutes the accumulated CO_2 without increasing the fire risk. Insufflation requires a high FGF of 10 L/min, consistent with twice the minute volume ventilation of the patient, required to prevent accumulation of CO_2.[20] A novel approach to insufflation has been the use of a forced-air warming blanket placed between the drapes and the patient during cataract surgery lasting less than 30 minutes.[22] The airflow was sufficient to prevent accumulation of CO_2 under the surgical drapes. No increases were seen in transcutaneous CO_2 or $ETCO_2$ values, and respiratory rate, heart rate, and oxygen saturation were unchanged from baseline. A conclusion, not supported by data, was that sufficient airflow occurred to wash out CO_2 accumulation.[22]

• ***Suction.*** The use of suction alone under the drapes during ophthalmic surgery under MAC has been advocated as a means to prevent accumulation of carbon dioxide under the drapes.[24] The proposed mechanism of action would be to remove CO_2 and to circulate ambient air into the space under the drapes and decrease accumulated CO_2.[4,7,20,24] The anecdotal use of suction has persisted among anesthesia practitioners, but this is not specifically supported in the literature. Multiple authors have combined the use of suction with either oxygen or air insufflation to control the environment under the drapes. Suction and oxygen insufflation is most effective when applied immediately after completion of draping. Delaying the application of suction and oxygen results in an almost immediate rise in the temperature, humidity, concentration of CO_2, and reduction of oxygen under the drapes.[4,20,24] The level of suction suggested to be applied is 50 mm Hg, a level that should evacuate CO_2 but not cause an audible distraction.[24]

Current State of Practice

Capnography for $ETCO_2$ has been a standard of care for general anesthesia since the mid-1980s and was expanded

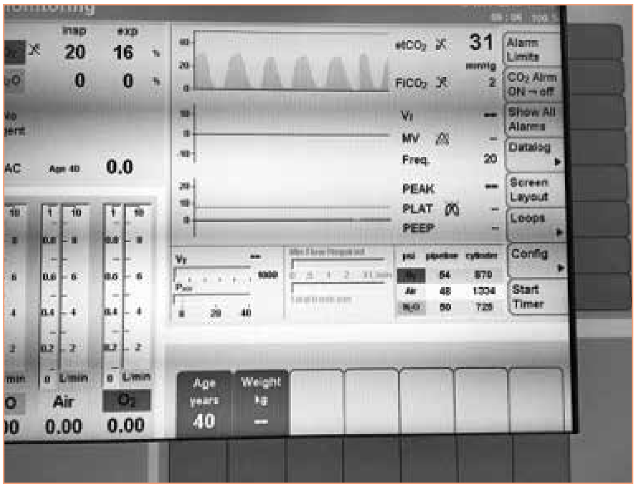

Figure 1. Draeger Apollo Ventilation Screen, Normal Capnograph, Oxygen by Cannula

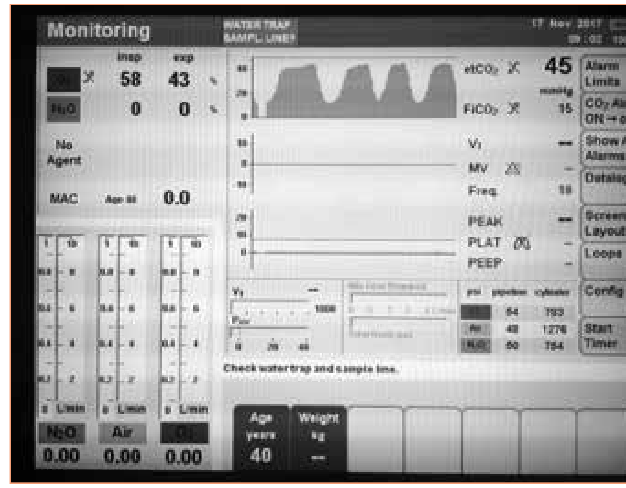

Figure 2. Draeger Apollo Ventilation Screen, High $FICO_2$ Capnograph, Oxygen by Cannula

Abbreviation: $FICO_2$, inspired concentration of carbon dioxide.

to include MAC in 2011. No major anesthesia professional organization has yet to include inspired CO_2 as a standard of care for MAC. Adverse events occurring under MAC now account for 10% of anesthesia liability claims. Specific to MAC, 38% of claims were the result of patient death.[8,17] Bhananker et al,[12] in an analysis of claims, revealed that a higher proportion of MAC claims filed involved patients who were older than 70 years of age and in poorer physical condition than did claims filed because of an adverse reaction to general anesthesia.[12] Typically patients under MAC are administered polypharmacy. Combinations of propofol, midazolam, and fentanyl can lead to blunting of the CO_2 response and respiratory depression, which was cited in 21% of claims. Pulse oximetry was used in 68% of these claims during 1990 to 2002 and was used in combination with $ETCO_2$ monitoring in 20% of the cases. Oversedation was responsible for death or permanent brain damage in 21 of 25 cases during this timeframe; care was judged substandard in 78% of cases, and 44% were deemed preventable with proper monitoring.[12] The American Society of Anesthesiologists standards require continuous monitoring of qualitative clinical signs of ventilation.[8] Pulse oximetry does not monitor ventilation but only oxygenation. Clinical signs of ventilation include capnography and continuous auscultation with a precordial stethoscope.[12] The precordial stethoscope was used widely by Cushing during cerebral surgeries, and references began to appear in anesthesia texts in the mid-1950s.[25] Placement over the trachea provides audible feedback of respiration or obstruction. The advent of pulse oximetry and capnography introduced a paradigm shift in anesthesia. By 1995 only 28% of practitioners were employing continuous auscultation.[26] It is difficult to assess the prevalence of student use of precordial stethoscopes, because the educational programs vary their requirement for use by case type. Most program directors support the use of precordial stethoscopes, but less than half require it for all cases. One survey reported an 8% mandatory use for MAC,[26] a sad commentary considering the rate of preventable respiratory events occurring with the use of MAC.

Capnography

Capnography for anesthesia today generally falls within 2 technologies: (1) Raman scattering, in which the sample gas is exposed to an argon laser for analysis, and (2) infrared, which is more common and less expensive.[18] A normal capnograph should exhibit a baseline starting at 0 with a sharp upstroke followed by a plateau and a rapid downslope that gives the wave a square appearance. Deviation from this classic appearance indicates an abnormality, including hyperventilation, hypoventilation, apnea, airway obstruction, or disconnection of the sampling line. Of particular interest to this review is an elevated baseline indicating the presence of retained CO_2 under the drapes or rebreathing of CO_2 by the patient.[18]

• ***Anesthesia Workstations.*** The current generation of anesthesia workstation, such as the Draeger Apollo (Draeger Inc), displays the respiratory rate, and inspired and expired CO_2 levels as part of the monitor function available for MAC. This real-time capnography and respiratory rate indication is clearly visible to the anesthesia provider (Figures 1 and 2). The vigilant anesthesia provider will see and address increases in the respiratory rate and inspired CO_2 levels with continual observation of both the patient and the monitor, improving patient safety and reducing the occurrence of preventable adverse events.[11,12]

• ***Nasal Cannulas.*** Manufacture of nasal cannulas for capnography has not been standardized. Accurate measurement is dependent on the positioning of sampling ports, positioning of oxygen delivery whether or not the patient is breathing through the nose, and FGF volume.[17] Current designs encompass several methods of delivery and sampling, including bifurcated designs that deliver oxygen and sample CO_2 in the same nasal prong, a multivented cloud delivery of oxygen with nasal prongs used to sample $ETCO_2$, and a cannula that uses one nasal prong for oxygen delivery and one prong for $ETCO_2$ measurement. The most accurate design across a wide range of FGF from 2 to 6 L/min is the design that delivers oxygen via one prong and samples $ETCO_2$ via a separate prong, minimizing the risk of erroneous $ETCO_2$ readings by FGF dilution of expired CO_2.[17]

• ***Another Paradigm Shift.*** Capnography in patients under MAC or deep procedural sedation is inherently inaccurate. It is dependent on multiple factors as diverse as the equipment used, FGF, and whether the patient is a mouth or nose breather.[17,21] Capnography is a poor indicator of changes in minute ventilation and may need to be supplemented by an impedance-based respiratory volume monitor as a direct measurement of minute ventilation. This is accomplished by placement of electrodes on the surface of the chest that detect electrical current conductivity through air in the lung and tissues. Anesthetic drugs administered during MAC may depress the respiratory drive to increased levels of CO_2 and blunt the normal response to increase the respiratory rate and volume. This would be detected earlier with a respiratory volume monitor than with capnography alone.[21]

Conclusion

High levels of inspired CO_2 under drapes during ophthalmic surgery performed under MAC have received scant mention in US medical journals, and this topic was primarily of interest in European literature in the 1990s and early 2000s. Approximately 97% of cataract surgery is performed using a local anesthetic technique, typically in older, more fragile patients, many of whom receive sedation with polypharmacy that can lead to respiratory depression. Nearly half of the cases of permanent disability or death occurring under MAC between 1990 and 2002 did not meet the standard of care for monitoring, even when they employed the required monitors. Multiple interventions have been discussed concerning high flow insufflation, supplemental oxygen, and the use of suction to evacuate gases retained under the drapes. None has been adopted as a standard of care. Monitoring of $FICO_2$ during MAC has not been addressed by professional anesthesia societies. Given the advances in capnography and the visibility of displays built into anesthesia workstations, $FICO_2$ during MAC has been ignored in the literature and professional organizations monitoring standards. It seems that this would be an ideal time to integrate the auscultation of our past, the capnography of the present, and the impedance-based respiratory volume monitoring of the future to prevent adverse respiratory events. Inspired CO_2 under MAC should be considered an area of future anesthesia research to improve patient safety. Research should include multiple variables including draping, positioning, control of the microenvironment surrounding the patient, and optimal monitoring requirements. This would be a challenging project for students and educators with interests in anesthesia and ophthalmology.

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AUTHOR

Thomas A. McHugh, MN, CRNA, is a graduate of Berkshire Medical Center School of Nurse Anesthesia. He wrote this article while a student in the generalist Master of Nursing program at Athabasca University, Athabasca, Alberta, Canada. He is currently employed as a staff CRNA at the John Cochran Veterans Affairs Medical Center, St Louis, Missouri.

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