Reducing the Incidence of Surgical Fires: Supplying Nasal Cannulae with sub-100% O_2 Gas Mixtures from Anesthesia Machines

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In June 2003, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) recommended: "As a general policy, use air or FIO_2 at ≤30% for open delivery (consistent with patient needs)" to prevent surgical fires. One way to interpret JCAHO's recommendation is that 100% O_2 should not be indiscriminately used, and anesthesia providers should have the ability, consistent with patient needs and their clinical judgment, to deliver sub-100% O_2 with nasal cannulae. An auxiliary O_2 flowmeter has a barbed outlet connector that offers a convenient means to connect a cannula to an anesthesia machine and is routinely used for open delivery of 100% O_2. The auxiliary O_2 flowmeter provides only 100% O_2 and thus does not allow titration of the O_2 concentration to patient needs and may increase the risk of surgical fires. This report clarifies the JCAHO recommendation and describes different means of addressing it that are based primarily on using the anesthesia machine to blend a sub-100% O_2 gas mixture and delivering it via a nasal cannula. The options presented depend on the model and manufacturer of the anesthesia machine and allow delivery via nasal cannula of O_2 concentrations that range from 21% to 100%.

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Surgical fires are largely preventable incidents that continue to occur (1). Reasons for fires may include, among others, lack of individual and team training, equipment design, human factors, poor communication among care team members, and culture. Reduction of the risk of surgical fires is also one of the Joint Commission on Accreditation of Healthcare Organizations' (JCAHO) 2005 Ambulatory Care National Patient Safety Goals: "Educate staff, including operating licensed independent practitioners and anesthesia providers, on how to control heat sources and manage fuels, and establish guidelines to minimize O_2 concentration under drapes."[1]

An oxidizer, a fuel, and an ignition source, the so-called "fire triangle," must all be present for a fire to occur. For example, plastic, cloth, or paper drapes, and alcohol-based preparation solutions can serve as fuel (2) and cautery, lasers, or endoscopes as ignition sources (3). The auxiliary ball-in-tube O_2 flowmeter mounted on many North American anesthesia machines delivers pure O_2 (Table 1 and Table 2). It is often used to supply nasal cannulae with pure O_2 during procedures performed under sedation or monitored anesthesia care and thus may provide the oxidizer of the fire triangle, especially in situations in which the supplemental O_2 is not quickly dissipated.

In a June, 2003 Sentinel Event Alert, the JCAHO recommended that health care organizations help prevent surgical fires by establishing guidelines for minimizing O_2 concentration under surgical drapes.[2] The Sentinel Event Alert quoted the ECRI (a nonprofit health services research agency): "**As a general policy**, use air or FIO_2 at ≤30% for open delivery," and added "(**consistent with patient needs**)" to the end of the

[1] JCAHO 2005 patient safety goals for ambulatory and office-based surgery (promulgated in July, 2005): http://www.jcaho.org/accredited+organizations/patient+safety/05+npsg/05_npsg_amb.htm.

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[2] Joint Commission on Accreditation of Healthcare Organizations Sentinel Event Alert. Preventing surgical fires. Issue 29, June 24, 2003. http://www.jcaho.org/about+us/news+letters/sentinel+event+alert/sea_29.htm.

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Table 1. Common Gas Outlet Characteristics in Datex-Ohmeda/GE Anesthesia Machines on the North American Market

Anesthesia machine model	Auxiliary ball-in-tube O_2 flowmeter delivers 100% O_2	Available with air flowmeter?	FGF hose readily disconnected/reconnected from CGO by clinician?	CGO accepts a 15-mm OD connector, e.g., a 5.0-mm endotracheal tube connector?	Manufacturer recommends against connection of nasal cannula to CGO?	Auxiliary CGO available?	Auxiliary CGO accepts a 15-mm OD connector, e.g., an endotracheal tube connector?	Manufacturer recommends against connection of nasal cannula to auxiliary CGO?
Modulus I	Yes	Optional	Yes	Yes	No	No	N/A	N/A
Modulus II	Yes	Optional	Yes	Yes	No	No	N/A	N/A
Modulus CD	Yes	Optional	Yes	Yes	No	No	N/A	N/A
Modulus CD-CV	Yes	Optional	Yes	Yes	No	No	N/A	N/A
Excel	Yes	Optional	Yes	Yes	No	No	N/A	N/A
Aestiva	Yes	Optional	No	N/A	N/A	Optional	Yes	No
ADU	Yes	Optional	Yes	Yes	No	Yes	Yes	No
Aespire	Yes	Optional	No	N/A	N/A	Yes	Yes	No
Avance	Yes (non-color specific)	Standard	No	Inspiratory port (configurable as "CGO") accepts 15-mm OD connector	N/A	Optional (separate outlet)	Yes	No

Data courtesy of Datex-Ohmeda.
FGF = fresh gas flow; CGO = common gas outlet; OD = outside diameter.

Table 2. Common Gas Outlet Characteristics in Dräger Anesthesia Machines on the North American Market

Anesthesia machine model	Auxiliary ball-in-tube O_2 flowmeter delivers 100% O_2?	Available with air flowmeter?	FGF hose readily disconnected/reconnected from CGO by clinician?	CGO accepts a 15-mm OD connector, e.g., a 5.0-mm endotracheal tube connector?	Manufacturer recommends against connection of nasal cannula to CGO?	Auxiliary CGO available?
Narkomed 2B	Yes (optional)	Optional	Yes	Yes	Undetermined	No
Narkomed 3	Yes (optional)	Optional	Yes	Yes	Undetermined	No
Narkomed 4	Yes (optional)	Optional	Yes	Yes	Undetermined	No
Narkomed Mobile	Yes	Standard	Yes	Yes	Undetermined	No
Narkomed GS	Yes (optional)	Optional	Yes	Yes	Undetermined	No
Narkomed 6000 series	Yes	Standard	No	N/A	N/A	No
Fabius GS	Yes (optional)	Standard	Standard, no; optional CGO, yes	Standard, N/A; optional CGO, yes	Standard, N/A; optional CGO, undetermined	No
Fabius Tiro	Yes (optional)	Standard	No	N/A	N/A	No
Julian	Yes	Standard	No	N/A	N/A	No
Narkomed MRI	Yes	Standard	Yes	Yes	Undetermined	No

Data courtesy of Dräger Medical Inc.
FGF = fresh gas flow; CGO = common gas outlet; OD = outside diameter.

ECRI guideline[3] (bold added by authors for emphasis).

The current practice of *routinely* supplying nasal cannulae with 100% O_2, which does not comply with the JCAHO/ECRI recommendations, is reinforced by the ease of connecting nasal cannulae to the barbed outlet of the auxiliary ball-in-tube O_2 flowmeter. Large O_2 concentrations and/or flow rates of O_2-enriched gas delivered by cannula may create a localized, O_2-rich environment that promotes surgical fires (Fig. 1, bottom) when combined with an ignition source and combustible material. ECRI reports that there are about 100 surgical fires annually, resulting in up to 20 serious injuries and 1 or 2 deaths (4).

The JCAHO/ECRI recommendations are especially relevant if drapes prevent dissipation of pure O_2 and cautery (electro- or thermal) and lasers are used in or near the O_2-rich region, usually around the head or neck. Furthermore, the user's guide for electrosurgery units *explicitly* warns against O_2 accumulation or pooling under surgical drapes or within the area where electrosurgery is performed.[4]

Addressing the JCAHO/ECRI recommendations poses challenges in terms of altering clinical practice, ensuring safe clinical care for patients requiring supplemental O_2, equipment, and added cost. The variety of designs and configurations of anesthesia machines (Tables 1 and 2) and individual clinical practices and

[3] ECRI: "Only You Can Prevent Surgical Fires" Poster, July, 2004 at http://www.mdsr.ecri.org/static/surgical_fire_poster.pdf.

[4] Valleylab, Force FX-C electrosurgical generator user's guide. 1999.

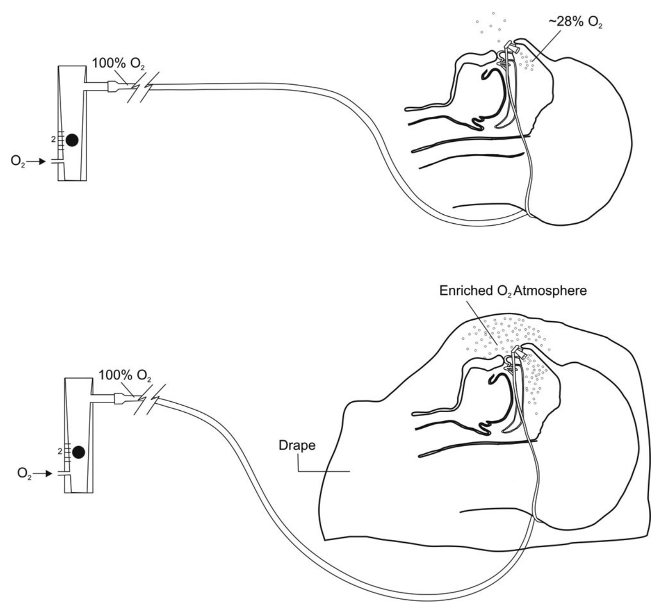

Figure 1. The top figure depicts the rule of thumb that 2 L/min pure O_2 delivered via nasal cannula results in an FIO_2 of about 28%. The excess O_2 can dissipate into ambient air and is diluted. In the bottom schematic, the patient is draped for eye surgery. Excess O_2 may become trapped below the drape where an enriched O_2 environment increases the risk of a surgical fire. Even though the patient's effective inspired O_2 approximates only 28%, because 100% O_2 exits the nasal cannula, there is a region of indeterminate size and location where 100% O_2 is present.

preferences compound these challenges. This report is based partly on the experience gained by our academic department in examining various alternatives that address the recent JCAHO/ECRI recommendations. This report is not about denying supplemental O_2 to a patient where there is a need. It is about providing equipment and practice recommendations that help prevent surgical fires during routine procedures.

Analysis

Figure 2 describes various alternatives for addressing the JCAHO/ECRI recommendations of generally using a fraction of delivered O_2 (F_DO_2) $\leq$30%, depending on the individual anesthesia machine configuration and the clinical logistics.

Anesthesia Machine with Air Flowmeter

Anesthesia machines with an air flowmeter can blend a sub-100% O_2 mixture in air and deliver it to the common gas outlet (CGO) and, if present, also the auxiliary CGO (ACGO). A nasal cannula can be mated via a 5-mm endotracheal tube connector to a CGO, a Y-piece (via the CGO) or, if present, an ACGO. A gas sampling connector can be inserted in series with the

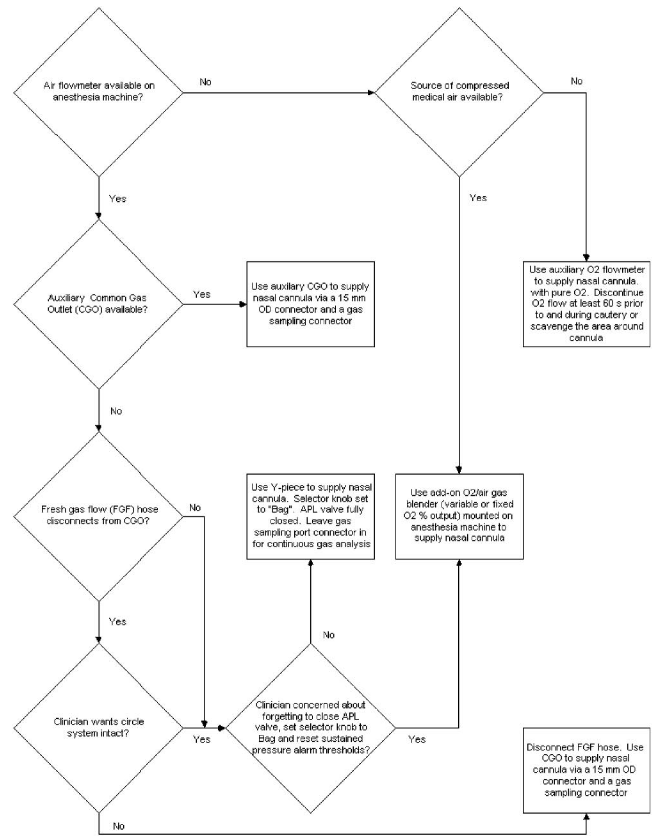

Figure 2. An algorithm to select means to deliver sub-100% O_2 to open delivery systems such as nasal cannulae and face masks.

endotracheal tube connector (~5 mm) to allow analysis of the gas composition actually delivered to the cannula (Fig. 3). To obtain an F_DO_2 $\leq$30%, use O_2-to-air ratios $\leq$1:7, e.g.: (0.5 L/min O_2:3.5 L/min air) or (1 L/min O_2:7 L/min air). In newer machines with an ACGO, the blended gas mixture issuing from the bank of flowmeters can be instantly rerouted to either the CGO or the ACGO, by simply flipping a selector lever. To make use of this feature, anesthesia providers must first be made aware of the presence and capability of the ACGO and reminded of the need to flip the selector lever to redirect the fresh gas flow (FGF) as intended.

A simple approach, which does not require a nasal cannula and works with all anesthesia machines with air flowmeters, uses a corrugated hose breathing circuit to deliver an F_DO_2 $\leq$30% gas mixture (e.g., 1 L/min O_2 and 7 L/min air) directly from a Y-piece placed close to the patient's nose. High FGFs have the advantages of washing away exhaled CO_2 from under the drapes, preventing CO_2 rebreathing, and producing a breeze on the face that reduces the claustrophobic sense of asphyxiation. If an O_2 analyzer is available, we recommend that the gas sampling connector be left on the Y-piece so that F_DO_2 can be continuously monitored.

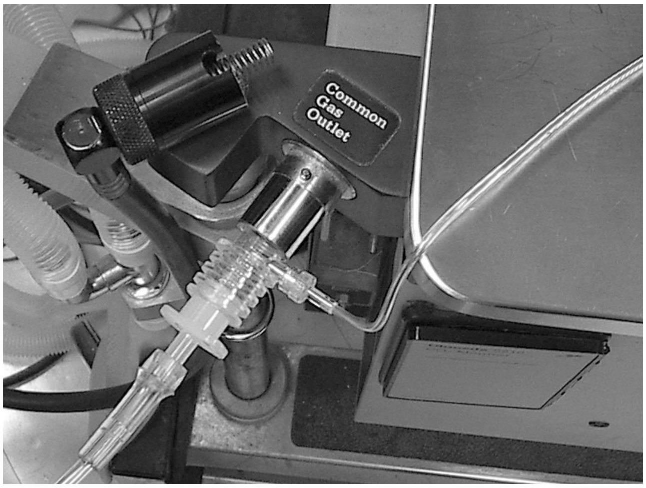

Figure 3. A nasal cannula mated to a common gas outlet via a 5-mm endotracheal tube connector and a gas sampling connector with a gas sampling line attached.

A variation is to connect a nasal cannula to the Y-piece of a standard circle breathing circuit with a 5-mm endotracheal tube connector and supply it with an F_DO_2 ≤30% gas blend from the flowmeter bank (5). The selector knob must be set to "Bag" and the adjustable pressure limiting (APL) valve *fully* closed. The airway pressure gauge needle will indicate a constant pressure in the 20- to 25-cm H_2O range, depending on the machine design. The reservoir bag will fill and can act as a visual indicator of the patency of the delivery circuit. If the selector knob is set to "Ventilator," the threshold (nominally 3 cm H_2O) on the ventilator pressure relief valve in an upright bellows ventilator will allow most of the FGF to exit to the scavenging system rather than flow to the nasal cannula. The same would be true of an open or partially open APL valve with the selector knob set to "Bag." Importantly, if a connector (such as the standard elbow connector) incorporating a gas sampling port is left interposed between the Y-piece and cannula, monitoring of the delivered gas composition becomes possible and practical. This provides convenient verification at all times that F_DO_2 ≤30% (a high O_2 alarm set at 30% will warn when F_DO_2 is >30%). F_DO_2 monitoring will also detect disconnection of a nasal cannula from its source if the low F_DO_2 alarm is set to 22% because F_DO_2 will decrease to 21% (ambient air O_2) during a disconnection. Gas analysis will also confirm that the gas issuing from the O_2 supply is actually O_2 and warn against gas mix-ups. Slow O_2 analyzers that are part of the CO_2 absorber in some designs monitor F_DO_2 whenever the breathing circuit or Y-piece is used to channel gas to the patient but not when the CGO or ACGO is used to supply nasal cannulae.

We tested the nasal cannula-at-Y-piece-method with 5 anesthesia machine designs available in our laboratory: Modulus I and II, Aestiva, Avance (GE Healthcare, Madison, WI), and the Fabius GS (Drager Medical, Telford, PA). We set the total FGF at 4 L/min, the threshold above which patient discomfort might occur. All machines were able to deliver 30% O_2 in air, with some adjustment of the flowmeters from the nominal 1:7 O_2/air ratio required. The machines differed in whether sustained airway pressure alarms were generated and could be eliminated by increasing the high pressure (Pmax) limit (Table 3). For the Modulus II, Aestiva, and Avance, the high limit for *sustained* pressure is half the high limit for Pmax. Flows >4 L/min or an O_2 flush through a nasal cannula connected to the Y-piece generated high pressures and alarms. Depressurization of the circuit by temporarily opening the APL valve removed the alarm condition.

In those machines in which the FGF hose can be readily disconnected from the CGO (e.g., Modulus, Excel, and Narkomed product lines), a nasal cannula can be supplied from the CGO. Some anesthesia providers, out of concerns for safety, insist on always having the circle system fully assembled and ready for use in the event complications arise and object to tying up the CGO or Y-piece to supply a nasal cannula, even when the circle system is not in use. In that case, supplying the nasal cannula from an ACGO (if available) meets the requirements for an intact circle system available at the flip of a selector lever.

When the O_2 flush button is pressed, pure O_2 is delivered to the CGO or ACGO at approximately 60 L/min, bypassing the flowmeter bank and overriding the flowmeter, i.e., F_DO_2 settings. When a nasal cannula is connected to and supplied from the CGO, ACGO, or Y-piece, clinicians must be aware that an ill-advised O_2 flush in the presence of an ignition source could initiate a surgical fire. Conversely, the O_2 flush function provides a convenient means, when clinically indicated, of temporarily and quickly increasing F_{IO_2} during periods when it is safe to do so (e.g., when there are no obvious ignition sources present or anticipated in the next minute).

Anesthesia Machine Without Air Flowmeter

In O_2/N_2O machines, including those in dental offices, N_2O should not be used as the balance gas when supplying nasal cannulae with F_DO_2 ≤30% because (a) as a result of its nature, it may provide unintended analgesia or loss of consciousness, (b) it will contaminate the room because scavenging in this application is not sufficiently reliable, and, most importantly, (c) N_2O, similar to O_2, is an oxidizer and supports combustion. Heliox can be used in machines with a heliox flowmeter. Generally, heliox is a 30% O_2/70% helium mixture but users should note that heliox may be more

Table 3. Sustained Pressure Alarms and Deactivation with Different Anesthesia Machines

Anesthesia machine design	Sustained pressure at 4 L/min flow through nasal cannula at Y-piece (cm H_2O)	Sustained pressure alarm triggered at default Pmax setting of 40 cm H_2O?	Sustained pressure alarm deactivated by adjusting pressure limits?
Modulus I/7000	20	No	N/A
Modulus II/7800	20	No (yes at FGFs > 4 L/min)	Yes (set Pmax > twice sustained pressure)
Aestiva	25	Yes	Yes (set Pmax > twice sustained pressure)
Avance	21	Yes	Yes (set Pmax > twice sustained pressure)
Fabius GS	21	Yes	No

FGF = fresh gas flow.

expensive and that heliox is supplied in different mixes such as 25% and 40% O_2.

Source of Compressed Medical Air Available

In anesthesia machines without an air flowmeter, an option is an add-on air/O_2 gas blender (disadvantages: added expense, plumbing, mounting hardware, and clutter).

Source of Compressed Medical Air Unavailable

An option is to use 100% O_2 from the auxiliary O_2 flowmeter and discontinue O_2 supplementation for at least 60 s before and during cautery use, or empirically scavenge in the region of the head and neck.

Discussion

This technical report considers primarily the equipment aspects of addressing the JCAHO/ECRI recommendations and only touches briefly on the oxygenation consequences of F_DO_2 ≤30% by nasal cannula. The JCAHO/ECRI recommendations have not been accepted by all clinicians. Some may have missed the qualifying phrases: "as a general policy" and "consistent with patient needs." Others question the merit of F_DO_2 30% against simply breathing room air as a general policy, especially at low flows that would result in ambient air entrainment and dilution to an effective F_IO_2 <30%. Our interpretation is that it is not the intent of the JCAHO Sentinel Event alert to prevent using an F_DO_2 >30% in patients in whom there is a need, but rather to avoid *routinely* using a higher F_DO_2 as has been customary practice. In patients who need a higher F_IO_2, simply making the surgeon aware and limiting, or even avoiding, cautery use and gas scavenging in the area of the drapes are all strategies to reduce the likelihood of a surgical fire. We wrote this report while keeping in mind that clinicians should be able to set the F_DO_2 at any value between 21% and 100%, if clinically indicated or if subsequent clinical and flammability studies suggest a different F_DO_2 threshold. At the time of writing, we are not aware of any clinical study of the JCAHO/ECRI recommendations. Although JCAHO does not apply the 2005 goals to the accreditation process for nonambulatory care facilities, such as acute care hospitals, it does not remove the need for these facilities and their practitioners to be proactive in surgical fire prevention.

The JCAHO recommendations in the 2003 Sentinel Event Alert used the term, "F_IO_2," the abbreviation for inspired fraction of O_2. In open systems, F_IO_2 is unknown because (a) O_2 is usually not monitored with open systems such as nasal cannulae, and (b) patients can always entrain ambient air in an open system so that the actual F_IO_2 is typically less than the delivered O_2 fraction. A heuristic rule states that F_IO_2 increases by 4% from a baseline of 20% O_2 in ambient air for every liter of pure O_2 flowing through a nasal cannula (6). That is, 1 L/min of 100% O_2 flowing out of the cannula after being diluted by entrained ambient air results in an approximate inspired F_IO_2 of 0.24, 2 L/min O_2 = F_IO_2 0.28, 3 L/min O_2 = F_IO_2 0.32 (see Fig. 1, top). Thus, the JCAHO recommendations could be misconstrued as recommending pure O_2 flows ≤2.5 L/min as a general policy. When contacted, ECRI confirmed that it meant the delivered fraction of O_2 and, thus, it is more appropriate to use F_DO_2 rather than F_IO_2.[5] The 2005 National Patient Safety goals do not mention the F_IO_2 details that were contained in the 2003 JCAHO Sentinel Event. However, the thrust of this report is very much on point related to the goals wherein the report's recommendations help meet the 2005 goal to "establish guidelines to minimize O_2 concentration under drapes."

The term "O_2 cannula" is used interchangeably with "nasal cannula" in medicine in general, subconsciously reinforcing the practice of using 100% O_2 with

[5] Personal communication by telephone, Al de Richemond, ECRI, March 19, 2004.

nasal cannulae. Words often carry both an explicit and implicit meaning that can subtly influence our actions, and terminology is an intrinsic part of medical culture. Patient safety efforts are beginning to focus on promoting a culture of safety, and simple actions, such as encouraging the use of "nasal cannula" and discouraging the use of "O_2 cannula" are examples of the small steps we can begin to take to improve patient safety.

The JCAHO recommendations specify "F_{IO_2}" but are not forthcoming on the flow rate of O_2. Anecdotal evidence seems to indicate that, in undraped patients, no surgical fires occur at flow rates of <2 L/min O_2. Rate of inflow of O_2 may be as important as O_2 concentration because it may be that it is the total amount of O_2 available that matters. Further investigation of the effect of total flow of O_2 on surgical fires is needed. When using the air and O_2 flowmeters to supply nasal cannulae, F_DO_2 can be titrated to patient need according to Sp_{O_2} while maintaining FGF at 4 L/min to minimize patient discomfort or, when needed, high flow rates of pure O_2 can also be delivered.

The added flow resistance from the length and narrow bore of nasal cannulae will generate back pressure as indicated by the dipping of the O_2 and air flowmeter bobbins when a nasal cannula is connected to the CGO, Y-piece, or ACGO—a phenomenon not observed when connecting a FGF hose to a common gas outlet. This observation raised justifiable concerns that the added flow resistance of nasal cannulae may affect the accuracy of the anesthesia machine flowmeters. When contacted, Datex-Ohmeda indicated that it does not have recommendations against connecting a nasal cannula to a CGO or ACGO (Table 1), and Dräger Medical Inc. stated that it does not make any recommendation regarding the use of the CGO for the supply of a nasal cannula. We conducted experiments indicating that back pressure generated by a nasal cannula connected to the CGO or ACGO affects the O_2 and air flowmeters similarly, resulting in no net effect in the Modulus I, II, and Aestiva anesthesia machines (7).

Gas composition is not always monitored during supplemental O_2 provided via open delivery systems, as was the case during the January, 2002 fatalities in New Haven where N_2O was inadvertently substituted for O_2 (8). Connecting a standard nasal cannula to an anesthesia machine with the gas sampling connector left in provides a quick and convenient way to monitor delivered gas composition, a capability unavailable until now with O_2 supplementation via standard nasal cannulae (not the newer type that allows gas monitoring).

Other approaches to reducing surgical fires that address the two other legs (fuel, ignition) of the fire triangle have been recommended by JCAHO.[2] In general, removal of the fuel component (drapes, nonflammable lubricants, soaking with saline, different drape materials, etc.) is the responsibility of the prep nurses, whereas the ignition source (cautery, scopes, etc.) is usually under the control of the surgical staff. Anesthesia providers are generally recognized to be in control of the third leg of the fire triangle, the oxidizer component. This report, written for anesthesia providers, focuses on actions under their direct control. Redundancy is an established principle in designing a safety system. A multidisciplinary team effort will result in a triply redundant safety system that reduces the occurrence of surgical fires.

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