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Safety in the use of compressed air versus oxygen for the ophthalmic patient

Oxygen, routinely administered during surgery to avoid hypoxia, poses risks including increased likelihood of surgical room fires and predisposition to retinal phototoxicity in patients. Compressed air to supplement ventilation may be safer than oxygen. The purpose of this study was to determine whether hypoxia occurs more frequently when compressed air replaces supplemental oxygen during ophthalmic surgery.

A convenience sample of 111 patients was randomly assigned to receive supplemental oxygen (group 1) or compressed air (group 2). Patients with serious cardiac or pulmonary disease were excluded. Blood oxygen levels were monitored during surgery by pulse oximetry. Oxygen was administered to all group 2 patients whose oxygen saturation fell to less than 90% or by more than 5% below baseline.

No differences were observed between groups in age, ASA classification, type of surgery, or anesthetic drugs or doses. Minor, but statistically higher oxygen values were observed in group 1. The frequency with which oxygen saturation decreased below 90% or below 5% of baseline was similar in both groups.

Supplemental oxygen is not required routinely in selected patients undergoing ophthalmic surgery. By using compressed air, the risk of operating room fires and retinal phototoxicity may be reduced.

Key words: **Cataract extraction, compressed air, oxygen, operating room fire, photosensitivity,**

Oxygen is used routinely during surgery to prevent hypoxia that may result from respiratory depression or airway obstruction. However, supplemental oxygen has hazards. Oxygen is a crucial ingredient in most operating room fires and also may predispose ophthalmic patients to photochemical retinal toxicity.[1-3] It was the intent of this study to determine whether compressed air could be administered safely to surgical patients in place of oxygen.

The incidence of operating room fires is difficult to determine accurately due to underreporting on both a local and national basis.[4] Between 1985 and 1994, an annual average of 43 fires occurring in surgical facilities throughout the United States was reported to US fire departments. Operating room fires approximate 1% of all hospital fires (K.D. Rohr, National Fire Protection Association, personal communication, March 26, 1998).

The first necessary ingredient for an operating room fire to occur is a source of heat. Numerous heat sources exist in the operating room. Electrocautery devices have been identified as the most common heat source relating to operating room fires.[3,5] Of 36 operating room fires reported between 1959 and 1974, 19 (53%) were attributed to the use of electrocautery.[6] Reyes et al[7] determined the minimum conditions necessary for combustion to occur when electrosurgical units are used near oxygen. These included an oxygen flow rate of 2 L/min, a coagulation level of 30 W, and a minimum distance of 5 cm directly in front of the oxygen source or within 2 cm on each side of the midline of the face.[7]

The second ingredient necessary to produce an operating room fire is an oxidizing substance.[4] In virtually all cases, the substance reported during surgery is oxygen. Oxygen-enriched atmospheres also predispose to more serious fires than those occurring in air.[3] Oxygen supplementation and oxygen pooling have an integral role in causing operating room fires. An oxygen-enriched environment is defined by the National Fire Protection Association as an atmospheric oxygen concentration of greater than 23.5%.[8] This results when drapes are placed over an oxygen delivery source without appropriate circulation.[4] Greco et al[8] measured the oxygen content in the operative field and beneath surgical drapes under conditions simulating routine facial surgery. They reported that oxygen concentrations beneath operative drapes increased with the level of oxygen delivered. Oxygen pooling began within 60 seconds following the administration of supplemental oxygen at 3 L/min.

The risk of an oxygen-related fire in the operating room is of special concern during ophthalmic surgery.[9-12] Of 15 operating room fires reported in a retrospective review by Neatrour and Lederman,[6] 4 occurred during cataract extractions. Draping of the head and neck during ophthalmic surgery especially predisposes to oxygen pooling. In addition, electrical instrumentation is used, such as ophthalmic microscopy that can act as a heat source. Finally, the face and head are especially tragic locations for fires to erupt in the operative field.

Administering oxygen during ophthalmic surgery may decrease the threshold for photochemical retinal damage.[13-15] Free radicals capable of tissue injury are produced through a process called photosensitization when

oxygen and light interact. Photosensitive retinopathy requires 3 factors—oxygen, light, and a photosensitizer.[15] Each of these factors is commonly present in the operating room during ophthalmic surgery. The production of free radicals, such as singlet oxygen, lipid peroxide, and hydroperoxide, correlates strongly with the surrounding concentration of oxygen.[16] Since the retina is rich in oxygen, it is a perfect milieu for photo-oxidative damage when exposed to high levels of focused light.

The damaging effects of light on the retina were first discussed by Calkins and Hochheimer.[1] They reported that the use of operating microscopes, which are up to 10 times brighter than ophthalmoscopes, may result in retinal damage. Parver et al[2] were among the first to document retinal histologic changes following exposure to unfiltered light emitted from an operating microscope. In a subsequent study, cynomolgus monkeys exposed to light developed foveomacular changes.[17] Jaffe et al[15] reported that rhesus monkeys exposed to light using an operating microscope developed phototoxic lesions in one eye that were 2.9 times larger, had more extensive histologic damage, and took longer to heal when exposed to light under conditions of 99% F_{IO_2} than the eye that was exposed to light under 21% oxygen. The results of the study by Jaffe et al[15] were similar to those of Ham and Mueller,[17] who found that oxygen exposure resulted in severe damage to the retina with focal swelling and depigmentation. In humans, Khwarg et al[14] identified retinopathy in 7.4% of patients undergoing cataract surgery during a retrospective study of 135 consecutive cases.

Since oxygen may contribute to the risk of fire and retinal injury, it may be desirable to reduce the use of supplemental oxygen during surgery on a routine basis. The conventional hemoglobin-oxygen saturation curve dictates that when oxygen saturation exceeds 90%, arterial blood oxygen tension exceeds 80 to 100 mm Hg. Thus, carefully performed pulse oximetry during ophthalmic surgery should safeguard against hypoxia.

Several investigators have reported that using compressed air during surgery can be safe.[6,18] Greco et al,[8] in a study conducted with 12 healthy volunteers, simply flushed the air beneath the surgical drapes with compressed fresh air and found a 14.9% reduction in oxygen pooling. A bolder recommendation was made by Neatrour and Lederman,[6] who concluded that ventilating surgical patients with compressed air was safe and effective. A prospective clinical study was conducted involving 100 medically healthy patients undergoing cataract surgery. Half received supplemental compressed air, and half were administered nasal oxygen with flow rates from 3 to 4 L/min. A small, statistically significant reduction in oxygen saturation was observed in the group in whom supplemental oxygen was withheld. However, the difference was not considered clinically relevant and was less than their 3% measurement error. In their study, 14% of patients were excluded due to a history of pulmonary disease, although the extent of pulmonary disease was not defined.[6]

Based on the relative risks of oxygen use in the operating arena and preliminary confirmation from others that supplemental oxygen can be safely withheld during routine anesthesia in selected patient populations, a randomized study was conducted to document the safety of substituting compressed air for oxygen during ophthalmic operations.

Materials and methods

An experimental, randomly assigned design was used to compare the safety of supplementing patients with compressed air or with supplemental oxygen during ophthalmic surgery. This study was conducted in the surgical division of a 929-bed acute tertiary care teaching hospital. The institution admits approximately 50,000 inpatients annually. Operating rooms are staffed with physician anesthesiologists and Certified Registered Nurse Anesthetists. In 1997, 2,653 patients underwent ophthalmic surgery, and 5,036 ophthalmic procedures were performed. Most cases in this study were performed in an independent surgical suite separate from the main operating rooms, which specializes in ophthalmic and plastic surgery. In 1997, 4,104 cases were performed in the suite. Data were collected after approval was obtained from the institutional review board, the nursing research committee, and the human investigations committee at the affiliated university and institution of study. A power analysis was performed with a sample size result of N = 110 (beta .19, medium effect size, power of 0.807, at an alpha of .05).

The principal investigator approached consecutive patients undergoing ophthalmic surgery under regional anesthesia during the timeframe of June through August 1998. Charts were reviewed, and subjects were interviewed to identify exclusion criteria. Subjects who met the criteria were informed of the study purpose. Those willing to provide written informed consent constituted the sample for the study. Subjects were randomized by the selection of 1 of 2 concealed cards selected before surgery. One card indicated that the patient was to be ventilated with compressed air, while the other card indicated that

supplemental oxygen was to be used. The subjects given oxygen were designated as the control group (group 1). Subjects in whom compressed air was used intraoperatively were designated as the intervention group (group 2). No attempt was made to control any other component of anesthesia at any time. Either oxygen or compressed air was begun on arrival into the operating room. In group 1, oxygen was administered via a Hudson hood at 10 L/min. In group 2, compressed air was administered also by a Hudson hood at 10 L/min. Oxygen was supplemented in both groups as necessary if oxygen saturation fell by more than 5% below the patient's baseline value or when any oxygen saturation fell below 90%.

The following data were obtained for each subject: age, ASA classification, ophthalmic diagnosis, preoperative sedative drugs and doses, room air pulse oximetry reading, regional anesthetic used, and drugs and doses used for intraoperative anesthesia. Oxygen saturation was obtained and recorded while the patient was in the preoperative area to assess each patient's baseline value while breathing room air. Oxygen saturation was again recorded on admission to the operating room, after securing the surgical drapes, and immediately before leaving the operating room. During surgery, oxygen and/or compressed air flow rates, vital signs, length of anesthesia, and the reason for oxygen use were documented. The subjects undergoing ophthalmic surgery met the following criteria: willingness to provide informed consent; older than 18 years; ASA class I, II, or III; a hemoglobin exceeding 100 g/L; a baseline preoperative room air pulse oximetry reading of more than 90%; and intention of the anesthesia provider to perform regional retrobulbar or peribulbar block.

Patients were excluded from the study who exhibited or had a history of severe cardiac disease within the past year, defined as a known hospitalization or physician visit during which a cardiac diagnosis was identified and a New York Heart Association classification of class III or IV was assigned. Also excluded were those with pulmonary disease within the past year, defined as a known hospitalization or physician visit during which a pulmonary diagnosis was identified including chronic obstructive pulmonary disease, asthma, or pulmonary fibrosis.

Pulse oximetry is a process of measuring oxygen saturation using an absorption measurement technique. Oxygen saturation was measured using the Sa_{O_2}/Plethysmography Module M1020A parameter unit (Hewlett Packard, Palo Alto, Calif). The unit measures oxygen saturation with an accuracy of ± 1.5% when the saturation exceeds 80%. The accuracy is ± 2.5% for a saturation below 80%. Reliability of the pulse oximeter is verified on an annual basis to ± 1%.

All continuous variables were expressed as a mean ± SD. Inferential analysis of single variables was made using a parametric, 2-tailed *t* test. Chi-square analysis was used to compare frequency distributions between the groups. No attempt was made to control for potential deviations from the normal distribution. Statistical significance was defined as a *P* value less than .05. The research hypothesis was that ASA classification I, II, or III patients undergoing regional anesthesia with retrobulbar or peribulbar block and intravenous sedation would maintain an oxygen saturation greater than 90% when receiving compressed air compared with those receiving supplemental oxygen.

Results

Of 122 patients approached to participate in the study, 7 chose not to participate and 4 patients were excluded. Of the 4 patients excluded, 2 patients had a history of asthma, 1 had emphysema, and 1 had angina. The remaining 111 patients served as the study population and were randomized to receive supplemental oxygen (group 1) or compressed air (group 2) during surgery.

Based on the randomization procedure, 64 patients received compressed air and 47 patients received supplemental oxygen. Homogeneity between the 2 groups was studied. The patient characteristics are summarized in Table 1. No significant differences were observed between the groups in patient age or the type of regional anesthesia used during surgery. Table 2 summarizes the selection of drugs and doses for intraoperative sedation, which also were similar in both groups. The types of ophthalmic surgery performed were similar in both groups. Cataract extractions were performed in 101 patients, and other ophthalmologic surgery was performed in the remaining 10 patients, including vitrectomy, blepharoplasty, and repair of ptosis or strabismus. Retrobulbar blocks were administered to 13 patients, and 90 patients received peribulbar blocks. The distribution of anesthesia classification was similar in both groups, with 0.9% in ASA class I, 84.7% in ASA class II, and 14.4% in ASA class III.

Oxygen saturation values recorded during the study are summarized in Table 3. Small, but statistically significant higher mean oxygen levels were observed in group 1 patients during and after the operation. The oxygen saturation did not fall below 90% in any patient in either group. Only one group 2 patient experienced a 5% drop in oxygen saturation; the drop responded to supplemental oxygen administration.

Table 1. Clinical comparisons of outcomes in patients randomized to receive oxygen (group 1) or compressed air (group 2) during ophthalmic surgery*

Variable	Group 1 (n = 47)	Group 2 (n = 64)	*P*
Mean ± SD age (y)	73.9 ± 9.8	73.8 ± 8	.95
Ophthalmic procedure			
Cataract extraction	44 (94)	57 (89)	.41
Other	3 (6)	7 (11)	
ASA class			
I (normal, healthy patient)	0 (0)	1 (2)	.68
II (mild systemic disease)	40 (85)	54 (84)	
III (severe, but not incapacitating disease)	7 (15)	9 (14)	

* Values are number (%) of subjects unless stated otherwise.

Table 2. Operative variables observed in patients randomized to receive oxygen (group 1) or compressed air (group 2) during ophthalmic surgery*

Variable	Group 1 (n = 47)	Group 2 (n = 64)	*P*
Time in operating room (min)	44 ± 23.3	45.7 ± 27.2	.72
Regional anesthetic			
Retrobulbar block	6 (13)	7 (11)	.85
Peribulbar block	37 (79)	53 (83)	
None	4 (9)	4 (6)	
Preoperative sedative medication			
Midazolam			
Number	47 (100)	64 (100)	.68
Dose (mg)	1.7 ± 0.16	1.8 ± .12	.50
Fentanyl			
Number	10 (21)	8 (12)	.05
Dose (mg)	50.0 ± 0.0	42.0 ± 5.3	.06
Methohexital			
Number	43 (91)	58 (91)	.22
Dose (mg)	32.0 ± 16.6	34.0 ± 47.3	.13
Propofol			
Number	2 (4)	4 (6)	.24
Dose (mg)	30 ± 0	30 ± 0	1.0
Intraoperative sedative medication			
Midazolam			
Number	5 (11)	4 (6)	.69
Dose (mg)	1.25 ± 0.25	1.0 ± 0.34	.53

* Values are mean ± SD or number (%) of subjects.

Table 3. Operative oxygenation data obtained in patients randomized to receive oxygen (group 1) or compressed air (group 2) during surgery

Mean ± SD oxygen saturation (%)	Group 1	Group 2	*P*
Preoperative	96.6 ± 1.8	96.6 ± 1.8	.83
On admission to operating room	97.5 ± .20	96.6 ± 1.8	.02
Intraoperative	98.8 ± 1.7	96.4 ± 2.2	.0001*
On discharge from operating room	99.2 ± 1.1	97.1 ± 1.4	.0001*

*** Statistically significant**

Discussion

Oxygen always has been considered an essential ingredient of safe and acceptable anesthesia. However, oxygen administration also has untoward effects. Recently, oxygen has been identified as a critical ingredient in operating room fires, and it also may have a role in predisposing ophthalmic patients to retinal phototoxicity.[1-3] Thus, the rationale to proceed with this study centered on the demonstration that oxygen can be safely withheld from surgical patients during routine ophthalmic surgery.

In this study, the safety of supplementing selected surgical patients with compressed air was confirmed. The goal was to achieve safe operating room conditions without compromising the anesthetic outcome. Despite a senior-aged population, fewer than 4% of patients screened before surgery were excluded. The 2 study groups were administered similar preoperative and intraoperative sedative drugs and doses (see Table 2). Slightly higher mean oxygen levels were observed in group 1 patients during and after surgery. Although statistically significant, clinical significance is not apparent as an oxygen saturation of 90% yields an adequate and safe arterial blood oxygen tension exceeding 80-100 mm Hg. Thus, in this study, it was demonstrated that most patients admitted for elective ophthalmic surgery can be ventilated safely with compressed air. This practice may reduce the prevalence of operating room fires and reduce the occurrence of photochemical retinal toxicity. When carefully monitored, supplemental oxygen usually is not required during ophthalmic surgery.

The results of this investigation confirm the conclusions of Neatrour and Lederman.[6] Only 4% of candidates were excluded from this study due to pulmonary or cardiac disease, compared with 14% in the study by Neatrour and Lederman.[6] This would suggest that the vast majority of patients undergoing ophthalmic surgery may be candidates for compressed air supplementation. Neatrour and Lederman[6] did not report the types of sedative drugs and the doses used during surgery. In the present study, the drugs and doses used were similar in both groups, suggesting the absence of any treatment bias during anesthesia based on randomization to compressed air.

Several limitations exist in this investigation. First, the amount of intraoperative sedation was not controlled. Nurse anesthetists and/or anesthesiologists administered varying amounts of sedation at their own discretion. The goal was to demonstrate that compressed air could be used safely in all ophthalmic surgical patients regardless of the choice of the anesthetic regimen. In addition, no control was placed on the number of nurse anesthetists or anesthesiologists administering anesthesia to patients enrolled in the study. Therefore, patients experienced a variety of sedation techniques dependent on the anesthesia provider. Although an approximate 10 L/min flow of oxygen was used through the Hudson hood, the oxygen levels beneath the drapes were not measured. Last, participants were 18 years of age or older. The results may not be generalized to the pediatric population.

Conclusions

Selected patients undergoing ophthalmic surgery can be safely ventilated during ophthalmic surgery with compressed air after having received regional anesthesia. This practice results in a clinical outcome that is similar to using supplemental oxygen. Avoiding oxygen, except when required to treat hypoxia, may help to reduce the incidence of operating room fires and predispose to less retinal phototoxicity in surgical patients.

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