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Scavenging Enflurane from Extracorporeal Pump Oxygenators

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The use of inhalation anesthetics during cardiopulmonary bypass via the extracorporeal pump oxygenator introduces a source of waste gases not scavenged by systems used for anesthetic circle systems and ventilators. Trace anesthetic gases contaminate the operating room environment,[1–3] and may adversely affect operating room personnel.[4,5] Two clinical reports[3,6] describe suction-type scavengers for the pump oxygenator; one[3] documents a reduction of halothane in the room air. The purpose of this study was to measure the concentrations of enflurane likely to be inhaled by operating room personnel when this vapor is used in the pump oxygenator, to evaluate the effectiveness and safety of a scavenging system in reducing room concentrations, and to define factors influencing the efficiency of scavenging.

METHODS AND MATERIALS

Enflurane concentrations were measured in the air in an operating room used for open-heart surgery. The oxygenator, pump console, operating table, and anesthesia machine were in their customary positions; no surgical procedure was under way during most measurements.

To provide scavenging we fabricated a metal cap (fig. 1) with a diameter 1½ times that of the exhaust port of a Bentley Temptrol blood oxygenator (Models Q100 or Q200). Vertical slots in the slides of the cap allowed for air entrainment, pressure relief, and accurate positioning of the cap over the exhaust port and molded plastic ridge of this oxygenator design (fig. 2). A Boehringer model 5203 suction flowmeter was interposed in a noncollapsible suction line connecting the hose nipple to a standard operating room vacuum source with a suction flow rate variable from 5 to 25 l/min.

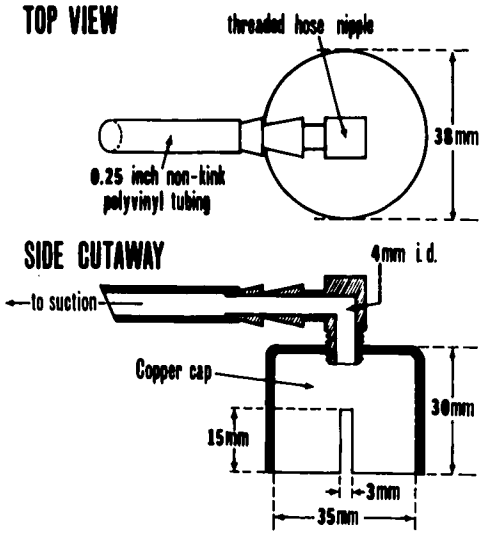

FIG. 1. Scavenging cap specifications.

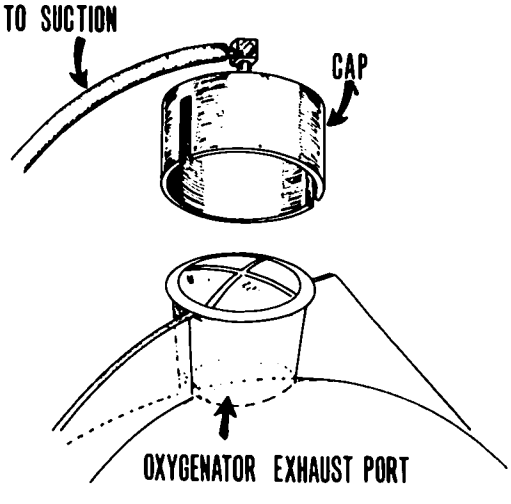

FIG. 2. Scavenging cap operating position.

Approximately 100 air samples were drawn in 250-μl Glenco syringes at specific locations. Three locations were chosen arbitrarily to represent the

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immediate vicinity of the oxygenator (5 cm immediately lateral to the oxygenator exhaust port, 85 cm above the floor; 24 cm lateral, 70 cm above the floor, and at the pump console surface, 58 cm lateral, 56 cm above the floor); the fourth was 3.5 meters from the oxygenator at the anesthesia machine. Samples were analyzed for enflurane immediately with a Hewlett-Packard F and M Scientific Model 402 Gas Chromatograph calibrated with known standards of 10, 20, 100, and 200 parts per million (ppm). In most cases, samples were drawn in triplicate and averaged. Measurements made under the same set of conditions at different times were also averaged.

Oxygenator gas inflow was a mixture of 97 per cent O_2–3 per cent CO_2 delivered through a calibrated Cyprane enflurane vaporizer with accuracy checked by gas chromatography. Ambient pressure within the oxygenator was measured by means of a polyethylene catheter connected to a glass water manometer column calibrated in millimeter increments. During one cardiopulmonary bypass procedure, a sterile catheter was inserted aseptically into the oxygenator gas reservoir for measurement of pressure. Measurement of Pa_{O_2} during bypass was by microelectrode at 37 C with correction to body temperature. The operating room air-conditioning system functioned in the nonrecirculating mode (16 complete air exchanges/hour), operating room doors were closed, and movement of personnel and equipment was minimal. Mean values were compared by t test.

Results

Prior to the use of enflurane for the study, air at the anesthesia machine and at the pump oxygenator console contained undetectable levels (less than 0.05 ppm) of residual anesthetic. Without scavenging, oxygenator gas flows of 5 and 10 l/min containing enflurane produced high levels of anesthetic in the room air as measured after 10 minutes (figs. 3 and 4). Concentrations ranged from 2.5 ppm to 5,000 ppm, depending upon the distance between the sampling site and the oxygenator exhaust port. The absolute level of trace anesthetic was proportional to the delivered anesthetic concentration, but the level was relatively independent of the flow rate through the oxygenator. With a 5 l/min oxygenator flow rate, room air concentrations (three samples, mean ± SD) at the anesthesia machine were 1.0 ± 0.2 and 2.3 ± 0.5 ppm for 0.5 and 2.0 per cent enflurane, respectively.

Marked reductions in measured enflurane concentrations occurred at almost all sampling sites with suction-type scavenging. For any given oxygenator flow rate, the reductions were proportional to the

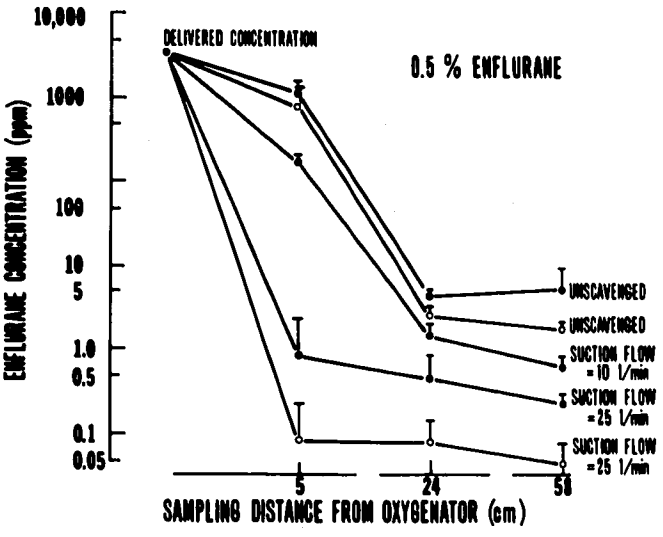

FIG. 3. Enflurane 0.5 per cent delivered. Semilogarithmic plot of ambient enflurane concentrations at three distances from the oxygenator exhaust port. Closed circles represent oxygenator flows of 10 l/min, open circles represent oxygenator flows of 5 l/min. Vertical bars represent standard deviation of the mean of multiple samples.

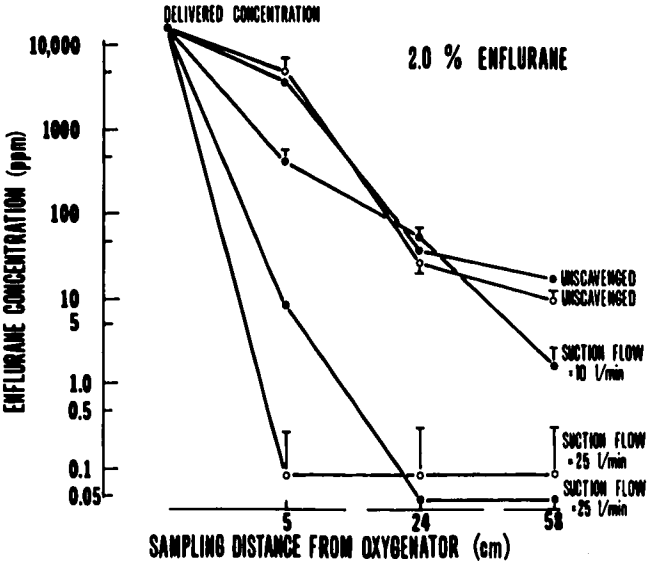

FIG. 4. Enflurane, 2.0 per cent delivered. Semilogarithmic plot of ambient enflurane concentrations at three distances from the oxygenator exhaust port. Closed circles represent oxygenator flows of 10 l/min, open circles represent oxygenator flows of 5 l/min. Vertical bars represent standard deviation of the mean of multiple samples.

suction flow of the scavenging system. With both 0.5 and 2.0 per cent enflurane, a high suction flow rate (25 l/min) in combination with a moderate oxygenator flow rate (5 l/min) reduced enflurane levels to 0.1 ppm or less.

During cardiopulmonary bypass, with an oxy-

TABLE 1. Intra-oxygenator Pressures at Various Inflow and Suction Rates with Scavenging Cap in Place

Oxygenator Inflow (l/min)	Scavenging Suction Flow (l/min)	Intra-oxygenator Pressure (cm H_2O)*
0	5	0.0
0	10	0.0
0	20	0.0
0	30	−0.2
2	0	0.0
2	5	0.0
2	10	0.0
2	20	0.0
2	30	−0.1
6	0	0.0
6	5	0.0
6	10	0.0
6	20	0.0
6	30	−0.1
12	0	0.0
12	5	0.0
12	10	0.0
12	20	0.0
12	30	0.0

* Referred to atmospheric pressure at the level of the oxygenator exhaust port.

genator inflow rate of 7 l/min and suction flow rate of 25 l/min, measurement of gas pressures within the oxygenator with a water manometer during scavenging revealed no visible deviation from atmospheric pressure. Subsequent measurements of pressures in an empty oxygenator demonstrated no significant negative or positive pressure over a wide range of clinically applicable inflow and suction rates (table 1). Prior to scavenging, during cardiopulmonary bypass, the P_{O_2} of arterialized blood (three samples, mean ± SD) was 416 ± 26 torr; after 10 minutes of continuous scavenging, Pa_{O_2} was 474 ± 26 torr ($P > 0.1$).

DISCUSSION

A "mock bypass" setup in the operating room was used to permit measurement of enflurane levels in room air without prior use of the anesthetic circle system. The desired flow rates and delivered concentrations were independent of patient requirements. Therefore, these levels were attained in the absence of anesthetic uptake by circulating blood, and represent the maximum room air concentrations likely under similar circumstances during cardiopulmonary bypass.

There are no specific published guidelines for allowable trace levels of enflurane at this time, but the chemical and pharmacokinetic similarities of enflurane and halothane suggest a similar target level of 0.5 ppm.[1] In this study, both low and high delivered enflurane concentrations are associated with room air levels of 1 ppm or more in the operating room when no scavenging system is employed. At 24 cm from the exhaust port, enflurane levels in room air of 30 ppm were typical; at the operating control surface of the pump console 58 cm away, where the pump technician is seated for much of the procedure, 13 ppm were found. Similar concentrations of halothane (15 ppm) are associated with reduction in alertness and with prolonged reaction times in volunteer subjects.[4]

Our data indicate that the suction-type scavenging cap described in this study was effective in markedly reducing room air concentrations of waste enflurane. Of equal importance, however, is the safety of this type of device. The effectiveness of the device described here depends upon the entrainment of room air through the slots and the loose-fitting bottom of the cap to "capture" waste gases; there are no gaskets, pressure relief valves, or close-fitting components to malfunction. Not mechanically fixed to the oxygenator, the scavenging cap straddles the molded plastic ridge of the oxygenator, held in position by gravity. With the sterile plastic exhaust port plug of the oxygenator in place, we could not jam or occlude the port with the scavenging cap. Finally, our data demonstrated that even complete suction failure with the cap in place did not cause a significant change in pressures within the oxygenator, although, of course, scavenging ceased. Pressure fluctuations under all observed conditions were well within the limits of ±0.25 cm H_2O currently being considered by the ANSI Committee Z-79 for this type of device.[7]

This study demonstrated the relationship between scavenging efficiency, gas inflow, and suction flow rate. In order to achieve enflurane levels of 1 ppm or less within 30 cm of the oxygenator, a suction flow rate of at least 2 to 2.5 times the rate of oxygenator gas inflow is necessary; a fivefold suction rate should assure levels less than 0.5 ppm over the clinical range of delivered enflurane concentrations at all points more than 5 cm from the oxygenator exhaust port. We conclude that the suction-type scavenging device described here is a safe and reasonable precaution. We emphasize that this device is a prototype, tested extensively by us before clinical use. It is not suggested that this or similar devices be constructed by others and put into routine clinical use without careful individual testing of the safety and effectiveness of each device.

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Interaction of Pancuronium and Corticosteroids

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Pancuronium bromide is a bis-quaternary ammonium compound with a steroid nucleus. It produces a competitive, nondepolarizing neuromuscular blockade characterized by fade on tetanic stimulation and posttetanic facilitation.[1] An apparent reversal of pancuronium-induced neuromuscular blockade by the intravenous administration of hydrocortisone has been reported recently.[2] A case that may represent a rapid termination of pancuronium-induced paralysis in a patient receiving massive doses of steroids is presented.

Report of a Case

A 21-year-old, 75-kg, white man was admitted for evaluation and treatment of idiopathic thrombocytopenic purpura. The platelet count on admission was 4,000/mm^3, and treatment with prednisone, 100 mg per day, orally, was begun. Following failure of the platelet count to rise above 30,000/mm^3, the prednisone dose was increased to 250 mg per day. This resulted in a cushingoid appearance without increase in circulating thrombocytes. The patient was, therefore, scheduled for splenectomy.

Preoperative evaluation elicited an unremarkable past history. Physical examination disclosed no abnormality except the cushingoid appearance and resolving ecchymoses. Results of laboratory studies, other than the platelet count of 65,000/mm^3, were normal. The patient was premedicated with Innovar, 1.5 ml, and atropine, 0.4 mg, im, 45 minutes before anesthesia. Induction was accomplished with Innovar, 7 ml in increments, and nitrous oxide (67 per cent) and oxygen (33 per cent) via semiclosed circle absorber system. Pancuronium bromide, 8 mg (0.1 mg/kg), was given iv, respiration was supported, and after 3 minutes the larynx was easily exposed and an 8.0 mm cuffed endotracheal tube inserted. Relaxation at the time of intubation was excellent and the cords were flaccid.

Sixty minutes after intubation an additional 2 mg of pancuronium was given during section of the left rectus muscle. However, 15 minutes later the surgeon reported inadequate relaxation and exposure. At that time a peripheral nerve stimulator was attached to subcutaneous needles placed in the medial volar surface of the forearm. Stimulation produced good twitch responses, no fade on tetanic stimulation and no discernible posttetanic facilitation. Three additional 2-mg doses of pancuronium, iv, over the next 60 minutes failed to cause any fade of tetanic contraction, but posttetanic facilitation was seen. The surgical procedure was completed uneventfully despite no improvement in abdominal relaxation. At the end of the procedure, neostigmine, 2.5 mg, and atropine, 1.0 mg, were administered iv for reversal and the trachea was extubated without difficulty.

Discussion

Pancuronium may be used to provide relaxation for intubation, with recommended doses ranging from 0.06[3] to 0.1 mg/kg.[1,4] Conditions suitable for intubation are present in 2 to 5 minutes, depending on the dose used. Our patient received 0.1 mg/kg pancuronium, which provided relaxation for easy laryngoscopy. We feel that adequate relaxation at laryngoscopy is evidence of profound neuromuscular blockade at that time. We postulate that an unusually rapid termination of action was responsible for the inadequate intraoperative relaxation in this case. In this young patient the only unusual factors were his thrombocytopenia and massive doses of prednisone. The recent report by Meyers of partial reversal of pancuronium-induced blockade by hydrocortisone points out the potential interaction of the two compounds.[2] We believe that an interaction between the pancuronium used for muscle relaxation and the corticosteroids our patient received may have

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