Comparison of Emergence and Recovery Characteristics of Sevoflurane, Desflurane, and Halothane in Pediatric Ambulatory Patients

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This study compares the emergence and recovery characteristics of sevoflurane, desflurane, and halothane in children undergoing adenoidectomy with bilateral myringotomy and the insertion of tubes. Eighty children 1–7 yr of age were studied. Thirty minutes prior to the induction of anesthesia, all patients received 0.5 mg/kg midazolam orally. Patients were randomly assigned to one of four groups: Group 1, sevoflurane induction and maintenance (S:S); Group 2, halothane induction and sevoflurane maintenance (H:S); Group 3, halothane induction and maintenance (H:H); or Group 4, halothane induction and desflurane maintenance (H:D). Tracheal intubation was facilitated with the use of a single dose of 0.2 mg/kg mivacurium. A Mapelson D circuit was used, and all patients received N_2O:O_2 60:40 for induction and maintenance at standardized appropriate fresh gas flow. Ventilation was controlled to maintain normocapnia. End-tidal concentration of anesthetics was maintained at approximately 1.3 minimum alveolar anesthetic concentration (MAC) (halothane: 0.56; sevoflurane: 2.6; desflurane: 8.3) until the end of surgery when all anesthetics were discontinued. Emergence (extubation), recovery (Steward score 6), and discharge times were compared among patients in the four groups using analysis of variance and Newman-Keuls tests. $P < 0.05$ was considered significant. There were no significant differences among the four groups with respect to age, weight, duration of surgery, or duration of anesthesia. Emergence and recovery from anesthesia were significantly faster in the desflurane group (Group 4) compared with the sevoflurane and halothane groups (Groups 1, 2, and 3) (5 ± 1.6 min vs 11 ± 3.7, 11 ± 4.0, 10 ± 4.0 min and 11 ± 3.9 min vs 17 ± 5.5, 19 ± 7.1, 21 ± 8.5 min, respectively). There was a significantly greater incidence of postoperative agitation and excitement in patients who received desflurane (55%) versus sevoflurane (10%) and halothane (25%). There were no significant differences among the four groups with respect to the time to meet home discharge criteria (134 ± 36.9, 129 ± 53.3, 117 ± 64.6, 137 ± 22.6 in Groups 1, 2, 3, and 4, respectively), in the time to drink oral fluids (139 ± 31.6, 136 ± 53.8, 123 ± 65.0, 142 ± 29.4 min, respectively), or in the incidence of postoperative vomiting. It is concluded that, although desflurane resulted in the fastest early emergence from anesthesia, it was associated with a greater incidence of postoperative agitation. Sevoflurane resulted in similar emergence and recovery compared with halothane. Desflurane and sevoflurane did not result in faster discharge times than halothane in this patient population.

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Sevoflurane and desflurane differ from halothane because of their lower solubility in blood, a feature that should result in more rapid emergence from anesthesia. The purpose of this study is to compare the emergence and recovery characteristics of sevoflurane, desflurane, and halothane anesthesia in children undergoing adenoidectomy with bilateral myringotomy and insertion of tubes.

Methods

Informed consent and institutional approval for the study were obtained. Eighty otherwise healthy (ASA physical status I or II) children 1–7 yr of age undergoing adenoidectomy with bilateral myringotomy and insertion of tubes were studied. Patients were fasted for 2–4 h prior to surgery. None of the patients had a prior history of sleep apnea.

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Thirty minutes prior to the induction of anesthesia, all patients received midazolam 0.5 mg/kg orally. Patients were randomly assigned via a computer-generated random numbers table to one of four groups: Group 1, sevoflurane induction and maintenance (S:S); Group 2, halothane induction and sevoflurane maintenance (H:S); Group 3, halothane induction and maintenance (H:H); or Group 4, halothane induction and desflurane maintenance (H:D). Sevoflurane was administered via an Ohmeda Sevotec 5 vaporizer, desflurane was administered via an Ohmeda Tec 6™ vaporizer, and halothane was administered via an Ohmeda Fluotec 4 vaporizer (Ohmeda, Madison, WI). A Mapelson D circuit was used, and all patients received N_2O:O_2 60:40 during induction and maintenance at standardized weight-appropriate fresh gas flows. Tracheal intubation was facilitated with the use of a single dose of mivacurium 0.2 mg/kg. Patients received intravenous (IV) lactated Ringer's solution up to four times the calculated hourly maintenance rate. Ventilation was controlled to maintain normocapnia. Usual monitors were used. No opioids were administered intraoperatively. End-tidal concentration of each anesthetic combination (volatile drug + N_2O) was maintained at approximately 1.3 minimum alveolar anesthetic concentration (MAC) [halothane 0.56 (1), sevoflurane 2.6 (2) and desflurane 8.3 (3)] until the end of surgery, when spontaneous recovery of neuromuscular function was confirmed and all anesthetics were discontinued. Ventilation was continued at the same fresh gas flow and minute volume until the return of a cough reflex. Each patient's trachea was extubated when he or she had a cough and gag reflex, grimace, and purposeful movements.

A single-blinded, independent observer evaluated each patient during the emergence and recovery phases. Emergence time was defined as the time from discontinuation of anesthetics to extubation. Recovery and discharge times were measured from the time the anesthetics were discontinued until the patient achieved a score of 6 on the Steward Recovery Score (4) and met home discharge criteria. Home discharge criteria included stable vital signs for ≥30 min, no signs and symptoms of excessive bleeding or pain, and ability to ambulate with minimal or no nausea or vomiting as appropriate for age. Time to drink clear fluids was also recorded, but patients were not required to drink before discharge home.

Postoperative excitement or agitation, pain, nausea, and vomiting were recorded. After a Steward Recovery score of 6 was achieved, if postoperative analgesia was required as indicated by a score of 6 or greater on the Objective Pain Scale (5), fentanyl 1–2 μg/kg IV was administered. Agitation was evaluated by using the three subjective components of the Objective Pain Scale (6). If the child was crying inconsolably, thrashing, and hysterical, he or she was reported to be "agitated" and was treated with fentanyl 1–2 μg/kg IV.

Emergence, recovery, and discharge times in the four groups were compared by analysis of variance, which in case of statistical significance was followed by pairwise comparisons using the Newman-Keuls multiple range tests (95% confidence). The incidence of postoperative events was compared by Fisher's exact test. $P < 0.05$ was considered statistically significant.

Results

There were no significant differences among the four groups with respect to age, weight, duration of surgery, or duration of anesthesia (Table 1).

The actual MAC maintenance values were 1.5 for halothane, 1.4 for sevoflurane, and 1.2 for desflurane (Table 2). The time from discontinuation of desflurane (Group 4) until the patient was ready for extubation (emergence) was 5 ± 1.6 min, significantly shorter than the time with sevoflurane in Groups 1 and 2 (11 ± 3.7 and 11 ± 4.0 min, respectively) or halothane in Group 3 (10 ± 4.0 min). The time from discontinuation of desflurane to achieving a score of 6 on the Steward scoring system in the postanesthesia care unit was 11 ± 3.9 min in the H:D group, significantly shorter than in the S:S group (17 ± 5.5 min), H:S group (19 ± 7.1 min), and H:H group (21 ± 8.5 min). There was, by contrast, no difference in time to meet discharge home criteria among the four groups. In all cases, it was approximately 2 h.

Differences in the incidence of postoperative nausea and vomiting among the four study groups were not statistically significant. Eleven of the 20 patients (55%) who received desflurane showed agitation and excitement. This high incidence of agitation increased the need for sedation and/or analgesia in the immediate postoperative period. Agitation was observed in 4 of the 40 patients (10%) who received sevoflurane and 5 of the 20 patients (25%) who received halothane.

Discussion

Induction and maintenance of general anesthesia in pediatric patients is often managed with an inhaled anesthetic, which should provide rapid, smooth induction and emergence, hemodynamic stability, analgesia, and amnesia. We found that with maintenance and discontinuation of anesthesia at similar MAC concentrations, desflurane resulted in the fastest early emergence from anesthesia. This was not a surprising finding considering the very low solubility of desflurane in blood (0.42).

Table 1. Demographic Data

	Group 1 S:S (n = 20)	Group 2 H:S (n = 20)	Group 3 H:H (n = 20)	Group 4 H:D (n = 20)
Age (yr)				
Mean ± SD	4 ± 2.0	3 ± 1.8	3 ± 1.4	2 ± 1.4
Range	1–6	1–7	1–6	1–5
Weight (kg)				
Mean ± SD	17 ± 5.3	16 ± 5.4	16 ± 4.0	14 ± 3.2
Range	11.5–30.5	10.5 – 31.0	10.0–26.5	9.5–20.0
Duration of surgery (min)				
Mean ± SD	22 ± 9.9	26 ± 12.3	24 ± 10.8	23 ± 10.2
Range	6–38	12–68	9–42	8–43
Duration of anesthesia (min)				
Mean ± SD	42 ± 12.1	47 ± 14.4	43 ± 11.8	40 ± 11.7
Range	19–62	30–95	26–6	22–64

S:S = sevoflurane induction and maintenance; H:S = halothane induction and sevoflurane maintenance; H:H = halothane induction and maintenance; H:D = halothane induction and desflurane maintenance.

Table 2. Emergence and Recovery Data

	Group 1 S:S (n = 20)	Group 2 H:S (n = 20)	Group 3 H:H (n = 20)	Group 4 H:D (n = 20)	P
Min (±SD) from end of anesthetic to					
Emergence	11 ± 3.7	11 ± 4.0	10 ± 4.0	5 ± 1.6	<0.0001[a]
Recovery	17 ± 5.5	19 ± 7.1	21 ± 8.5	11 ± 3.9	<0.0001[a]
Discharge criteria met (without drinking)	134 ± 36.9	129 ± 53.3	117 ± 64.6	137 ± 22.6	NS
Drinking	139 ± 31.6	136 ± 53.8	123 ± 65.0	142 ± 29.4	NS
Postoperative events (n)					
No. patients who received fentanyl	19	19	19	19	
Nausea/vomiting	6	9	4	4	
Excitement	1	3	5	11	<0.008[b]

S:S = sevoflurane induction and maintenance; H:S = halothane induction and sevoflurane maintenance; H:H = halothane induction and maintenance; H:D = halothane induction and desflurane maintenance; NS = not significant.
[a] H:D versus S:S, H:S, and H:H, Newman-Keuls.
[b] Fisher's exact test: H:D versus S:S, H:S, and H:H, $P < 0.008$; S:S versus H:D, $P < 0.006$; H:S versus H:D, $P < 0.019$; H:H versus H:D, $P < 0.064$.

Emergence and recovery times were not significantly different after halothane and sevoflurane anesthesia. This is at variance with previously published studies (7–10), including those from our own institution (7,8). The observation that sevoflurane did not result in faster emergence and recovery than halothane may be related to the design of this study and can be explained by one or a combination of the following.

First, our study maintained a constant minute volume and fresh gas flow throughout surgery and after the abrupt discontinuation of the inhaled anesthetic. This allowed for proper comparison of the washout characteristics of the individual drugs, without adding the confounding variable of changing the minute ventilation that may result from breath holding, irregular respiration, or manually assisting or controlling ventilation by the anesthesiologist if breath holding is prolonged. These variables were not controlled and may have speeded the recovery from sevoflurane in previous studies.

Secondly, although the blood:gas partition coefficient is considerably lower for sevoflurane compared with halothane (0.59 vs 2.4), the solubility in other tissues, e.g., muscle, is very similar (3.1 vs 3.4) (11). Thus, when the inspired concentration of the inhaled drug is abruptly reduced to zero at the conclusion of an anesthetic, muscle will continue to release the drug back to blood (for delivery to the lungs for exhalation) at an essentially similar rate for both drugs and therefore prolongs the washout of sevoflurane in spite of its low blood:gas solubility (12).

Thirdly, it is possible that we did not use MAC multiples for sevoflurane and halothane during maintenance of anesthesia in our patients equivalent to those used in previous studies. For the age group of children that we studied, we assumed the MAC in O_2 for halothane, sevoflurane, and desflurane to be 0.9,

2.5, and 8.5, respectively (13–15). In addition, all our patients received N_2O. When two anesthetic drugs are combined, the requirement for each is reduced (16). Sixty percent N_2O decreases the MAC of halothane in children by 60% (to a calculated value of 0.56) (1), that of sevoflurane by 25% (to 1.87) (2), and that of desflurane by 20% (to 6.8) (3). Therefore, the actual MAC multiples (in N_2O) that were used in our patients were 1.5 for halothane, 1.4 for sevoflurane, and 1.2 for desflurane. All previous comparative studies calculated higher MAC values for halothane in N_2O than ours. It is possible therefore that our patients who received halothane were maintained at a lighter level of anesthesia compared with those in other studies, including those reported previously from our center (12).

Finally, we do not know what the MAC equivalents for each of the three anesthetics were at the end of surgery. The assumption that MAC equivalents at the time of skin incision are the same as at the end of surgery has never been demonstrated. Further studies should examine whether tapering the anesthetic affects emergence time for each drug differently.

The observation that fast emergence is associated with a high incidence of agitation is rather disturbing. This is particularly evident in children who received desflurane; postoperative agitation occurred in 55% of those patients. This is an incidence similar to the previously reported 50% incidence by Davis et al. (6) and 42% by Welborn et al. (17). This phenomenon may be directly related to the speed of emergence; it is possible that the rapid transition from anesthesia to consciousness in a strange area with unfamiliar people taking care of the child results in fear and apprehension. Further studies are required to investigate the potential role of having the parents present at awakening and using opioids or similar drugs in controlling this phenomenon.

Despite the more rapid recovery associated with desflurane, patients in this group did not meet our standard home discharge criteria any faster than those who received halothane or sevoflurane. The power to detect a time difference of 15 minutes with our sample size of 20 patients per group is only about 0.15; however, this study was designed to detect anticipated rapid recovery differences, for which the power was sufficient. To obtain a power of 0.8 for the detection of discharge time differences of 15 minutes, about 180 patients per group would be required. Furthermore, the similarity of the groups' discharge times may have been due to residual sedation from postoperative opioid administration and to the relatively high incidence of vomiting in all groups after this type of surgery.

In summary, we conclude that desflurane results in faster emergence and recovery than either halothane or sevoflurane in premedicated patients undergoing adenoidectomy. Halothane and sevoflurane emergence and recovery were not significantly different. Emergence agitation is more commonly observed in patients who receive desflurane. Sevoflurane and desflurane do not result in faster discharge from the hospital in this patient population.

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