Minimum Alveolar Concentration of Isoflurane for Tracheal Extubation in Deeply Anesthetized Children

Gundappa Neelakanta, M.D.,* Jordan Miller, M.D.†

Background: The end-tidal anesthetic gas concentration required to prevent the anesthetized patient from coughing or moving during or immediately after tracheal extubation is not known.

Methods: We studied 19 nonpremedicated children between 4 and 9 yr of age (5.5 ± 1.8, mean ± standard deviation), ASA physical status 1 or 2, undergoing muscle surgery for correction of strabismus. General anesthesia was induced by a mask using halothane, nitrous oxide, and oxygen, and the trachea was intubated. Anesthesia was maintained with either isoflurane, nitrous oxide, and oxygen (12 patients), or isoflurane, air, and oxygen (7 patients). However, nitrous oxide was discontinued before the end of surgery. At the end of surgery, a predetermined end-tidal isoflurane concentration was achieved, a steady state maintained for at least 10 min, and the trachea was extubated. In patients who coughed or bucked on the endotracheal tube during suctioning of the stomach or pharynx, or who moved or coughed within 1 min of tracheal extubation, or who developed breath-holding or laryngospasm after tracheal extubation, extubation was considered as unsatisfactory. Results were plotted as satisfactory or unsatisfactory extubation versus end-tidal isoflurane concentration. End-tidal concentration of isoflurane at which tracheal extubation was accomplished in 50% of patients satisfactorily was estimated by probit analysis.

Results: The minimum alveolar concentration of isoflurane at which 50% of patients had satisfactory tracheal extubation was found to be 1.27% (standard error ± 0.04%).

Conclusions: In 50% of anesthetized children age 4–9 yr tracheal extubation may be accomplished without coughing or moving at 1.27% end-tidal isoflurane concentration. (Key words: Anesthesia; pediatric. Anesthetic techniques: tracheal extubation. Anesthetics, volatile: isoflurane. Potency, minimum alveolar concentration: extubation.)

* Assistant Clinical Professor of Anesthesiology.
† Associate Professor of Anesthesiology.

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Address reprint requests to Dr. Neelakanta: University of California, Los Angeles, CHS, BH-718, 10833 Le Conte Avenue, Los Angeles, California 90024-1778.

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NO previous studies have quantified the depth of anesthesia, expressed as end-tidal gas concentration, required to perform tracheal extubation. This information may be of clinical importance because tracheal extubation during deep anesthesia may be associated with fewer airway-related complications.† By applying the concept of minimum alveolar concentration we have attempted to quantify the depth of anesthesia required to prevent coughing or moving during or immediately after tracheal extubation.

Materials and Methods

Nineteen children undergoing extraocular muscle surgery for correction of strabismus were included in the study. Institutional human subject protection committee approval and informed consent from the parents or guardians of each participating child were obtained. The children were between ages 4 and 9 yr (5.5 ± 1.8, mean ± standard deviation) and were ASA physical status 1 or 2. Children who had upper respiratory infection or reactive airway disease were excluded from the study.

There was no premedication given preoperatively. General anesthesia was induced via mask using halothane, nitrous oxide, and oxygen. The trachea was then intubated under deep halothane anesthesia except in two children where vecuronium was used to facilitate tracheal intubation. After the airway was secured, an orogastric tube was advanced into the stomach. Halothane was then discontinued and anesthesia was maintained with either isoflurane, nitrous oxide, and oxygen (12 patients), or isoflurane, air, and oxygen (7 patients). However, nitrous oxide was discontinued before the end of surgery. No further muscle relaxant was given in cases where vecuronium had been used. In these two patients, the muscle paralysis was reversed using edrophonium and atropine and spontaneous breathing was established well before the end of sur-
surgery. After the end of surgery, a predetermined end-tidal isoflurane concentration was achieved and a steady state maintained for at least 10 min to allow equilibration between the alveolar and brain concentrations. The end-tidal concentration of isoflurane was sampled from a mask elbow attached to the endotracheal tube connected to a circle system and was measured continuously by Perkins Elmer Mass Spectrometry calibrated previously. There was no residual halothane detected in the end-tidal sample at the time of tracheal extubation. Immediately before tracheal extubation, the stomach contents were suctioned via the indwelling orogastric tube, and the orogastric tube was removed with continuous suction to clear the pharyngeal contents. The trachea was then extubated and the following events were noted: movement, coughing or bucking within 1 min of extubation, breath-holding or laryngospasm on extubation.

Patients who coughed or bucked on the endotracheal tube during suction of the stomach or pharynx, or who moved or coughed within 1 min of tracheal extubation, or who developed breath-holding or laryngospasm immediately after tracheal extubation were all considered to have had unsatisfactory extubation.

Patients were studied in groups of four, starting at 1.7%, 1.4%, 1.3%, 1.2%, and 1.1% end-tidal concentration of isoflurane. Within each group the initial end-tidal isoflurane concentration was administered and the patient’s response to extubation was noted. The end-tidal concentration of isoflurane of the next patient was then increased by 0.1% if there was a response to extubation (unsatisfactory) or decreased by 0.1% if there was no response to extubation (satisfactory). The results were analyzed by applying probit analysis (procedure PROBIT, Statistical Analysis System Institute, Cary, NC) to estimate the end-tidal concentration of isoflurane at which tracheal extubation was accomplished satisfactory in 50% (MAC_{50}) and 95% of patients.

**Results**

In two patients laryngospasm occurred after extubation and was easily treated without any sequelae. There were no other study related complications. Results are shown in figure 1. The MAC_{50} for isoflurane is estimated at 1.27% (standard error ± 0.04%). The MAC_{95} of isoflurane for 95% of patients is estimated at 1.46% (standard error ± 0.1%).

![Response to Extubation Diagram](image)

**Fig. 1.** Data from each patient are represented by a single line and are plotted as no response to extubation (satisfactory) or response to extubation (unsatisfactory) at their respective end-tidal isoflurane concentrations.

**Discussion**

Minimum alveolar concentration of anesthetic has been widely used as a measure of potency of inhalational agents and gives an estimate of depth of anesthesia required for skin incision. Similarly, minimum alveolar concentration for tracheal intubation, blocking the adrenergic responses to surgical incision, and for opening eyes to verbal commands during recovery from anesthesia have also been estimated. In this study, we have extended this concept to include MAC_{ex} in the deeply anesthetized patient. We have defined MAC_{ex} as the alveolar concentration of inhalational anesthetic at which 50% of patients undergoing tracheal extubation cough or move within 1 min of extubation or develop breath-holding or laryngospasm immediately after extubation.

Tracheal extubation in the deeply anesthetized patient is used in a variety of settings. It is commonly used after certain surgical procedures, e.g., after intracocular surgery to prevent a sudden increase in intraocular pressure. It is also used for certain patients (for example, patients with reactive airway disease to avoid precipitating bronchospasm on extubation). Tracheal extubation in the deeply anesthetized children may also decrease episodes of hemoglobin oxygen desaturation during emergence from anesthesia compared to tracheal extubation after they are awake. Satisfactory tracheal extubation in the deeply anesthetized patient should not result in coughing or bucking, breath holding or laryngospasm on extubation. Attempts at satisfactory tracheal extubation in the deeply anesthetized patient, however, are not always successful, in part because of lack of knowledge regarding the depth of anesthesia required for this procedure. The results of our study indicate that in 95% of children age 4–9 yr tracheal extubation may be accomplished satisfactorily at 1.46% end-tidal concentration of isoflurane.
MAC FOR EXTUBATION IN ANESTHETIZED CHILDREN

A potential source of error in our study could have resulted from use of nitrous oxide in 12 children during the surgery. There was a significant but small end-tidal concentration of nitrous oxide measured at the time of extubation, but this was always less than 7% (4.3 ± 1.7%, mean ± standard deviation). Although the effect of this residual nitrous oxide on our final result is unpredictable, it is unlikely to change the MACex by more than 0.05% isoflurane.

The gases were sampled from a mask elbow attached to the endotracheal tube in our patients. It has been shown previously that the site of gas sampling can effect the end-tidal gas measurements in pediatric patients.8–10 Placing the sampling catheter between the endotracheal tube and the rebreathing circuit potentially contaminates the end-tidal gas with fresh gas. More accurate measurement of end-tidal gas therefore requires sampling from the distal end of the endotracheal tube. However, in pediatric patients weighing 12 kg or more, using an Ayre’s T-piece breathing system, the mean difference in carbon dioxide tension measurements between the distal end of the endotracheal tube and the proximal side-stream adapter is less than 1 mmHg.11 All our patients were at least 13 kg in weight (mean 19 kg). Also, isoflurane was used for maintenance of anesthesia at concentrations close to the end-tidal concentration at the time of extubation. The alveolar isoflurane concentration at the end of surgery is expected to be more than 80% of the inspired isoflurane concentration. Even at 10 min after a change in inspired isoflurane, the alveolar concentration is expected to be greater than 70% of the inspired concentration.12 Because only small changes in the inspired isoflurane concentrations were made at the end of surgery in order to achieve the desired end-tidal isoflurane concentration at the time of extubation; we expect the alveolar concentration of isoflurane to be greater than 70%–80% of the inspired. The error due to proximal sampling, based on the fact that end-tidal minus arterial carbon dioxide difference is small, is only a small percentage of the already small difference between the inspired and expired isoflurane concentration. Taking all this information together we believe, in our patients, at the time of extubation, this error is unlikely to have been more than 4% of the measured end-tidal isoflurane concentration.

In conclusion, we have determined MACex in the deeply anesthetized patient: tracheal extubation in 50% of anesthetized children age 4–9 yr may be accomplished without coughing or moving at 1.27% end-tidal isoflurane concentration.

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Anesthesiology, V 80, No 4, Apr 1994