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End-tidal Enflurane Concentration for Endotracheal Intubation
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Inhalational induction followed by endotracheal intubation is a technique frequently employed in pediatric anesthesia. In an earlier study1 we introduced the term MAC4, defined as the end-tidal concentration of a gas or vapor needed by 50 per cent of the population to prevent all movement both during and immediately after laryngoscopy and endotracheal intubation. MAC4 for halothane was calculated to be 1.33 per cent at sea level. In the present report, similar methods were employed to determine MAC4 for enflurane in pediatric patients.

METHODS

Twenty-four studies were performed in 22 ASA I surgical patients, aged 2 to 6 years. Informed consent regarding the nature and risks of the study was obtained from the parent or guardian of each participant. Premedication consisted of atropine, 0.015 mg/kg. A precordial stethoscope was used to monitor heart and breath sounds. Blood pressure was measured indirectly, and lead II of the electrocardiogram was continuously displayed. Body temperature was monitored with a rectal thermistor. Induction of anesthesia was accomplished with enflurane, 4–5 per cent, and oxygen (5 l/min) delivered from an Enfluromatic vaporizer through a Jackson-Rees modification of an Ayres.
Four end-tidal enflurane concentrations were studied: 2.07, 2.48, 2.98, and 3.55 per cent. Two patients were tested with more than one concentration. However, no patient was exposed to more than two test concentrations during the same procedure, and none of the test concentrations was administered more than once to the same patient. After induction, the randomly-selected end-tidal concentration was approached by slowly decreasing the inspired concentration. Spontaneous respirations were manually assisted. The estimated end-tidal concentration was established at the desired value (±0.05 per cent), and maintained for 10 min to allow equilibration of cerebral and arterial blood gas tensions. Endotracheal intubation was then attempted. The process of intubation was evaluated according to the adequacy of conditions for laryngoscopy (easy visualization of the glottis, relaxation of the vocal cords, and absence of extremity movement) and the incidence of coughing or "bucking" immediately after an otherwise successful intubation. Logit analyses of responses to intubation were performed. In this manner the MAC<sub>ET</sub> for enflurane was derived.

**RESULTS**

Table 1 shows mean values, at each sampling site, for the end-tidal concentrations tested. The response curve constructed on the basis of logit analyses of data in this patient population (fig. 1) revealed that MAC<sub>ET</sub> is 3.28 per cent. Based on the slope equation, MAC<sub>ET</sub> for 95 per cent of this population equals 4.50 per cent. These investigations were performed at an altitude of approximately 760 m (2,500 ft), where the barometric pressure is about 700 torr. Traditional MAC values have been determined at essentially sea level. After appropriate barometric corrections, MAC<sub>ET</sub> at sea level is calculated to be 2.93 per cent.

**DISCUSSION**

Attempting endotracheal intubation without muscle relaxant and in the presence of an insufficient depth of anesthesia is hazardous. Inhalational induction with subsequent intubation is frequently performed in pediatric anesthesia. Enflurane has been recommended for this surgical population due to the rapidity of induction and emergence. In children, MAC for enflurane has been estimated in the range of 2.0 to 2.2 per cent. These estimates are based on the assumption that an age–MAC relationship for enflurane is not linear.

### Table 1. Enflurane Concentrations and Percentages of Patients Moving upon Intubation

<table>
<thead>
<tr>
<th>Number of trials</th>
<th>Inspired&lt;sup&gt;*&lt;/sup&gt; Mean ± SD</th>
<th>End-tidal&lt;sup&gt;†&lt;/sup&gt; Mean ± SD</th>
<th>Patients Moving (Per Cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.06 ± .01</td>
<td>2.03 ± .03</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>2.55 ± .09</td>
<td>2.52 ± .07</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>3.01 ± .03</td>
<td>2.95 ± .03</td>
<td>56</td>
</tr>
<tr>
<td>8</td>
<td>3.57 ± .04</td>
<td>3.53 ± .05</td>
<td>38</td>
</tr>
</tbody>
</table>

<sup>*</sup> Measured in nonbreathing apparatus.

<sup>†</sup> Measured through catheter in endotracheal tube.
flurane exists and is similar to that for halothane. At sea level MAC$_{95}$ values for enfurane and halothane are 2.98 and 1.33 per cent, respectively. In both instances, MAC$_{95}$ values appear to be about 30 per cent greater than MACs. It is not known whether similar relationships obtain with other volatile anesthetics. Of additional interest is that a plotting of log dose–response curves for enfurane and halothane (fig. 2) suggests a striking parallelism. This would indicate that, in regard to anesthetizing the upper airway, the potency differential between the two agents is fairly uniform over a wide range of possible responses.

Contrary to the experience of others, inhalational induction to end-tidal enfurane concentrations of 2.9 per cent or more required a considerable period (15 to 20 min). This may be explained by the fact that, relative to MAC$_{95}$, the inspired concentration of enfurane administered during induction (4–5 per cent) in this study was proportionately less than that delivered for induction with halothane (2–3 per cent) in the previous study. If the relationship between inspired concentration and MAC$_{95}$ for enfurane had been of the same magnitude as that which existed with halothane, enfurane administration would probably have resulted in a more rapid rate of anesthetic induction. Other possible explanations for prolonged induction are that we avoided hyperventilation, which would hasten establishment of a prescribed end-tidal concentration, and we strove to achieve an F$_{1}$/F$_{2}$ ratio near unity.

Enfuran is known to produce central nervous system excitation beginning at an alveolar concentration of 2.5 per cent. This cerebral activity may be manifested by muscular movements. We observed such movements (primarily tonic-clonic twitching of hands and feet) in 15 of the 17 patients studied with end-tidal enfurane concentrations of 2.9 per cent or more. In six of these 15 patients, obvious muscular movement was accompanied by an apparent decrease in chest-wall compliance with concomitant difficulty in assisting respirations. Conceivably, this resistance may have been due to increased tonus in chest or upper airway musculature. The condition was effectively treated by lowering the inspired enfurane concentration. Such reactions at higher enfurane concentra-

![Fig. 2. Comparative plots of log dose–response curves for halothane and enfurane. Corrected to barometric conditions at sea level, MAC$_{95}$ values for halothane and enfurane are 1.33 and 2.98 per cent, respectively.](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931487/)