Halothane is the most commonly used anaesthetic agent in paediatric anaesthesia (Reynolds, 1962; Krivosic-Horber, Sauvage and Calmes, 1973; Gov-aerts and Sanders, 1975) and, like all halogenated hydrocarbon anaesthetics, depresses ventilation (Munson, 1972) — an effect dependent on the age of the patient (Lindahl, Olsson and Thomson, 1981) and on the alveolar concentration of the anaesthetic (Munson et al., 1966). However, few studies are available which detail the changes in ventilatory patterns during halothane anaesthesia in children (Wilson and Harrison, 1964). This paper describes measurements of minute ventilation ($VE$), tidal volume ($VT$), respiratory frequency ($f$), mean inspiratory flow ($VT/TTi$), inspiratory timing ($TV/TTtot$) and end-tidal carbon dioxide tension ($PE'CO_2$) in 12 children weighing between 10 and 20 kg. The measurements were made at increasing inspired concentrations of halothane.

**PATIENTS AND METHODS**

Twelve children, scheduled for elective minor surgical procedures, were studied. Mean (± SD) age was 39 ± 17 months (range 20–68 months), weight 15 ± 2.9 kg (range 10.5–20 kg) and height 96 ± 11.5 cm (range 77–111 cm). All patients were healthy, were taking no medication and had normal cardiopulmonary function. Parental consent was obtained after full explanation before anaesthesia. None of the children included in this study was premedicated. The study was performed either immediately before surgery (eight children), or during the period after operation (four children) if no anaesthetics apart from halothane and nitrous oxide had been used during the surgical procedure.

Anaesthesia was induced with oxygen and nitrous oxide in equal parts ($F_{1O_2} 0.5$) and 2–2.5% halothane using an appropriate mask and an open circuit with a non-rebreathing valve. Intubation was performed without neuromuscular blockade under appropriate inspired halothane concentration (uncuffed endotracheal tube). The total fresh gas flow was identical for all patients (oxygen 4 litre, nitrous oxide 4 litre) throughout the study, and was sufficient to prevent rebreathing (Lindahl, Hulse and Hatch, 1984). Intubation was performed without neuromuscular blockade under appropriate inspired halothane concentration (uncuffed endotracheal tube). The total fresh gas flow was identical for all patients (oxygen 4 litre, nitrous oxide 4 litre) throughout the study, and was sufficient to prevent rebreathing (Lindahl, Hulse and Hatch, 1984). After tracheal intubation, the inspired concentration of halothane was decreased to 0.5%; the children were breathing spontaneously.

Rectal temperature was monitored and maintained between 36.5 and 37.5 °C for all children. The ECG was monitored continuously.

The tidal volume ($VT$) was measured by integrat-
ing the flow signal obtained from a Fleish No. 0 pneumotachograph with an internal volume of 4.7 ml connected to a Godart differential pressure transducer. The pneumotachograph was placed between the endotracheal tube and a non-rebreathing valve with a low opening pressure (Dighby-Leigh). The fraction of carbon dioxide in the expired gas \(F_{\text{ECO}_2}\) was monitored continuously in the tracheal tube by a capnograph with automatic correction for nitrous oxide (Datex). The rate of sampling was 50 ml min\(^{-1}\).

The study was divided into four different periods. In the first period, the children were maintained at an inspired concentration of halothane of 0.5% for at least 15 min and a recording of respiratory patterns obtained, breath-by-breath for 1 min \(T_0\). Then, the inspired halothane concentration was increased to 1% for 10 min and measurements obtained for 1 min \(T_1\). The inspired halothane concentration was increased again, to 1.5% for 10 min \(T_2\). Finally, the inspired halothane concentration was decreased to 0.5% for 15 min. This last period, called \(T'_0\), was studied to determine individual variations and eventual consequences of prolonged anaesthesia. Records of \(VT\) and \(F_{\text{ECO}_2}\) were made throughout the study, but breath-by-breath recordings were performed only during the 1 min at the end of each period. The children were not stimulated in any way throughout the period of study.

At each inspired halothane concentration, the durations of inspiration \(TV\), expiration \(TE\), and total breathing cycle \(TV+TE\) were measured by averaging 10 successive breaths.

The following respiratory variables were calculated: minute ventilation \(VE\) (ml min\(^{-1}\) kg\(^{-1}\)), respiratory frequency \(f\), mean inspiratory flow \((VT/TV)\) (ml kg\(^{-1}\) min\(^{-1}\)), inspiratory duty cycle \(TV/TV_{\text{TOT}}\) and end-tidal carbon dioxide partial pressure \(P_{\text{ECO}_2}\) (kPa).

Carbon dioxide output \(\dot{V}_{\text{CO}_2}\) was calculated for each period using the following formula:

\[
\dot{V}_{\text{CO}_2} (\text{ml min}^{-1}) = \frac{VE \times F_{\text{ECO}_2}}{100}
\]

\(F_{\text{ECO}_2}\) is the expired carbon dioxide fraction. \(VE\) was corrected to body temperature and pressure saturated (BTPS), \(\dot{V}_{\text{CO}_2}\) values to ambient temperature and pressure saturated (ATPS).

Statistical evaluation of the data utilized a two-way analysis of variance between the four periods of the study and the two-tailed \(t\) test for paired samples. \(P\) values < 0.05 were regarded as significant. The values are expressed as mean ± standard error of the mean (SEM).

RESULTS

Values (mean ± SEM) of \(VE, VT, f, VT/TV, TV/TV_{\text{TOT}}, P_{\text{ECO}_2}, \dot{V}_{\text{CO}_2}\), obtained at various inspired concentrations of halothane are shown in table I. Values at \(T_0\) were not significantly different between the chil-

<table>
<thead>
<tr>
<th>Inspired halothane concentration (%)</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (T_0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(VE) (ml kg(^{-1}) min(^{-1}))</td>
<td>148.22 ±6.74</td>
<td>129.90*** ±7.79</td>
<td>113.40*** ±5.99</td>
<td>140.8* ±6.85</td>
</tr>
<tr>
<td>(VT) (ml kg(^{-1}))</td>
<td>4.98 ±0.36</td>
<td>4.11*** ±0.29</td>
<td>3.34*** ±0.25</td>
<td>5.06 ±0.34</td>
</tr>
<tr>
<td>(f) (b.p.m.)</td>
<td>±2.52</td>
<td>±2.45</td>
<td>±2.66</td>
<td>±1.94</td>
</tr>
<tr>
<td>(TV/TV_{\text{TOT}})</td>
<td>0.55 ±0.02</td>
<td>0.53 ±0.02</td>
<td>0.52* ±0.01</td>
<td>0.52* ±0.02</td>
</tr>
<tr>
<td>(P_{\text{ECO}_2}) (kPa)</td>
<td>5.2 ±0.19</td>
<td>5.5*** ±0.22</td>
<td>6.1*** ±0.23</td>
<td>5.3** ±0.19</td>
</tr>
<tr>
<td>(\dot{V}_{\text{CO}_2}) (ml kg(^{-1}) min(^{-1}))</td>
<td>743 ±20.1</td>
<td>692 ±23.7</td>
<td>682*** ±22.5</td>
<td>741.5 ±26.4</td>
</tr>
<tr>
<td>(VT/TV) (ml kg(^{-1}) min(^{-1}))</td>
<td>272.7 ±12.9</td>
<td>243.4*** ±14.4</td>
<td>217.7*** ±11.6</td>
<td>262.5 ±13</td>
</tr>
</tbody>
</table>

**TABLE I. Ventilatory variables (mean ± SEM) at various inspired concentrations of halothane. Comparisons are made between the initial period \(T_0\) and the other periods, \(T_1, T_2\) and \(T'_0\). ***P < 0.001; **P < 0.01; *P < 0.05**
HALOTHANE AND VENTILATORY PATTERN IN CHILDREN

Children studied before operation and those studied after operation. Carbon dioxide output was statistically linked to weight ($P < 0.001$), height ($P < 0.001$) and age ($P < 0.001$).

The changes in the ventilatory patterns at various depths of halothane anaesthesia are summarized in figure 1. There was a significant decrease in $\dot{V}_E$ when the inspired concentration of halothane increased, mainly as a result of a significant decrease in $V_T$. The increase in respiratory rate was significant between 0.5 and 1.5%, but no increase was found between 0.5 and 1%. Changes in effective respiratory timing were significant between 0.5 and 1.5% halothane. Mean inspiratory flow decreased significantly with increasing depth of halothane anaesthesia. Changes in $P_{E}CO_2$ were also related to changes in inspired halothane concentration, but the increase obtained between 1 and 1.5% was twice that obtained between 0.5 and 1%. $VCO_2$ decreased significantly only between 0.5 and 1.5% inspired halothane concentration. The control period was marked by a significant decrease in inspiratory timing and an increase in $P_{E}CO_2$, but no significant change in $V_T$, respiratory rate, mean inspiratory flow or $VCO_2$.

**DISCUSSION**

Few data are available on normal ventilatory patterns in children younger than 6 years of age, probably because of difficulties in obtaining real cooperation at this age.

In comparison with normal data for awake children (Crone, 1983), the respiratory rate at $T_0$ was markedly increased, tidal volume was decreased, but minute ventilation did not change markedly. The end-tidal carbon dioxide tension was at the normal upper range limit for age, and mean values for $VCO_2$ were similar to published data for anaesthetized children (Nightingale and Lambert, 1978; Lindahl, Olsson and Thomson, 1981; Lindahl, Hulse and Hatch, 1984), and not different from those obtained by Lewis, Dural and Iliff (1943) in awake children. The effect on the respiratory patterns, of the use of nitrous oxide in this study, is difficult to delineate. Nitrous oxide has been shown to have either a mild stimulant effect (Eckenhoff and Helrich, 1958) or a ventilatory sparing effect (Hornbein et al., 1969). In children, Salanitre and Rackow (1976) demonstrated a decrease in $\dot{V}_E$ during halothane anaesthesia with 70% nitrous oxide when compared with 3% nitrous oxide. However, a mixture of nitrous oxide, oxygen and halothane is generally used during general anaesthesia to reduce the MAC of halothane, and this study was essentially performed to define the changes in ventilatory patterns under general anaesthesia with halothane in children.

An increase in inspired halothane concentration produced significant decreases in $\dot{V}_E$, $\dot{V}_T$, $V_T$, $V_T/T_I$, with a significant increase in $P_{E}CO_2$. Thus, the increase in inspired halothane concentration produced, as previously reported in adults (Devine, Hamilton and Pittinger, 1958; Larson et al., 1969; Munson et al., 1966), a marked decrease in alveolar ventilation. In children, Wilson and Harrison (1964) found, as we did, a marked decrease in $\dot{V}_E$ and $V_T$, but only a mild difference in mean respiratory rate.

**FIG. 1.** Per cent change in ventilatory variables, expressed as per cent of the initial value (Period $T_0$).

- $P < 0.05$; $**P < 0.01$; $***P < 0.001$. 

*Inspired Halothane Concentration* 
- 1 v. 0.5 
- 1.5 v. 0.5 
- 0.5 (control) v. 0.5 

$\dot{V}_E$, $V_T$, $V_T/T_I$, $T_I/T_T$. 

$P_{E}CO_2$. 

$\dot{V}_E$, $V_T$. 

Mean values for $VCO_2$ were similar to published data for anaesthetized children (Nightingale and Lambert, 1978; Lindahl, Olsson and Thomson, 1981; Lindahl, Hulse and Hatch, 1984), and not different from those obtained by Lewis, Dural and Iliff (1943) in awake children.
during halothane anaesthesia and recovery from anaesthesia. Decrease in $V_{CO_2}$ at high inspired halothane concentration is most likely the result of a large decrease in effective alveolar ventilation. The decrease in tidal volume seems to result from a central action of halothane, which has a primary direct action on the central regulatory and integratory mechanisms (Ngai, Katz and Farhie, 1965). The significant decrease in mean inspiratory flow reflects a decrease of the rate of increase of the centrally generated inspiratory activity (Gautier, 1980). The effect of halothane on respiratory rate is less well known. In agreement with the results recently reported in cats (Nishino et al., 1984), our study demonstrated a decrease in the timing of the inspiratory drive during halothane anaesthesia. This effect was true essentially for high inspired concentrations and suggests that there was a direct effect of halothane on inspiratory muscles.

Using the return to baseline concentration ($T_0$), individual variations can be assessed and the role of the duration of anaesthesia characterized. We did not find any significant change in $V_T$, $V_{CO_2}$, $V_T/TI$ and respiratory rate between $T_0$ and $T_{0}$. However, there was a significant decrease in inspiratory duty cycle and a significant increase in $PECO_2$ between the two periods. Changes in inspiratory timing may result from a direct effect of halothane on inspiratory muscles with progressive recovery. Changes in $PECO_2$ are also related to work output of inspiratory muscles (Milic-Emili and Tyler, 1963). Indeed, the duration of anaesthesia does not seem to influence carbon dioxide response curves in the dog and the increase in $PECO_2$ cannot be explained by changes in the carbon dioxide sensitivity (Brandstater, Eger and Edelist, 1965). In this study, the duration of anaesthesia did not change $VCO_2$ either, although carbon dioxide production increased with inspiratory muscle fatigue (Macklem, 1980). Thus, the changes in respiratory variables we have observed in this study may be an additional reason for assisting ventilation in children undergoing surgical procedures of long duration (Hulse, Lindahl and Hatch, 1984) to avoid prolonged ventilatory depression and possible alterations in muscle activity.

REFERENCES


