Pulmonary Ventilation in Children During Halothane Anesthesia

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Tidal volumes and minute volumes were measured in 59 patients between the ages of six hours and five years (thirty-one less than one year) during halothane anesthesia and correlated with age, height, weight and surface area. Tidal volume was best estimated from body weight, minute volume from height. For use in estimating maximal requirements during halothane anesthesia, values of 5.5 ml./kg. body weight for tidal volume and 40 ml./cm. height for minute volume are suggested. Minimum values for tidal volume approached 1 ml./kg., especially in those cases with minimal decreases in temperature, dramatically emphasizing the importance of apparatus dead space and maintenance of body temperature.

ALTHOUGH pulmonary ventilation of adults during anesthesia and surgery has been extensively studied, there is a striking lack of information concerning respiratory parameters in young children during anesthesia. This paper describes pneumotachographic measurements of tidal volume, minute volume, maximum inspiratory and expiratory flow rate, respiratory rate and patterns of ventilation in 59 children under the age of 5, during halothane anesthesia. An attempt is made to relate these figures to height, weight, surface area, and age of the patient.

Method

Measurements were made in 59 patients under the age of 5 years, 31 under one year, during halothane anesthesia for the following procedures: inguinal and umbilical herniorrhaphy, circumcision, operations on the extremities, body surface and rectum. Age varied from 6 hours to 4 years, 11.5 months, weight from 2.9 to 20 kg., height from 48 to 117 cm., surface area from 0.19 to 0.80 square meters. All of the patients had normal cardiopulmonary function with a hemoglobin greater than 10 g./100 ml. and hematocrit greater than 30 per cent. None had a temperature above 38° C. In all patients under the age of one year, and in those under 2 years undergoing abdominal surgery temperature was maintained as close as possible to the preoperative level by the use of a water mattress and wrapping the extremities during operation, the temperature monitored by either rectal or esophageal thermister probes. All patients were in classification 1 or E1 according to the revised A.S.A. classification.

Preanesthetic medication in patients under one year consisted of 0.1 mg. of atropine; in those over one year of secobarbital 2 mg./kg., meperidine 1 mg./kg. or morphine 0.1 mg./kg. plus atropine or scopolamine 0.01 to 0.02 mg./kg. All drugs were given intramuscularly one-half to one and one-half hours preoperatively.

Induction of anesthesia was usually carried out with halothane and oxygen using an appropriate Rendell-Baker-Soucek mask attached to a Rendell-Baker T-piece mask adapter with an expiratory limb.[1] In those cases in which halothane was preceded by nitrous oxide, nitrous oxide was discontinued within two minutes of loss of consciousness and at least fifteen minutes elapsed before taking a pneumotachographic tracing. Anesthesia was maintained with the same apparatus, fresh gas flow entering the mask adapter directly. The expiratory valve was not used. Fresh gas flow into the circuit varied from 5 to 6 liters per minute (never less than 1½ times the minute volume and usually more than 2 times the minute volume) delivered from the rotameters of a Foregger Texette machine, the halothane

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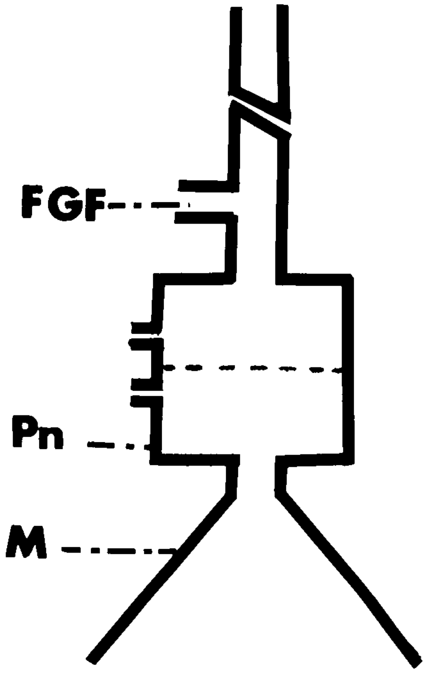

FIG. 1. Schematic drawing of apparatus used for recording respiratory values; FGF entrance of fresh gas flow; Pn pneumotachometer; and M Rendell-Baker mask.

vaporized from a Copper Kettle. These rotameters were calibrated using a Vol-O-Flow linear flow meter.* Following induction, the patient was maintained on 1.3 to 2.0 per cent halothane for satisfactory operating conditions.

Recordings of ventilation were made using one of two Fleisch pneumotachometers connected to a Sanborn differential pressure transducer and a Sanborn direct writer. Figure 1 is a schematic drawing of the apparatus used. The Rendell-Baker-Soucek mask,[1] the pneumotachometer and an Ayre T-piece, 1 cm. in diameter, were used for recording providing a maximum dead space (measured by water displacement) from 8 ml. in those under seven months, to 19 ml. in the older children. In a few cases the position of the pneumotachometer and Ayre T-piece were reversed. The system adopted for each patient was that which provided a linear response to rate of air flow through the pneumotachometer, a good tracing, minimal dead space, and minimal resistance. Linear responses up to 60 liters/minute were obtainable; the maximum in this series was 31 liters/minute. To minimize the effect of increased resistance and deadspace recording periods were limited to six seconds.

Measurements were made immediately prior to incision (approximately 20 minutes after induction), immediately following initial surgical stimulation, at intervals throughout operation, during recovery from anesthesia without surgical stimulation and just before return to the recovery room. Following each case the apparatus was calibrated with known flows of oxygen. Nitrous oxide was not used because the pressure difference across the pneumotachometer differed for the two agents at the same flows.

Results

Tidal Volume. The minimum tidal volume occurred during anesthesia in the absence of surgical stimulation. Maximum tidal volume coincided with the most intense surgical stimulus, usually with the skin incision, traction on the peritoneum, anal dilatation or incising periosteum. An attempt to correlate maximum tidal volume, minimum tidal volume and tidal volume observed during recovery with the patient's physical characteristics revealed tidal volume to correlate best with the weight of the patient (fig. 2). Correlation with height or surface area in this study gave comparable figures. When the patients were divided into groups, those under one year without sedation and those over one year with sedation, there was a significant difference when the index for tidal volume was based on height or surface area, while the difference was not significant when tidal volume was based on weight, permitting the entire group to be considered as a unit when body weight is used. Tidal volume correlated less well with age, the correlation coefficient being 0.71 for age and 0.79 for weight.

Mean values for tidal volume were 3.1 ml./kg. ±1.3 during anesthesia with no stimulation, 4.4 ml./kg. ±2.1 for maximum tidal volume in response to a surgical stimulus, and 5.9 ml./kg. ±3.2 during recovery. There were six patients with tidal volumes of 1.5 ml./kg.

* Manufactured by the National Instrument Laboratories, 828 Evarts St. N.E., Washington, D. C. Flow measurements are accurate to within 1 per cent.

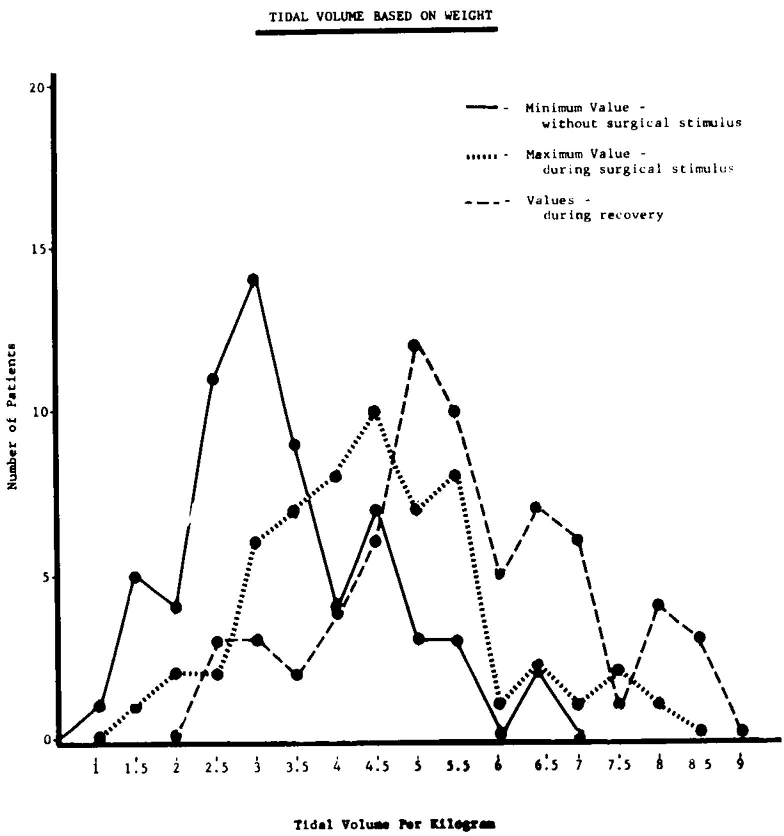

FIG. 2. Tidal volumes plotted against weight in kilograms.

or less during periods of no stimulation; of these, four patients demonstrated a fall in temperature, between 35.5° and 36° C. Four of five patients whose maximum tidal volume during surgical stimulus was less than 2.5 ml./kg. were the same four whose temperature had fallen. During maximum ventilatory response to surgery only four patients exceeded a tidal volume of 7 ml./kg. and only eight exceeded 5.5 ml./kg. As shown in figure 2, the range of values during recovery ranged very widely. Most of these patients with high tidal volumes during operation underwent exceptionally stimulating procedures.

Minute Volume. An attempt to correlate maximum minute volume with physical characteristics revealed the best correlation to be with height (fig. 3). When the minute volume was based on the height there was no difference between those under one year without sedation and those over one year with sedation. This was not the case if estimates were based on weight or surface area. Age was unreliable as a basis for estimating minute volume, age supplying a correlation coefficient of 0.45 compared to 0.55 for height. The mean for the minute volume was 17 ml./cm. height ±3.1 for the minimum ventilatory response during anesthesia, 28 ml./cm. ±5.1 during the maximum ventilatory response to surgery and 29 ml./cm. ±11 during recovery. During operation one value exceeded 50 ml./cm., and seven exceeded a minute volume of 40 ml./cm. Only nine patients exceeded a value of 40 ml./cm. during the recovery phase.

Respiratory Rate. Figure 4 shows the small differences in mean respiratory rate during anesthesia and recovery, also the highest and lowest rates during maximum and minimum ventilation are noted.

Flow Rate. Maximum inspiratory and expiratory flow rates obtained during uneventful

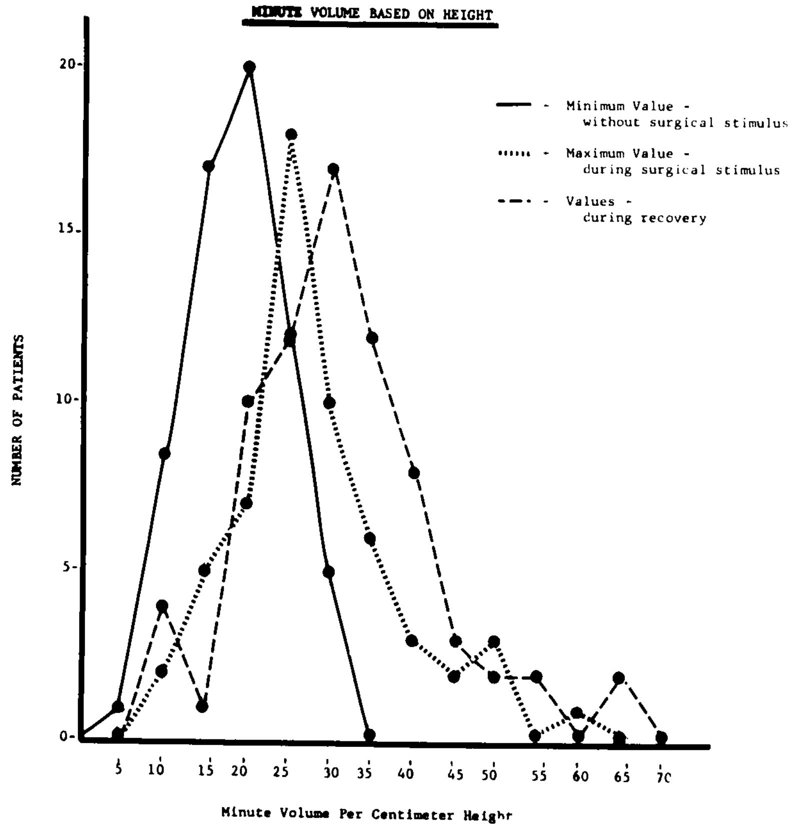

FIG. 3. Minute volume plotted against height in centimeters.

anesthesia in the various age groups are noted in tables 1 and 2.

The presence of an expiratory pause seemed to be related to the rate of respiration, the age and degree of sedation. Only one patient exhibited an expiratory pause with a respiratory rate greater than 50 per minute and only two of nine had no expiratory pause with respiratory rates less than 30. The youngest patient with an expiratory pause was 6 months old. The incidence of expiratory pause increased from 11 per cent in patients under one year to almost 50 per cent in the 4 to 5 year olds (tables 3 and 4).

Discussion

Since the arterial P_{CO_2} of the patients investigated in this series was not measured, it

TABLE 1. Inspiratory Flow Rates According to Age Liters per Minute

Age	Maximum	Minimum	Mean
0–3 months	9	3	4.9
3–6 months	11	6	7.8
6 months–1 year	12	7	8.0
1–2 years	25	6	13.0
2–3 years	18	6	12.0
3–4 years	20	12	15.1
4–5 years	21	7	14.9
	Only 2 over 20		

TABLE 2. Expiratory Flow Rates According to Age Liters Per Minute

Age	Maximum	Minimum	Mean
0–3 months	6	2	3.7
3–6 months	8	4	5.7
6 months–1 year	10	5	6.6
1–2 years	13	4	7.7
2–3 years	12	3	8.0
3–4 years	12	7	9.7
4–5 years	15	5	9.2
	Only 1 over 13		

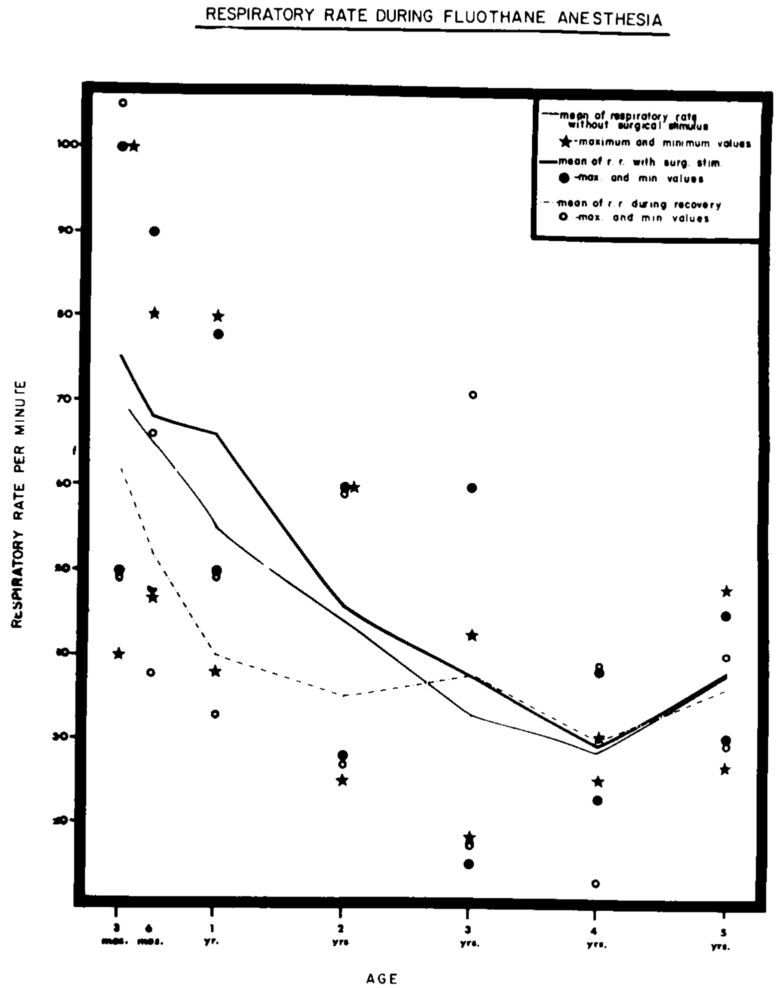

FIG. 4. Respiratory rate during operation and recovery.

is not possible to state whether the ventilation recorded in any particular case was adequate, although there was no clinical evidence to suggest otherwise. Further, caution must be exercised in assigning figures for mean values to individual patients inasmuch as the range of values varied considerably and was obviously affected by such factors as depth of anesthesia, technique, presence or absence of nitrous oxide, intensity of surgical stimulus and body temperature. These mean values are of interest as a rough guide. On the other hand, the maximum and minimum values are signifi-

TABLE 3. Expiratory Pause According to Age

Age	Number of Patients	Percentage of Patients
0–1 year	4	11%
1–2 years	4	33%
2–3 years	5	38%
3–5 years	6	46%

TABLE 4. Expiratory Pause According to Respiratory Rate

Respiratory Rate Per Minute	Percentage of Tracings	Number of Tracings
20–29	78	7
30–39	31	10
40–49	30	9
50–59	4	1
60+	2	1

cant as they were recorded during apparently uneventful anesthesia in a large number of cases. It can be assumed that such values would not regularly be exceeded.

It is important to make some estimate of the minute volume during anesthesia, particularly when semiclosed circuits without carbon dioxide absorbers are used. Ayre's T-piece arrangement[2] and Rees' modification[3] are popular with many anesthesiologists as modifications of Mapleson's systems C and D.[4] Although there is still doubt as to the volume of fresh gas flow needed to prevent rebreathing in these systems, it has been shown mathematically[5] and experimentally with mechanical models[6] that a flow rate twice the patient's minute volume is probably adequate to prevent hypercarbia. As respiratory rate is easily measured the minute volume could be calculated if some reliable estimate of tidal volume could be based on some physical characteristic of the patient. Alternatively, a figure for minute volume could be based directly on the patient's body habitus. Also, some knowledge of the tidal volume is essential in infants in considering the amount of mechanical deadspace allowable in anesthetic apparatus.

In attempting to estimate the fresh gas flow, the most important figure for tidal volume is the maximum value which occurs during anesthesia. In this series only four patients exceeded 5.5 ml./kg. These values occurred at times of maximum surgical stimulus such as traction on the peritoneum. The tidal volume was in general slightly lower during the course of the procedure. Therefore, a figure of 5.5 ml./kg. provides an adequate estimate for most patients except at the time of intense surgical stimulus.

On the other hand, the minimum tidal volumes were recorded during steady anesthesia in the absence of surgical stimulation, with one value as low as 1 ml./kg. and in another 5 patients between 1 and 1.5 ml./kg. Therefore, when using or designing pediatric equipment the fact must be remembered that such low tidal volume may be encountered even in normal children.

In these studies the best correlation between maximum minute volume during anesthesia was with the height of the patient. The minute volume of one patient exceeded 50 ml./cm. and in seven patients exceeded 40 ml./cm. during anesthesia. The latter provides adequate indication of the minute volume at all times during anesthesia, except during periods of maximum surgical stimulation. Although calculations based on weight or surface area give satisfactory figures, the indices appear to change with increasing age, necessitating different indices for each age group. These findings suggest the value of including height in the data available on an anesthetic record.

In many cases the minute volume and tidal volume during recovery were higher than those during operation. However, since the patient breathed into the apparatus for only a short time at this stage, we do not consider these volumes as important as those previously mentioned.

Our measurements agree rather well with estimated values recorded in the literature for this age group. These have been interpolated[6, 7] from data available in the newborn and older children or from estimates of other physiologic parameters such as carbon dioxide production.[8] Krieger[9] recently published his findings of various pulmonary parameters in 24 patients under 24 months, sedated with chloral hydrate. Values for tidal and minute volume agree with our measurements obtained during recovery. Hall[10] made measurements on 487 patients up to eight years of age during recovery from anesthesia, with the values reported larger than any in this series. While satisfactory for the estimation of maximum tidal and minute volumes, his figures, unwisely applied, could lead to the use of apparatus with deadspace excessive for the majority of children.

Respiratory rates were higher than expected from previously published data with other anesthetic agents, which is not surprising from the known pharmacological properties of halothane. In all age groups in this series there was a wide range in respiratory rate, with a tendency for the rate and range to decrease with increasing age.

Maximum flow rates in the respiratory tract are of importance when estimating the resistance of valves and orifices in anesthetic equipment. In addition, it has been shown that the flow rates are important in relation to the use of automatic ventilators in children.[7]

Summary

Parameters of pulmonary ventilation were measured in 59 patients under the age of five receiving halothane anesthesia. The data revealed that the tidal volume is reliably estimated from body weight, and minute volume from the height of the patient. Applicable values are considered to be 5.5 ml./kg. body weight for tidal volume and 40 ml./cm. height for the minute volume. Values for other parameters of ventilation are also presented.

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METASTASES AFTER ANESTHESIA Stress may influence the growth of a tumor or metastases. The stress may be trauma, operation, injection of chemicals or cortisone. To study the influence of anesthetics, tumor suspensions (Walker carcinosarcoma 256) were injected intravenously into four groups of 100 rats each. One group was anesthetized with intraperitoneal pentobarbital, one with chloroform, one with ether, and one was a control group. All animals died, or were sacrificed after nine weeks, and autopsies were done. Pulmonary metastases occurred as follows: Controls 37 per cent; pentobarbital 46 per cent; chloroform 64 per cent; ether 55 per cent. The difference is statistically significant between control and the ether and chloroform groups. Similar effects have been noted by others and may be due to lung irritation, reduced resistance, stress, or hypercoagulability of blood. (*Agostino, D., and Clifton, E. E.: Anesthetic Effect on Pulmonary Metastases in Rats, Arch. Surg. 88: 735 (May) 1964.*)

ELECTROLYTE DEFICIENCY Retention of salt and water by the kidneys occurs as one of the body's primary responses to injury and to disease. This is observed even after uncomplicated surgical procedures such as cholecystectomy with insignificant extrarenal losses of water. The antidiuretic effect following an elective operation may last for 48 to 72 hours and may be magnified as to extent and duration after severe trauma or chronic illness. Water loading, primarily in the extracellular phase, results. Whereas the healthy kidney continues to excrete potassium in the presence of low body concentrations, it is to conserve sodium when body stores become low. As a rule extrarenal losses of both fluids and electrolytes should be replaced as soon as they occur. (*McDonald, G. O.: Treatment of Electrolyte Deficiencies in Surgery, Surg. Clin. N. Amer. 44: 125 (Feb.)1964.*)