Inspiratory and Exspiratory Carbon Dioxide Concentrations During Halothane Anesthesia in Infants

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Carbon dioxide concentrations in respired air were measured in 23 infants, who underwent operation to correct cleft lip and palate. Measurements were carried out before, during and after halothane anesthesia, using various non-rebreathing valves, pediatric circle systems, and the Ayre T piece. End-tidal CO_2 concentrations in awake infants were lower than in adults. During halothane anesthesia end-tidal CO_2 concentrations increased significantly. Differences between the various non-rebreathing valves and pediatric systems were discussed.

THE DEVELOPMENT of the infrared analyzer and mass spectrograph for medical purposes permits the continuous registration of CO_2 concentration in respired air.[2, 6, 9, 20a, 24] In the last several years measurements have been made of CO_2 concentrations during inspiration and expiration in infants.[11, 14, 17b, 19, 29, 32] Determinations of CO_2 concentrations in infants during cyclopropane anesthesia have been made by Leigh and his co-workers [17b] and by Freemann and co-workers.[11] To our knowledge, measurements of end-tidal CO_2 concentrations in infants during halothane anesthesia have not been carried out. We therefore studied the relation between inspiratory and expiratory CO_2 concentrations and the use of different rebreathing and non-rebreathing systems for pediatric anesthesia with halothane.

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Methods

Carbon dioxide concentrations were measured in the respired air of 23 infants who underwent operation for correction of cleft lip and cleft palate. Their ages ranged from 4 to 16 months, and their weights between 7.1 and 11.5 kg. There was no evidence of any other disease of congenital anomaly, particularly heart disease.

Group I. Thirteen infants were premedicated with 1 mg. promethazine and 0.01 mg. atropine sulfate per kilogram of body weight, intramuscularly one hour before anesthesia.

Group II. Ten infants received 1 mg. promethazine per kg. of body weight 2 hours before operation and 1 to 2 mg. pethidine and 0.01 mg. atropine sulfate per kilogram of body weight, intramuscularly one hour before anesthesia.

The tracheas of 8 infants of group I and 5 of the group II were intubated in deep halothane anesthesia and 5 infants of each group in light halothane anesthesia, with the aid of 1 to 2 mg. succinylcholine per kg. body weight, intramuscularly in combination with hyaluronidase. After intubation anesthesia was maintained with a mixture of nitrous oxide, oxygen and halothane. Flow rates of nitrous oxide and oxygen were 2:1 or 2:2 liters per minute. Usually the infants required 0.3–0.7 per cent halothane in the inspired gas for satisfactory surgical conditions. Halothane was vaporized by means of a calibrated vaporizer, "Vapor" (Dräger Company, Germany).

The duration of anesthesia averaged 2 to 3 hours: infants breathed spontaneously. A non-rebreathing Frumin valve [12, 27] was used in 17 cases, and a Stephen–Slater valve [26] in 6 cases. The Frumin valve was connected to a special pediatric anesthesia system (Dräger Company)

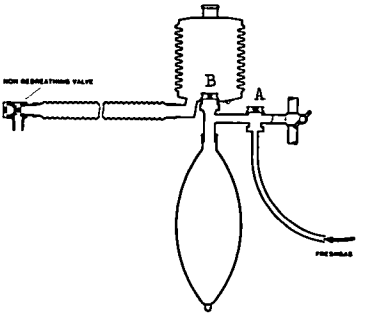

FIG. 1. The Dräger apparatus for pediatric anesthesia.

(fig. 1). The system contains two valves, the resistance of which is about 1.0 cm. of water, with flows up to 20 liters/min. During spontaneous respiration pressure equilibrium occurs at valve A. Measurement of maximal pressures in the system at different flows during spontaneous respiration gave the following results:

Flow Rate (liters/minute)	Pressure (cm. of water)
3	0.5
4	0.7
6	0.8
8	0.9
20	1.0

The bag serves as a reservoir. The corrugated rubber cylinder permits assisted or controlled respiration by closure of valve B.

For CO_2 analysis an infrared analyzer (URAS M) was used. The error introduced by the admixture of nitrous oxide was not greater than 0.1 per cent, by volume. URAS M was standardized using 3 different gas mixtures with known CO_2 concentrations between 3 and 8 per cent. The rate of flow of the gas aspirated through the analyzer was adjusted in such a way, that the curve obtained showed a definite plateau during expiration with the infant awake, and return to zero during inspiration (fig. 2). For registration a direct writing apparatus was used. The values obtained by the URAS M were corrected to alveolar conditions. Statistical significance was evaluated by the t test.[28] Bypass gaseous flow through the analyzer averaged 200 to 400 ml. per minute. The distal ends of the suction catheters were split in order to avoid the aspiration of mucus (fig. 3); there were 24–28 cm. long and 0.9 mm. in diameter.

The infants not anesthetized had the suction catheter inserted either through one nostril or into the large defect of the cleft lip and cleft palate. During aspiration either one or both nostrils were manually closed. The children were allowed to play or their attention was distracted by singing, etc.; infants who cried or were restless and whose curves did not show a regular pattern were not included in the investigation. The children anesthetized had the suction catheters inserted 2–4 cm. into a lateral opening of the endotracheal tube (fig. 4). The reinforced Magill tubes were 3.5–5 mm. in diameter and 13–16 cm. long. The infants breathed spontaneously during all measurements. Measurements were carried out on the awake child before and after premedication, 5–15 minutes after intubation, before and after extubation and several hours after the end of anesthesia. After intubation CO_2 concentrations were measured in each infant using the Stephen–Slater valve,[26] Ruben[23] and Frumin valves,[12, 27] Ayre T

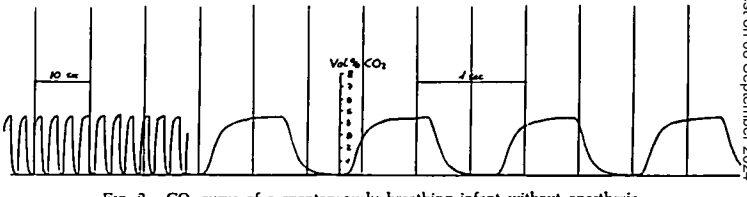

FIG. 2. CO_2 curve of a spontaneously breathing infant without anesthesia.

piece [1a, 1b, 5, 7] and the circle pediatric systems of Bloomquist [3] and Leigh.[17a] After these measurements the operation began. During operation the system as described above was used. After operation measurements of the end-tidal CO_2 concentrations were made with the Stephen–Slater, Ruben and Frumin valves, the Ayre's T piece of Bloomquist and Leigh circuits.

Results

In only 4 cases were we able to obtain useful curves from unpremedicated infants. The mean value of the end-tidal CO_2 was 32.4 mm. of mercury. After premedication with promethazine and atropine or with promethazine/pethidine/atropine the mean value of end-tidal CO_2 concentration was 34.3 mm. of mercury (S.D. ± 3.82) in 23 cases (table 1). End-tidal CO_2 concentrations after promethazine/pethidine/atropine were somewhat higher than after promethazine and atropine. The difference was statistically not significant. The small number of curves from unpremedicated infants does not permit comparison with the values obtained after premedication.

After tracheal intubation all infants showed a marked rise in end-tidal CO_2 concentrations with the mean value in 21 infants, 45.7 mm. of mercury (S.D. ± 4.06) (table 1). The difference between end-tidal CO_2 concentrations before and after the beginning of anesthesia was highly significant ($P < 0.001$). There were no remarkable differences between infants during deep or light halothane anesthesia. During the inspiratory phase no measurable quantities of CO_2 were found.

After the start of operation, which lasted 2–3 hours, little decrease of end-tidal CO_2 concentrations was registered. The mean value for 15 infants was 43.5 mm. of mercury (S.D. ± 6.56). The decrease was of no statistical significance. Differences among various pediatric circle systems, non-rebreathing valves and Ayre's T piece were noted only in inspiration never in expiration. Using the Stephen–Slater valve and the Ayre T piece we found no measurable CO_2 concentrations during inspiration at respiratory rates of 24 to 60 per minute. On the other hand we were able to measure inspiratory CO_2 concentrations of 0.1 to 0.5 vol. per cent using the circle absorption systems of Bloomquist and Leigh and the Frumin and Ruben valves while the infants were breathing at a rate greater than 40 per minute. At respiratory rates below 40 per minute we were unable to measure any respired CO_2 concentrations with these systems (table 1).

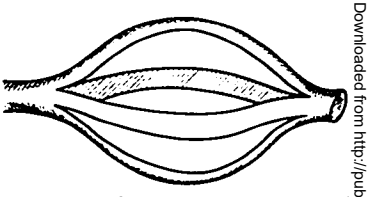

FIG. 3. Split-end of a suction catheter to avoid aspiration of mucus.

The measurements obtained immediately after extubation were unsatisfactory because most of the infants started to cry or cough. Therefore we repeated the measurements 2 to 4 hours after operation. The mean value of the end-tidal CO_2 concentration of 17 infants was 32.8 mm. of mercury (S.D. ± 4.38). This was in the normal range and shows that there had been full recovery from anesthesia.

Discussion and Conclusions

According to the literature it is assumed that the end-tidal CO_2 concentration corresponds to the CO_2 concentration in the alveoli.[9, 20b, 20c] Provided that the patient has no cardiac or pulmonary disease one may calculate the arterial pressure of CO_2 from the end-tidal CO_2 concentration. The alveolar-

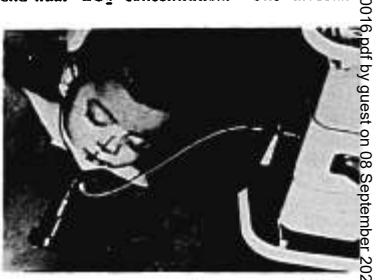

FIG. 4. Arrangement for measuring CO_2 concentrations during anesthesia.

TABLE 1. Respiratory Rates and End-Tidal CO_2 Concentrations Before, During and After Anesthesia

	Age (mos.)	Body Weight (kg.)	Premedication		5–15 Min. After Intubation		2–3 Hours After Intubation		2–4 Hours After Extubation	
			Resp. rate/min.	$P_{ET}CO_2$ mm. Hg	Resp. rate/min.	$P_{ET}CO_2$	Resp. rate/min.	$P_{ET}CO_2$	Resp. rate/min.	$P_{ET}CO_2$
1	8†	8.5	48	33.4	48	42.1	48	36.3	48	29.1
2	8†	8.4	45	34.7	45	39.9	42	43.9	—	—
3	11†	9.0	42	29.0	42	39.8	42	44.9	—	—
4	7.5†	8.1	29	32.7	39	42.3	—	—	60	31.6
5	6†	7.5	45	35.0	45	45.6	42	42.6	—	—
6	16	11.5	59	32.1	49	52.2	—	—	42	32.1
7	9	11.7	51	37.9	—	—	—	—	—	—
8	8	9.2	42	33.4	60	57.1	—	—	48	32.1
9	16	10.0	21	36.7	33	37.2	24	42.3	24	39.4
10	4.5	7.0	48	36.5	—	—	—	—	42	24.0
11	11	10.2	42	28.8	78	46.7	48	35.4	54	30.0
12	6	8.2	36	33.5	56	35.4	—	—	—	—
13	9	8.3	38	30.6	48	56.9	30	43.0	42	29.2
14*	7†	7.6	39	39.1	48	48.8	33	45.7	48	28.4
15*	6†	7.2	44	40.5	78	40.5	66	32.7	42	36.3
16*	6†	7.4	32	41.2	36	37.2	51	45.9	48	36.1
17*	8.5†	7.5	40	35.5	48	50.9	—	—	51	29.0
18*	7†	8.5	48	25.5	22	47.3	42	48.8	42	31.2
19*	7	8.2	28	34.0	—	54.7	32	49.5	42	40.5
20*	9	9.1	38	29.9	39	43.4	40	43.4	36	37.6
21*	15	10.7	30	33.8	42	49.5	36	49.4	36	32.4
22*	8	9.2	24	39.9	36	48.5	36	49.5	30	38.0
23*	7	8.3	48	34.5	—	45.1	—	—	—	—
$\bar{x}$				34.3		45.7		43.5		32.8
SD				±3.82		±4.06		±6.56		±4.38

* With meperidine.
† With succinylcholine for intubation.

arterial CO_2 pressure gradient in the resting adult is 0.4 to 1.0 mm. of mercury according to Katsaros and his co-workers,[16] Rahn [20b] and Ulmer and Reichel.[20c] For our measurements, however, we had to consider the influence of anesthesia and apparatus. Severinghaus and his co-workers,[25] Ramwell [21] and Nunn and Hill [18] found a rise in the alveolar-arterial pressure gradient during anesthesia, which reached a mean value of 4.6 mm. of mercury under conditions of normal dead space. Slight hemorrhage may cause a rise of the alveolar-arterial CO_2 gradient.[13] Taking these facts into account, we found a further elevation of the arterial CO_2 pressure during the use of halothane.

Freemann and his co-workers [11] and Digby-Leigh and co-workers [17b] registered end-tidal CO_2 concentrations in infants during surgical cyclopropane anesthesia. Because the latter measurements were done under hypothermic conditions we are not able to compare their results with ours. Freemann and co-workers did not carry out control measurements. We can only compare our results with the end-tidal CO_2 concentrations in awake infants below three months of age published by Hahn *et al.*,[14] Proenca and Wenner,[19] Riegel [22] and Strang [29] (table 2). Our data obtained with and without premedication and several hours after operation show a significantly lower end-tidal CO_2 concentration than in adults. Our values agree with those of others,[14, 19, 22, 29, 31] who found lower arterial or alveolar CO_2 concentrations in infants than in adults (table 2).

The cause of the rise of the end-tidal CO_2 concentration during halothane anesthesia is, we believe, the result of a depression of res-

TABLE 2. Alveolar and Arterial CO_2 Tensions in Infants

Author	Age, days	n	Determination	mm. Hg	S.D.
Hahn[11]	16 (hrs)–9	10	End-tidal air	31.5	
Proenca and Wenner[19]	16–366	25	End-tidal air	32.5	±3.14
Proenca and Wenner[19]	60–366	10	Art. capillary blood*	32.79	±2.05
Riegel[22]	6–27	12	Blood from art. temporalis	36.7	±4.08*
Riegel[22]	38–60	15	Blood from art. temporalis	34.8	±3.58*
Riegel[22]	61–97	13	Blood from art. temporalis	32.9	±2.74*
Riegel[22]	118–480	13	Blood from art. temporalis	32.1	±3.77*
Strang[29]	8–30	9	End-tidal air	33.2	±4
Wenner *et al*[31]	11–330	37	Blood from sinus sagittalis sup.	31.6	±3.5
Podlesch *et al.*	116–484	23	End-tidal air†	34.3	±3.82
Podlesch *et al.*	136–484	17	End-tidal air‡	32.8	±4.38

* After premedication with 18 mg. dioxo-diethyl-methylpiperidine per kg. body weight.
† After premedication with promethazine/atropine or promethazine/pethidine/atropine.
‡ Two to four hours after operations of cleft lips and cleft alveoli.
* Mean variation of single determinations.

piration by halothane. Fink and his co-workers [10] stated that, in adults, the deepening of halothane anesthesia corresponds closely with an elevated threshold of the respiratory center. The question remains whether the rise of the end-tidal CO_2 concentrations for the duration of anesthesia has any physiological significance. Hypercarbia may be followed by disturbances in the regulation of the respiration and by changes of the electrolytes. In our patients we detected no ill effects although we have done only measurements of blood pressure and heart rate. But, we believe that an optimal anesthetic technique must guarantee the constancy of physiological conditions, particularly of the blood gases. Therefore we must conclude that assisted or controlled respiration is desirable in all infants during halothane anesthesia.

The differences in inspiratory CO_2 concentrations we measured, being dependent upon respiratory rate and the various anesthetic systems used can, we think, be explained by the varying dead space in the systems used. These differences, however, may be overlooked with assisted or controlled respiration. The usefulness of systems or valves for administering anesthesia to infants operated upon for cleft lip and palate will depend therefore upon other factors: the possibility of controlled respiration away from the operating field; lack of disturbance created by the size or weight of the system or valve, and low cost. In these respects we found the Frumin valve in combination with the Dräger system most useful.

Summary

Inspiratory and expiratory CO_2 concentrations were measured before, during and after halothane anesthesia in 23 infants who underwent operation to correct cleft lip and palate. The conscious infants had significantly lower end-tidal CO_2 concentrations than values reported in adults. During halothane anesthesia, end-tidal CO_2 concentrations rose significantly. Differences among the Frumin, Ruben and Stephen–Slater valves, the Ayre T piece and the circle systems of Bloomquist and Leigh were discussed.

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