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Exhaled Carbon Dioxide in Healthy Term Infants Immediately after Birth

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Objective To measure exhaled carbon dioxide (ECO$_2$) in term infants immediately after birth.

Study design Infants >37 weeks gestation born at The Royal Women's Hospital, Melbourne, Australia were eligible. A combined flow sensor and mainstream carbon dioxide (CO_2) analyzer was placed in series proximal to a facemask to measure ECO$_2$ and tidal volumes in the first 120 seconds after birth.

Results Term infants (n = 20) with a mean (SD) birth weight of 2976 (697) g and gestational age of 38 (2) weeks were included. Infants took a median (range) 3 (1-8) breaths before ECO$_2$ was detected. The median (range) of maximum ECO$_2$ was 51 (40-73) mm Hg at 70 (21-106) seconds after birth. Within the first 10 breaths, CO_2 increased from 0-27 (22-34) mm Hg. The median (IQR) tidal volume during the breaths without CO_2 was 1.2 (0.8-3.1) mL/kg compared with 7.3 (3.2-10.9) mL/kg during the first 10 breaths where CO_2 was exhaled.

Conclusions The first breaths for an infant after birth did not contain ECO$_2$. With aeration of the distal gas exchange regions, tidal volume and ECO$_2$ significantly increased. ECO$_2$ can be used to monitor lung aeration immediately after birth. *(J Pediatr 2015;166:844-9)*.

Before birth, the airways are liquid-filled, and the lungs take no part in gas exchange, which occurs across the placenta.[1,2] At birth, lung liquid has to be cleared from the airways to allow air entry and establishment of a functional residual capacity (FRC).[1,2] Although much airway liquid can be removed before birth, a significant amount remains in the airways and its removal after birth is dependent on the infant's respiratory effort.[2] In the minutes after birth, the liquid within the airways is gradually cleared and replaced by air. Term and preterm infants use several different breathing patterns immediately after birth to achieve lung aeration.[3] However, when infants fail to breathe adequately immediately after birth, it is important to apply positive pressure ventilation sufficient to facilitate gas exchange but without causing lung injury.[4] At present, very little information is available to the clinician to assess the effectiveness of positive pressure ventilation.[5,6] Clinicians lack feedback from either the patient or standard monitoring equipment to achieve the desired balance of aerating the distal gas exchange units (alveoli) without over-distending the lung thereby causing lung injury.[7,8]

Carbon dioxide (CO_2) is produced in the tissues, transported to the lung, and exhaled from the lung. Therefore, CO_2 can only be detected in expired gas if the lung is aerated, effective gas exchange has occurred, and adequate cardiac output is present.[8-10] Hooper et al recently described how exhaled CO_2 (ECO$_2$) levels are an important indicator of ventilation of the distal gas exchange units.[8] Several studies reported the use of ECO$_2$ monitoring during neonatal transition to: (1) determine correct tube placement[11,12]; (2) identify airway obstruction[13,14]; (3) using CO_2 targeting during mask ventilation[15]; or (4) assessing lung aeration in preterm infants.[8-10,16]

No study has reported ECO$_2$ values in the first minutes after birth in term infants. The aim of the study was to measure the amount of ECO$_2$ in term infants in the first 120 seconds after birth.

Methods

All infants were born at The Royal Women's Hospital, Melbourne, Australia, a tertiary perinatal center where ~7300 infants are born each year. Infants who were >37 weeks postmenstrual age were eligible for the study. Consent was requested before birth and if the mother was not in established labor. Infants were excluded from final analysis if they had a congenital abnormality that might adversely affect their breathing. The Royal Women's Hospital Research and Ethics Committees approved the study.

The NICO Cardiopulmonary management system (Novametrix Medical System, Wallingford, Connecticut) consists of a combined CO_2/flow sensor, which

CO_2	Carbon dioxide
ECO$_2$	Exhaled CO_2
FRC	Functional residual capacity

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measured ECO_2 by infrared absorbance and gas flow, tidal volume, respiratory rate, and airway pressures with a flow sensor. The dead space of the CO_2/flow sensor is ~1 mL. The CO_2/flow sensor was attached to a facemask (Laerdal round mask; Laerdal, Stavanger, Norway). Immediately after birth, the infants were placed on the mother's chest, and the facemask was placed on the infants face to cover the mouth and the nose. This procedure was performed before the cord was clamped. To minimize interference with parent-infant bonding and to allow standard assessments and monitoring of term infants at birth, we only took measurements for the first 120 seconds from birth. If there were any signs of respiratory compromise, the study was abandoned and respiratory support was given according to the Neonatal Resuscitation guidelines.[4]

Data Collection and Analyses

All recordings in the delivery room were performed by G.S. Time of birth was defined as delivery of the whole baby. The signals of airway flow, tidal volume, airway pressure, and ECO_2 were recorded at 200 Hz using Spectra physiological recording program (a customized neonatal respiratory physiology program). Demographic characteristics of study infants were recorded. A breath-by-breath analysis was performed manually for the duration of each recording. Tidal volume, inflation time, gas flow, and ECO_2 were measured. Breaths were excluded if mask leak was >30%. The data are presented as mean (± SD) for normally distributed continuous variables and median (IQR) when the distribution was skewed. For all respiratory variables, the mean value for each infant was calculated first and then either the mean or median of the median calculated. The clinical characteristics and outcome variables were compared using Student *t*-test for parametric and Mann-Whitney *U*-test for nonparametric comparisons for continuous variables, and χ^2 for categorical variables. ECO_2 values during different breathing patterns were compared using repeated measures ANOVA with Bonferroni post-test. *P* values are 2-sided, and $P < .05$ was considered statistically significant. Statistical analyses were performed with Stata (Intercooled 10; StataCorp, College Station, Texas). The study was reported according to The Strengthening the Reporting of Observational Studies in Epidemiology statement guidelines.[17]

Results

We included a convenience sample of 20 term infants. All infants initiated spontaneous breathing, and none required respiratory support, intubation, chest compressions, or epinephrine. The mean (SD) birth weight was 2976 (697) g, and gestational age 38 (2) weeks. Seven infants (35%) were male and the median (IQR) 1 and 5 minute Apgar scores were 9 (7; 9) and 9 (9; 10), respectively. A total of 1129 breaths were analyzed, with a median (IQR) of 54 (42-69) per infant. The face mask was placed over the baby's mouth and nose at a median (IQR) of 5 (3-8) seconds after birth.

CO_2

ECO_2 was first detected at a median (range) of 3 (1-8) breaths or 15 (12-22) seconds after birth (Table). Within the next 10 breaths, CO_2 increased significantly to 27 (22-34) mm Hg in all infants ($P < .0001$) (Table and Figures 1 and 2). Three infants had significantly less measured ECO_2 in the first 10 breaths compared with the other 17 infants (Table). Increases in ECO_2 were associated with increases in tidal

Table. Tidal volume, exhaled CO_2, and mask leak during the first 120 seconds

ID number (n = 20)	Number of breaths without ECO_2	V_{Te} (mL/kg) without ECO_2	V_{Te} (mL/kg) from the first 10 breaths with ECO_2	*P* values for comparison of V_{Te} with and without CO_2	ECO_2 (mm Hg)	Mask leak (%)
1	3	0.9 (0.6-4.0)	11.4 (6.7-12.7)	.0078	21 (18-24)*	23 (16)
2	3	0.9 (0.6-4.0)	12.1 (6.9-13.2)	.0084	22.5 (13-25)*	22 (15)
3	8	2.5 (1.5-3.5)	13.4 (6.6-20.3)	.0015	31 (28-35)*	33 (23)
4	4	0.8 (0.5-1.3)	7.7 (3.1-10.4)	.0289	25 (20-26)*	24 (24)
5	1	3.7	10.7 (9.7-11.6)		29 (26-33)*	20 (14)
6	1	0.8	1.1 (0.8-1.7)		12 (8-14)*	38 (25)
7	8	2.1 (0.8-2.9)	6.3 (1.9-11.7)	.0165	50 (20-53)*	43 (25)
8	2	0.5	9.6 (4.0-11.2)		53 (50-57)*	26 (20)
9	1	0.3	2.5 (2.4-3.3)		34 (27-43)*	12 (9)
10	0	-	4.6 (3.8-4.9)		22 (18-30)*	36 (21)
11	2	0.7 (0.6-0.8)	7.0 (6.7-8.3)	.0076	27 (17-38)*	27 (20)
12	5	0.9 (0.7-2.9)	12.5 (6.0-14.2)	.0032	36 (35-40)*	17 (13)
13	1	0.6	3.7 (1.2-7.1)		29 (20-42)*	24 (17)
14	5	1.6 (1.2-2.1)	1.4 (1.1-2.8)	.6163	8 (7-10)*	27 (17)
15	1	3.1	10.8 (4.4-16.5)		26 (10-35)*	34 (29)
16	1	6.3	1.9 (0.9-2.4)		8.5 (7-10)*	28 (22)
17	2	0.6	11.0 (4.6-12.8)		52 (49-57)*	26 (21)
18	1	0.3	2.4 (2.2-3.1)		33 (27-42)*	12 (9)
19	0	-	4.6 (3.8-5.0)		22 (18-29)*	35 (21)
20	2	0.8 (0.7-0.9)	7.8 (7.4-9.2)	.0076	26 (17-37)*	26 (19)

ID, identification; V_{Te}, expiratory tidal volume.
Values are presented as median (IQR) unless indicated *mean (range).