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Spontaneous Breathing Patterns of Very Preterm Infants Treated With Continuous Positive Airway Pressure at Birth

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ABSTRACT: There are no data describing how very preterm infants breathe spontaneously immediately after birth. We studied a convenience sample of spontaneously breathing infants ≤32 wk' gestation treated with facemask continuous positive airway pressure at birth. Airway pressure and flow were measured and each breath analyzed. Twelve infants had 792 breaths suitable for analysis. Results are given as mean (SD). Gestational age and birth weight were 29 (1.9) wk and 1220 (412) g. Recordings were started 159 (77) s after birth. The inspiratory pattern and duration was similar in all breaths at 0.36 (0.11) s. There were five expiratory patterns; most infants had more than one. In 79% of breaths expiratory duration (1.6 (1.1) s) was slowed or held by interruption or braking of expiratory flow. It was braked in 47% to a complete expiratory hold, in 22% by grunting or crying, and in 10% by slow or interrupted expiration. In 21% of the breaths, expiration was not interrupted and lasted 0.53 (0.13) s. Half of these breaths represented a panting pattern (rate >60 /min). Immediately after birth, most very preterm infants, treated with continuous positive airway pressure, frequently prolong their expiration by braking the expiratory flow. **(*Pediatr Res* 64: 281–285, 2008)**

Very preterm infants may have difficulty aerating their lungs after birth because of poor respiratory drive, weak muscles, flexible ribs, surfactant deficiency, and impaired lung liquid clearance (1–4). However, many very preterm infants treated immediately after birth with continuous positive airway pressure (CPAP) breathe well and achieve normal blood gases (5,6).

Between 1960 and 1986, observational data were gathered immediately after birth from small numbers of spontaneously breathing term infants and used to inform international guidelines for neonatal resuscitation (7–14). There are no data describing how very preterm infants breathe and aerate their lungs immediately after birth. It may be inappropriate to assume the results of studies of term infants also apply to very preterm infants.

The aim of this study was to investigate the spontaneous breathing patterns of very preterm infants treated with CPAP immediately after birth.

PATIENTS AND METHODS

These physiologic studies [1]were approved by the Royal Women's Hospital Research and Ethics committees. Parental consent for these recordings was obtained.

At the Royal Women's Hospital, Melbourne, spontaneously breathing newly born very preterm infants with respiratory difficulty are assisted with a facemask CPAP. Between 2004 and 2007, we recorded physiologic parameters during delivery room stabilization of very preterm infants. All recordings of infants born at ≤32 wk' gestation, who were spontaneously breathing, while treated with CPAP *via* a face mask, were identified and their breathing patterns in the first 10 minutes of life were analyzed. Our guidelines recommend to start with a CPAP-level set on 8 cmH_2O. Infants were excluded if positive pressure ventilation was given at birth. We only used recordings of infants if there were: a) no signs of mask leak, b) a clean flow signal, not disturbed by secretions or infant movements, and c) no signs of movement of the mask.

Recording equipment. Gas flow in and out of the infant was measured with a hot-wire anemometer (Florian: Acutronic Medical Systems AG, Zug, Switzerland) placed between the T-piece of a resuscitation device (Neopuff Infant Resuscitator, Fisher and Paykel, Auckland, New Zealand) and the facemask. This signal was integrated to derive inspired and expired tidal volume. Airway pressure was measured immediately proximal to the mask. The signals of airway flow, tidal volumes, and airway pressure were digitised and recorded at 200 Hz using a neonatal respiratory physiologic recording program (Spectra, Grove Medical Limited, Hampton, UK).

Data collection. Demographic data were collected from the hospital records. The total number of breaths analyzed for each infant was noted, including their time after birth. Details of the waveforms of pressure, flow, and tidal volume were carefully analyzed to identify the breathing patterns. Breaths of each pattern were analyzed in detail and the following parameters noted (see also Figures): respiratory rate, inspiration pattern and duration, expiratory hold (the time from zero flow at the end of inspiration to the start of the main expiratory flow), expiratory duration, postexpiratory pause (the time from zero flow at the end of expiration to the start of positive flow at the beginning of inspiration), duration of each breath, peak inspiratory flow, peak expiratory flow; inspiratory and expiratory tidal volumes (15).

Data analysis. Data were analyzed with SPSS (SPSS for windows, version 12.0, 2005, Chicago, IL) and presented as mean (SD) or number (%) where appropriate.

RESULTS

Recordings from 103 infants were examined in detail, 91 of these were excluded from analysis for the following reasons: 58 infants were ventilated with mask and bag at the start of resuscitation, 27 recordings showed mask leak and 6 flow signals were disturbed by secretions or movement of the mask. Twelve infants had recordings that were suitable for analysis. Their mean (SD) gestational age was 29 (1.9) weeks, birth weight 1220 (412) g and median (range) of the 5 min Apgar score was 8 (8,9). Eleven received prenatal steroids and seven were born by

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Abbreviation: CPAP, continuous positive airway pressure caesarean section. The mean time for the start of recording the analyzed breaths was 159 s (range, 26–301) after birth. None of the infants were intubated in the delivery room.

A total of 792 breaths (range, 17–105 per infant) were analyzed. The pattern of inspiration was similar in all breaths with a duration of 0.36 (0.11) s. There were five different patterns of expiratory flow (Figs. 1–5). Three were characterized by interruption or braking of expiration and were seen in 79% (627/792) of the breaths. They prolonged the expiratory time to 1.6 (1.1) s. The remaining two patterns were seen in 21% (165/792) of the breaths. These showed no evidence of interruption or braking of expiration and had an expiration time of 0.53 (0.13) s. The numbers of breaths of each pattern for each patient are shown in Table 1. In most infants, more than one pattern was observed. The respiratory parameters of each pattern are shown in Table 2.

Expiratory hold. In 47% (372/792) of the breaths expiration was braked to a complete hold, postponing the main expiratory flow (Fig. 1). This pattern was characterized by a period of no expiratory flow ending with a single expiratory flow peak or multiple expiratory flow peaks. Expiration was immediately followed by an inspiration, *i.e.*, there was no postexpiratory pause.

Slow expiration. In 10% (83/792) of breaths, the expiratory pattern was characterized by an initial low expiratory flow rate ending with a single expiratory flow peak late in expiration and/or frequently interrupted expiratory flow waves (Fig. 2). These were immediately followed by an inspiration.

Crying/grunting. In 22% (172/792) of the breaths, expiration was slowed by either grunting or crying (Fig. 3*A* and *B*). This pattern was characterized by a large inspiration followed by high frequency interruptions to the expiratory flow wave, observed as a noise signal in the wave. Expiration was then immediately followed by inspiration. We categorized crying and grunting as one pattern as it was difficult in most cases to distinguish between them from the recording and we did not record sound.

Patterns where expiration was not braked. In 21% (165/792) of the breaths, an unbraked or normal expiratory pattern was seen (Figs. 4 and 5). This was characterized by uninterrupted expiration with peak expiratory flow early in expiration. Expiration was not prolonged (I:E time approximately 1:1.5) although sometimes the expiratory flow was followed by an expiratory pause before the next inspiration (Fig. 4). In 91/165 of these breaths, the pattern was characterized by a

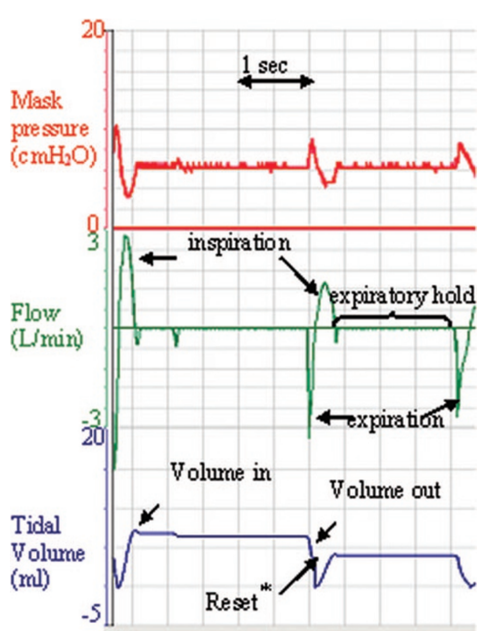

Figure 1. Two examples of the expiratory hold pattern, characterized by a period of no expiratory flow ending with a single expiratory flow peak or multiple expiratory flow peaks. Expiration is immediately followed by an inspiration; there is no postexpiratory pause. *Note that the software setting is that it resets volume trace as soon as expiratory flow trace reaches baseline.

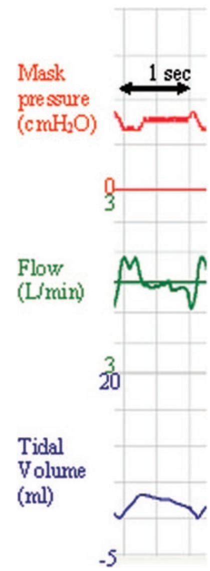

Figure 2. An example of a slow expiration pattern, expiratory flow is slowed or frequently interrupted. Expiration is immediately followed by an inspiration, there is no postexpiratory pause.

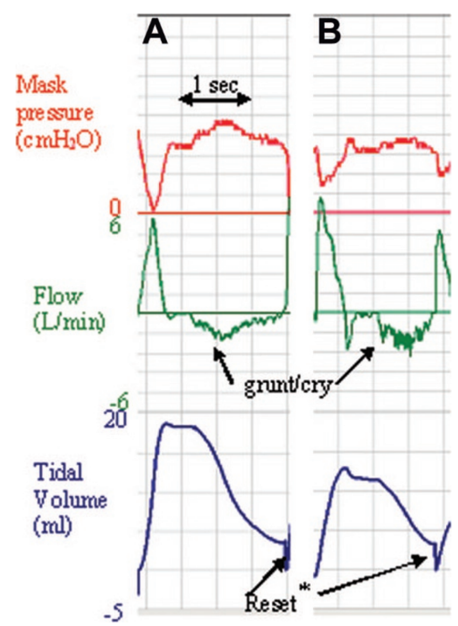

Figure 3. *A*, *B*. Two examples from patient 11 with the crying/grunting pattern (scale of flow is doubled to fit peak inspiratory flow rate). In both breaths expiration is slowed down and a noise signal with high frequency is visible. *Note that the software setting is that it resets volume trace as soon as expiratory flow trace reaches baseline.

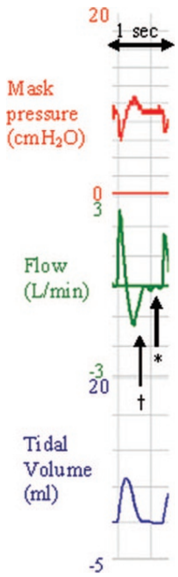

Figure 4. An example of a normal expiratory pattern without braking, characterized by a peak expiratory flow† at the beginning of expiration and showing a postexpiratory pause*.

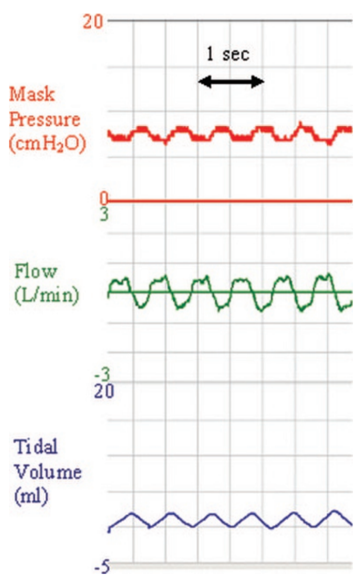

Figure 5. An example of panting pattern with respiratory rate of 96/min, tidal volume 2 mL/kg and expiratory time is approximately equal to inspiratory time.

respiratory rate greater than 60/min by shortening the expiratory time (I:E time to approximately 1:1) and small tidal volumes. In these breaths, there was no postexpiratory pause before inspiration. We named this the panting pattern (Fig. 5).

DISCUSSION

Most of the breaths of these very preterm infants, recorded in the minutes after birth, were characterized by interruption, or braking, of the expiratory flow. This slowed or even stopped the expiration and increased the expiratory time. Slow expiration, grunting/crying, and the expiratory hold pattern each represent different forms of expiratory braking (16–23). These patterns were shown to prevent a loss of lung volume during expiration in older term (16–23) and preterm infants (19,20).

Airflow is controlled throughout the breathing cycle by reflex action of diaphragmatic and laryngeal muscle activity (24–30). These reflexes are present at birth in term and preterm infants and have a crucial role in the control of breathing and lung volume (22,31–37). There are two mechanisms for stopping or slowing expiratory flow and maintaining an elevated lung volume during expiration. The first is diaphragmatic postinspiratory activity, which slows the rate of lung deflation by counteracting its passive recoil (16–20). The second is by closure or narrowing of the larynx (19,21–23). The expiratory noise associated with vocal cord adduction, *i.e.*, grunting has been recognized as a dynamic braking of expiration by the larynx (22,38). In absence of an audible grunt, the larynx still maintains a dynamic role in slowing expiration (27).

The pattern that we most frequently observed, the expiratory hold pattern, has similar characteristics to the first breaths observed in term infants at birth (13,39,40). After inspiration, gas is held in the lung under pressure by laryngeal adduction braking the expiratory flow. This has also been observed in preterm and term infants during spontaneous breathing later in life, but did not occur as frequently as in our study (16–19,22,23,38).

During braked expiration, the closed or narrowed glottis, with increased intra-pulmonary pressure from abdominal muscle contraction, causes the airway pressure to be maintained above atmospheric. This could represent an important force for clearing the fluid from the lung, facilitating distribution of gas within the lung, and splinting the alveoli and airways open (9,10,13,14,22,39).

Another strategy infants can use to increase end-expiratory volume is a high respiratory rate. This was seen in the panting pattern. The shortened expiratory time reduces the time for gas to leave the lung (35).

The spontaneous gas flow patterns we observed are different from those seen when manual inflations are given during neonatal resuscitation (Fig. 6). The neonatal resuscitation guidelines do not mandate any particular ventilation pattern, although they do suggest a rate of 40–60/min (41). Prolonged inflations are mentioned but not mandated for the initial breaths (41). This study demonstrates that very preterm infants have specific mechanisms to inflate their lungs and try to keep them inflated immediately after birth. It is possible that a similar strategy used during the initial resuscitation of a preterm infant who is apnoeic or breathes insufficiently, *i.e.*, inflation followed by a hold and a short expiration, may be more effective than traditional techniques which use a short inspiratory time and no hold.

Making recordings of how very preterm infants breathe immediately after birth is very difficult. Because of the constraints of not interfering with the infant's care or resuscitation and yet applying a facemask with a pneumotachograph and CPAP device attached, as soon as possible after birth, limited the number of infants that could be recorded in the time available and the number of recordings that could be made. This is an area of research where it is not possible to study large numbers in detail and obtaining a recording of sufficient quality for analysis limited the number of inflations that could be studied. In particular, it caused a large variation in the number of breaths

Table 1. *Number of each type of breathing pattern for each infant*

Infant	Gestation (wk)	Expiratory hold	Crying/grunting	Slow expiration	Panting	Unbraked expiration, normal respiratory rate	Total
1	26	49	10	5	2	2	68
2	28	22	0	0	0	0	22
3	28	32	5	1	0	0	38
4	30	8	0	1	31	2	42
5	29	37	5	1	12	0	55
6	29	58	28	10	5	3	104
7	27	46	0	10	18	15	89
8	27	5	11	0	11	51	78
9	32	42	16	37	2	1	98
10	29	56	22	17	10	0	105
11	32	10	66	0	0	0	76
12	28	7	9	1	0	0	17
Total		372	172	83	91	74	792

Table 2. *Respiratory parameters for each breathing patterns for all infants*

Parameter mean (SD)	Expiratory hold $n = 372$	Slow expiration $n = 83$	Crying/grunting $n = 172$	Unbraked expiration, normal respiratory rate $n = 84$	Panting $n = 81$
Respiratory rate (min^{-1})	32 (11)	48 (16)	42 (18)	54 (4)	88 (18)
Inspiratory time (sec)	0.36 (0.10)	0.34 (0.15)	0.38 (0.14)	0.40 (0.08)	0.34 (0.07)
Expiratory hold (sec)	1.53 (1.10)	0	0	0	0
Expiratory time (sec)*	1.85 (1.14)	1.10 (0.90)	1.30 (0.75)	0.65 (0.11)	0.41 (0.14)
Postexpiratory pause (sec)	0	0	0	0.07 (0.03)	0
Peak inspiratory flow (ml/s)	32 (16)	29 (130)	63 (37)	22 (9)	20 (10)
Peak expiratory flow (ml/s)	−42 (30)	−24 (14)	−36 (24)	−19 (15)	−18 (12)
Tidal volume (ml/kg)	5.8 (4.1)	3.5 (2.3)	7.5 (4.2)	4.2 (1.5)	3.1 (1.7)

* Expiratory time of expiratory hold pattern is time of expiration plus duration of the hold.

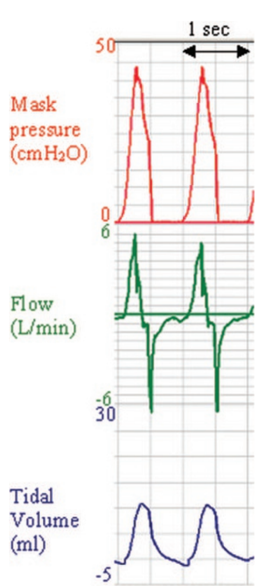

Figure 6. Part of a recording of resuscitation of a neonate born at 26 wk gestation showing two inflations with Laerdal mask and bag. Inspiration is immediately followed by expiration, with no expiratory hold or pause.

analyzed per infant. Analyzing a longer breath sequence over a longer period would have been ideal but was not practical. Future studies should endeavor to achieve this. Similar studies immediately after birth done by Karlberg *et al*. (39), Milner and Sauders (9), and Mortola *et al*. (13) also recorded a limited number of breaths in small groups of patients.

Our observation could be biased by the practical difficulties of making respiratory recordings immediately after birth. Our neonatal resuscitation research team has extensive experience in making physiologic recordings and recognized it was very difficult to get long recordings without ventilation, mask leak, movement of the mask or patient, secretions, *etc*. All recordings with artifacts have been excluded from analysis and as expected, only a minority of recordings was suitable for inclusion in this study. Both small number of recordings and the wide range of analyzed breaths per infant could have led to a bias. Therefore, we cannot assume that the patterns observed in this study represent the patterns of all spontaneously breathing preterm infants. Nevertheless, they are similar to those described in newly born term infants (13,39,40) and in older preterm infants (19,20).

Although a mask on the face is a standard procedure for delivering positive airway pressure to infants after birth it might influence the breathing pattern by stimulating respiratory reflexes and thereby influence the tidal volume and respiratory rate (42,43). However, it is impossible to measure inspiratory and expiratory flows and tidal volumes in this situation without use of face mask (44,45). Previous studies reported no adverse effects of a face mask during the first breaths (7–14). It is possible that the added dead space of the face mask caused carbon dioxide accumulation and influenced the breathing pattern (46,47). However, the wide diameter of the mask reduced rebreathing and firm application of the mask reduced the dead space (15).

In these very preterm infants, it was not appropriate to use a facemask without also providing CPAP. The use of CPAP might have influenced the breathing pattern. However, the patterns we have recorded are similar to some breathing patterns described in term infants at birth without CPAP (13,39,40).

A nCPAP of 8 cm H_2O was used for several reasons. Studies show a distending pressure is important for maintaining FRC (48), increasing lung compliance and improving oxygenation, and that 8 cm H_2O is more effective than a lower pressure (49). Studies have used pressures up to 10 cm H_2O (50) and Gregory *et al.*(51) used a nCPAP pressure up to 12 mm Hg. Immediately after birth is the time when most assistance is needed to develop and maintain an FRC because the lungs are fluid filled and the lungs are stiff. It is likely that a relatively high pressure may be necessary in the first few minutes. Animal studies show that a pressure of 8 cm H_2O improves oxygenation and reduces lung injury better than lower pressures (52,53). The optimum nCPAP pressure for treating individual very preterm infants from birth is unknown.

In conclusion, this is the first study reporting the spontaneous breathing patterns in very preterm infants in the minutes after birth. We frequently observed prolongation of expiration in very preterm infants treated with facemask CPAP immediately after birth, predominantly characterized by a breath hold. This braking of expiration is recognized as an attempt to defend lung volume. Our speculation is that techniques of positive pressure ventilation that mimic expiratory braking might improve the effectiveness of respiratory support in the delivery room.

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