

Breathing Patterns in Preterm and Term Infants Immediately After Birth

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ABSTRACT: There is limited data describing how preterm and term infants breathe spontaneously immediately after birth. We studied spontaneously breathing infants ≥ 29 wk immediately after birth. Airway flow and tidal volume were measured for 90 s using a hot wire anemometer attached to a facemask. Twelve preterm and 13 term infants had recordings suitable for analysis. The median (interquartile range) proportion of expiratory braking was very high in both groups (preterm 90 [74–99] vs. term 87 [74–94]%; NS). Crying pattern was the predominant breathing pattern for both groups (62 [36–77] vs. 64 [46–79]%; NS). Preterm infants showed a higher incidence of expiratory hold pattern (9 [4–17] vs. 2 [0–6]%; $p = 0.02$). Both groups had large tidal volumes (6.7 [3.9] vs. 6.5 [4.1] mL/kg), high peak inspiratory flows (5.7 [3.8] vs. 8.0 [5] L/min), lower peak expiratory flow (3.6 [2.4] vs. 4.8 [3.2] L/min), short inspiration time (0.31 [0.13] vs. 0.32 [0.16] s) and long expiration time (0.93 [0.64] vs. 1.14 [0.86] s). Directly after birth, both preterm and term infants frequently brake their expiration, mostly by crying. Preterm infants use significantly more expiratory breath holds to defend their lung volume. (*Pediatr Res* 65: 352–356, 2009)

Between 1960 and 1986, observational data were gathered on breathing patterns immediately after birth from small numbers of term infants and were used to inform international guidelines for neonatal resuscitation (1–8). These studies demonstrated that the first breaths tend to be deeper and longer than subsequent breaths and are characterized by a short deep inspiration followed by a prolonged expiratory phase. This is known as expiratory braking and helps to develop and maintain functional residual capacity (FRC) during the immediate newborn period when the lung is partially liquid filled and the chest wall is very compliant (9,10). Although this respiratory pattern has also been observed in preterm and term infants later in life (11–15), there are no data describing the breathing pattern of very preterm infants immediately after birth.

Antenatal glucocorticoid treatment has greatly improved postnatal lung function and many preterm infants breathe well and establish an FRC at birth by themselves or with only the support of continuous positive airway pressure (16–20). However, preterm infants have a poor respiratory drive, weak muscles, flexible ribs, surfactant deficiency, and impaired lung liquid clearance, which make it difficult for them to breathe easily at birth (21–24). With these inherent problems, we

hypothesized that preterm infants in the minutes after birth will show more expiratory braking than term infants.

The aim of this study was to compare the breathing patterns of preterm and term infants immediately after birth.

METHODS

All inborn infants, term and preterm ≥ 29 wk gestation, who were expected to require no respiratory support at birth, were eligible for this study. The study was approved by the Royal Women's Hospital Research and Ethics committees. Written consent was obtained before birth.

Immediately after birth, as soon as the infant was placed on the resuscitation trolley, a facemask (Laerdal round mask, Laerdal Stavanger, Norway) was applied to the face, enclosing the mouth and nose. To ensure that there was no mask leak, a finger was applied around the infant's chin and held firmly during the recording. A hot wire anemometer (Florian: Acutronic Medical Systems AG, Zug, Switzerland) was attached proximally to the Laerdal mask measuring inspiratory and expiratory gas flow (see also Fig. 1) (25). The flow signal was integrated to provide inspired and expired tidal volume. The signals of airway flow and tidal volumes were digitized and recorded at 200 Hz using a neonatal respiratory physiologic recording program (Spectra, Grove Medical Limited, Hampton, UK).

To eliminate the risk of carbon dioxide retention caused by the mask (26), a bias flow of 2 L/min of air was fed in through the face mask and the anemometer zeroed (Fig. 1) (26). The dead space of the hot wire anemometers is 1 mL and clinically negligible (27).

To minimize interference with the normal monitoring and stabilization of preterm and term infants at birth, we recorded for only 90 s. If there were signs of respiratory compromise, the study was abandoned and ventilatory support was given according to the Australian Neonatal Resuscitation guidelines (28).

Data collection. The following clinical data were collected: gestational age, birth weight, sex, mode of delivery, and Apgar score. 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 breathing patterns. Breaths of each pattern were analyzed in detail by a breath-to-breath analysis and the following parameters were calculated: 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 (29).

Recordings were excluded if: a) there were signs of mask leak, b) the flow signal was disturbed by secretions or infant movements, c) there were signs of movement of the mask, or if ventilatory support was given.

Based on our earlier observations of spontaneous breathing patterns in infants at birth, we divided the breathing patterns by the type of expiration: braked or unbraked. These patterns were defined as follows.

Expiratory hold. Expiration is braked to a complete hold, postponing the main expiratory flow (Fig. 2). This pattern is 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, *i.e.*, there is no postexpiratory pause.

Slow expiration. Expiration is characterized by an initial low expiratory flow rate ending with a single expiratory flow peak late in expiration and/or

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Abbreviations: FRC, functional residual capacity



Figure 1. Placement of the open facemask demonstrated on a mannequin. The facemask was applied to the face, enclosing the mouth and nose. To ensure that there was no mask leak a finger was applied around the infant's chin was held firmly during the recording. A hot wire anemometer was attached proximally to the Laerdal mask. A bias flow of 2 L/min of air was given through the facemask.

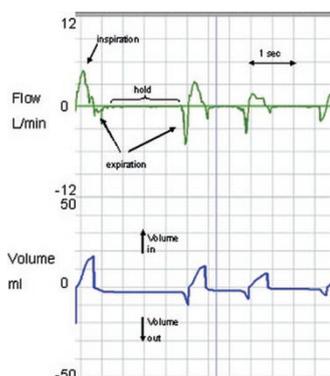


Figure 2. An example of three breaths showing an expiratory hold pattern in a spontaneously breathing infant of 31 wk. The pattern is characterized by a period of no expiratory flow ending with a single expiratory flow peak or multiple expiratory flow peaks. Expiration is immediately followed by an inspiration; there is no postexpiratory pause. Note in all figures that the software resets the volume trace at the end of inspiration and end of expiration as soon as the flow reaches baseline. In this example, more volume enters than leaves the lung, which implies an increase in functional residual capacity.

frequently interrupted expiratory flow waves (Fig. 3). These are immediately followed by an inspiration.

Crying. Expiration is slowed by crying (Fig. 4). This pattern is characterized by a large inspiration followed by high frequency interruptions to the expiratory flow wave, which can be seen in the wave as a noise signal. Expiration is then immediately followed by inspiration. A cry was differentiated from a grunt in the recording by the following: 1) during the recording session, we labeled the breath in the recording the moment a cry or a grunt was heard, 2) in general, the noise signal in the expiratory pattern of a cry has a larger amplitude and higher frequency than a grunt.

Grunting. Expiration is slowed by grunting (Fig. 5). This pattern is characterized by a large inspiration followed by high frequency interruptions to the expiratory flow wave, which can be seen in the wave as a noise signal. Expiration is then immediately followed by inspiration.

Unbraked expiration patterns. These are characterized by uninterrupted expiration with peak expiratory flow early in expiration. Expiration is not

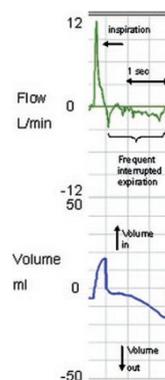


Figure 3. An example of a breath with a slow expiration pattern in an infant of 30 wk gestation. In this pattern, expiratory flow is slowed or frequently interrupted. Expiration is immediately followed by an inspiration, *i.e.*, there is no postexpiratory pause.

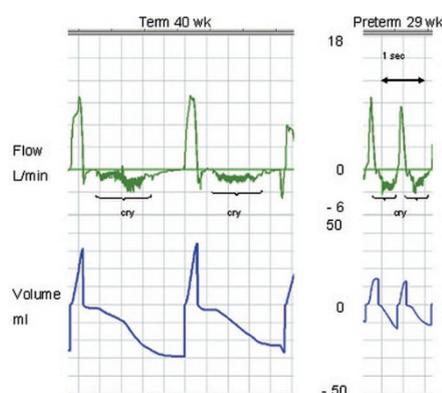


Figure 4. Examples of crying pattern in a term infant of 40 wk gestation and a preterm infant of 29 wk gestation. This pattern is characterized by a large inspiration followed by high frequency interruptions to the expiratory flow wave, which can be seen in the wave as a noise signal. Expiration is then immediately followed by inspiration. A cry has a higher amplitude and frequency than a grunt.

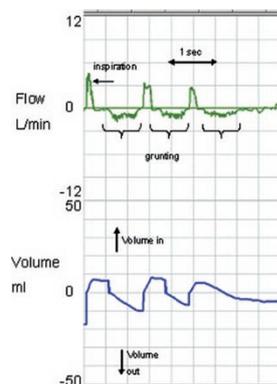


Figure 5. An example of expiration slowed by grunting in an infant of 33 wk of gestation. This pattern is characterized by a large inspiration followed by high frequency interruptions to the expiratory flow wave, which can be seen in the wave as a noise signal. Expiration is then immediately followed by inspiration. In general, a grunt has lower amplitude and frequency than a cry.

prolonged (I:E time approximately 1:1.5) although sometimes the expiratory flow is followed by an expiratory pause before the next inspiration (Fig. 6).

The unbraked breathing pattern was called panting when the respiratory rate was greater than 60/min. This is achieved by shortening the expiratory time (I:E time to approximately 1:1) and often small tidal volumes were noted. In these breaths, there was no postexpiratory pause before inspiration (Fig. 7).

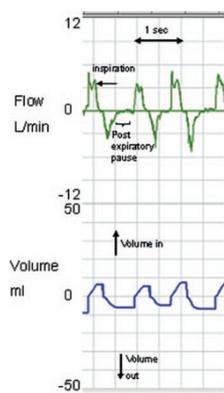


Figure 6. An example of a breath with a “normal” expiratory pattern without braking in an infant of 32 wk gestation. This pattern is characterized by a peak expiratory flow at the beginning of expiration and sometimes showing a postexpiratory pause.

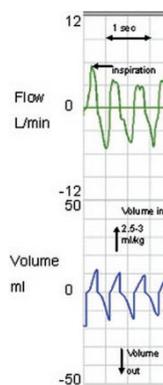


Figure 7. Example of panting pattern in a term infant. This pattern is characterized by a respiratory rate greater than 60/min (in this example 130/min) by shortening the expiratory time (I:E time to approximately 1:1) and small tidal volumes are noted (in this example 2.5–3.0 mL/kg). In these breaths, there is no postexpiratory pause before inspiration.

Data analysis. Data are presented as numbers and proportions (%) for categorical variables, and means with SD for normally distributed continuous variables and median (interquartile range) when the distribution was skewed. The χ^2 test was used to detect differences between the two groups for categorical variables and student's *t* test for continuous variables. Data were analyzed using SPSS software (SPSS for windows, version 15.0, 2006, Chicago, IL).

RESULTS

During the period August 2007–February 2008 there were 62 eligible infants. In seven infants, the mothers were not approached because the midwife/doctor considered it would be too stressful for the parents. In ten infants, the parents did not consent. In four infants, no recording was obtained due to technical problems. Forty-one recordings were made in 27 preterm infants and 14 term infants. Of these 16 recordings were excluded from analysis because secretions causing dirty flow signal in one term and one preterm infant and a further 14 preterm infants needed ventilatory support. Thus, there were 25 recordings available for analysis, 12 preterm and 13 term infants. We analyzed 769 breaths in the preterm infants and 749 breaths in the term infants. The characteristics of the infants studied are shown in Table 1.

Patterns of Breathing. The incidence of breaths of each pattern for both groups are shown in Table 2, and examples of each pattern are shown in Figures 2–7.

Table 1. Characteristics of the term and preterm infants

Characteristics	Preterm (N = 12)	Term (N = 13)	<i>p</i>
Gestational age, wk, mean (SD)	32 (2.2)	38.9 (0.9)	<0.001
Birth weight, g, mean (SD)	2000 (560)	3340 (530)	<0.001
Apgar at 5 min, median (IQR)	9 (9–9)	9 (8–9)	NS
Time start recording, s, mean (SD)	30 (15)	29 (14)	NS
Caesarean delivery (%)	33	54	NS

Table 2. The proportion of breaths with different expiratory patterns for preterm and term infants

	12 Preterm	13 Term	<i>p</i>
No. breaths	58 (45–82)	62 (34–73)	0.5
Braked expiration			
Prolonged	12 (3–17)%	11 (3–18)%	0.9
Hold	9 (4–17)%	2 (0–6)%	0.02
Grunt	2 (0–10)%	0 (0–6)%	0.5
Cry	62 (36–77)%	64 (46–79)%	0.4
Unbraked expiration			
Normal	4 (0–16)%	11 (3–18)%	0.9
Panting	0 (0–1)%	0 (0–12)%	0.5

The median (interquartile range) proportion of expiratory braking patterns was very high in both groups, in preterm infants 90 (74–99)% and in term infants 87 (74–94)% ($p = 0.6$). Of the braked patterns, expiratory hold pattern occurred more often in preterm infants (9 [4–17]% vs. 2 [0–6]%; $p = 0.02$). The most common breathing pattern for both groups was the crying pattern (62 [36–77]% vs. 64 [46–79]%; $p = 0.4$). The incidence of unbraked pattern was low in both groups (10 [3–27]% vs. 13 [6–25]%; $p = 0.6$).

Respiratory Parameters. There was no difference in the average tidal volume measured between preterm and term infants (6.7 [3.9] vs. 6.5 [4.1] mL/kg; $p = 0.5$). The breaths in both groups were characterized by a high peak flow during inspiration (5.7 [3.8] vs. 8.0 [5] mL/kg; $p < 0.001$) and a lower peak flow during expiration (3.6 [2.4] vs. 4.8 [3.2] mL/kg; $p < 0.001$). The average inspiration time was short and not different between the groups (0.31 [0.13] vs. 0.32 [0.16] s; $p = 0.5$). The average expiration time in both groups was long, but in preterm infants, it was shorter than in term infants (0.93 [0.64] vs. 1.14 [0.86] s; $p < 0.001$).

The values of the respiratory parameters of both groups when divided into breaths with braked and unbraked expiration are shown in Table 3. In both groups, breaths with braked expiration were characterized by larger tidal volume, larger peak inspiratory flow, longer expiration time, and smaller respiratory rate (see Table 3).

DISCUSSION

We have shown in this study that both term and preterm infants frequently brake their expiration in the first minutes of life. This is achieved most commonly by crying. The crying pattern has not been described in earlier reports (7,30,31). All other interrupted expiratory patterns shown in this study were described previously and were considered strategies to defend

Table 3. The respiratory parameters of the braked and unbraked breaths for both groups

Respiratory parameters, mean (SD)	Braked expiration			Unbraked expiration		
	Preterm (N = 652 breaths)	Term (N = 598 breaths)	<i>p</i>	Preterm (N = 117 breaths)	Term (N = 151 breaths)	<i>p</i>
Tidal volume (mL/kg)	7.2 (3.8)*	6.8 (4.2)*	NS	3.7 (2.2)*	5.5 (3.4)*	<0.001
Inspiration time (s)	0.32 (0.14)	0.33 (0.16)	NS	0.30 (0.09)	0.30 (0.13)	NS
Expiration time (s)	1.03 (0.84)*	1.33 (1.02)*	<0.001	0.41 (0.16)*	0.43 (0.26)*	NS
Peak flow inspiration (L/min)	6.2 (3.9)*	8.4 (5.2)*	<0.001	2.9 (1.8)*	6.5 (4.2)*	<0.001
Peak flow expiration (L/min)	-3.8 (2.4)*	-4.3 (2.8)*	<0.001	-3.0 (2.4)*	-6.3 (4.0)*	<0.001
Respiration rate (min ⁻¹)	60 (30)*	50 (23)*	<0.001	90 (26)*	91 (31)*	NS

* Values of braked vs. unbraked pattern were significantly different in both groups ($p < 0.001$).

lung volume (11,12,14,15,32–35). We were not able to show a difference in breathing between the groups, except that preterm infants use the expiratory breath hold more often than term infants.

This is the first study comparing the breathing patterns of term and preterm infants immediately after birth. Karlberg *et al.* (30) and Mortola *et al.* (7) reported the first few breaths in term infants and described similar interruptions in expiration with small or zero flow. These expiratory interruptions or braking were also observed in term infants at 10 min of life (11). They also occur in preterm and term infants later in life during active sleep (15,33).

In newborns, with a very compliant chest wall, it is likely that expiratory braking mechanisms help maintain FRC. There are two mechanisms for stopping or slowing expiratory flow and maintaining an elevated lung volume during expiration. Diaphragmatic postinspiratory activity slows the rate of lung deflation by counteracting its passive recoil (12,14,15,32,33). Closure or narrowing of the larynx increases the resistance to expiration (11,15,34,35). During braked expiration, the closed or narrowed glottis, with increased intrapulmonary pressure from abdominal muscle contraction, causes the airway pressure to be maintained above atmospheric. This helps clear fluid from the lung, facilitate distribution of gas within the lung, and splint the alveoli and airways open (3,4,7,8,11,30).

A cry at birth reassures clinicians that the infant is capable of taking a deep inspiration (36). The sound is produced during forced expiration by vibration of the vocal cords (37). In this study, we have shown that crying is a similar breathing pattern to grunting. It is an interruption of the expiratory flow with a higher frequency (Fig. 3) and amplitude than grunting. Grunting has been recognized as a dynamic braking of expiration by the larynx (11,13), but crying has not been described earlier as a braking mechanism. The most likely reason for this is that in earlier studies breaths were excluded from analysis if the infant was crying (7,11). Interestingly, Engstrom *et al.* recorded sound and intraesophageal pressure in the first minutes of life. Although they did not record flow and volume, they described breathing in the first minutes of life as a “crying period” characterized by deep breaths (31). It is likely that the prolonged high intrathoracic pressure on expiration during crying represents an important force for clearing fluid from the lung and facilitating lung aeration.

The tidal volumes in the nonbraked patterns are significantly lower in preterm infants compared with term infants. Preterm infants have difficulties aerating their lungs because

of poor respiratory drive, weak muscles, flexible ribs, surfactant deficiency, and impaired lung liquid clearance (21,22,24). We speculate that these factors become more obvious when breaths are not braked.

We observed an expiratory hold pattern more often in preterm infants. Preterm infants may have difficulty aerating their lungs and keeping them open and may need these expiratory hold maneuvers more often. It is possible that when these patterns are observed very frequently, it could indicate the infant may need respiratory support or, when already started, need to be optimized.

The braked pattern was characterized in both groups by a larger tidal volume. This probably reflects the large proportion of crying pattern that is accompanied by a large inspiration. The peak inspiratory flow we measured during the crying pattern in term infants is comparable to what has been measured in crying term infants later in life (36). However, we measured a much lower peak expiratory flow, which could indicate more braking occurred at birth than during crying later in life (36).

Making respiratory measurements immediately after birth is very difficult. This is an area of research where it is not possible to study large numbers in detail. We were only able to record more mature preterm infants because we aimed to record only those who were breathing without assistance. To have minimal interference with the monitoring and stabilization of preterm and term infants at delivery, we recorded for only 90 s. It is possible that more differences between the groups would have appeared if more immature preterm infants were studied or if recordings were made for longer periods.

Although using a face mask with a pneumotachometer attached is an accepted and only method for measuring respiratory parameters after birth (37,38), it may have influenced the breathing pattern by stimulating respiratory reflexes and thereby influencing the tidal volume and respiratory rate (39,40). In previous studies, no adverse effects of using a face mask during the first breaths were reported (1,2,7,11). In addition, an open face mask with a small pneumotachograph attached causes less interference to the infants’ breathing than methods used in previous studies (1–6,8).

In conclusion, this is the first report that describes in detail the breathing patterns of preterm and term infants immediately after birth. Both preterm and term infants frequent brake expiration, most often represented by a crying pattern. The crying pattern has not been described before but seems to be a method of breathing that uses expiratory braking and facil-

itates lung volume recruitment. We have shown that preterm infants use significantly more expiratory breath holds to defend their lung volume.

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