ORIGINAL ARTICLE

A non-invasive technique for evaluation of respiratory efforts in preterm infants during feeding

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KEYWORDS
Method; Breathing; Feeding

Abstract The aim of this study was to develop a minimally invasive technique to evaluate respiratory patterns in preterm infants during feeding.

Methodology: Respiratory flow was obtained with a pneumotachograph coupled initially to a mask and then to a prong, both with a differential pressure transducer. Respiratory plethysmography was used to measure thoraco-abdominal movements. This recording allowed calibration of the preterm infant’s tidal volume prior to feeding experiments. Electromyography was used to monitor oral muscle movements through electrodes attached to the buccinator, masseter and mentalis muscles. A pulse oximeter and cardiac monitor were used for continuous monitoring of vital signs. The infants were positioned vertically in a semi-sitting position in an infant seat.

Results: The methodology developed here was considered effective in achieving the proposed aims. With the integration of all these systems, it was possible to evaluate the respiratory patterns of preterm infants during cup feeding.

Conclusion: This method allows the analysis of respiratory flow, volume, and O₂ saturation during feeding and identification of the moment in which a change in breathing occurs (i.e., pausing or feeding). This method is minimally invasive, providing the preterm infant with an environment that is as close to normal as possible.

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Introduction

Due to advances in technology and medical science, the survival of preterm infants has become increasingly frequent. Preterm infants face a number of special challenges, and significant evidence-based research approaches have aimed to improve treatment of these patients.

An infant’s first need at birth is to breathe, and the second is to eat (Paula et al., 2002); both of these are a challenge for preterm infants. In order to feed safely and effectively, the infant must be able to coordinate sucking, swallowing and breathing, a skill that tends to improve with gestational age (Sakalidis et al., 2013). Impairment of any one of these functions can put the infant at risk for aspiration, pneumonia, oxygen desaturation, apnea, and bradycardia (Lau and Hurst, 1999). Thus, understanding how preterm infants breathe during feeding represents an important step toward further improving their health and development.

Few methods for evaluating the behavior of the respiratory system during neonatal feeding have been described in the literature, and most of the existing methods are invasive (Daniels et al., 1986; Gewolb et al., 2001; Koenig et al., 1990) and these have been described in a review by Tarrant et al. (1997). Invasive techniques can alter the respiratory patterns and may cause discomfort. Thus, the development of a non-invasive technique for evaluating the respiratory effort in preterm infants during feeding is important.

The techniques used to evaluate breathing coordination during feeding that have been described in the literature were used during bottle feeding. However due to the implementation of cup feeding in neonatal units it was necessary to adequately assess this technique. A Cochrane review of feeding methods in preterm infants (Flint et al., 2007) highlighted the limited number of scientific articles on this topic that exhibited sufficient methodological rigor for inclusion. It is thus necessary to establish efficient methodologies for studies of feeding in preterm infants.

The aim of this study was to assess the feasibility of the use of a non-invasive technique to evaluate breathing coordination during cup feeding in preterm infants.

Methodology

The study was approved by the Institutional Review Board of the Instituto Nacional de Saúde da Mulher, da Criança e do Adolescente Fernandes Figueira in Brazil (study protocol 0059.0.008.000-06). It was conducted in the lung function laboratory, which is staffed and equipped to conduct detailed investigations of thoraco-abdominal movements and respiratory flow patterns.

Infants born at Instituto Nacional de Saúde da Mulher, da Criança e do Adolescente Fernandes Figueira from August 2006 to March 2007 were included. The inclusion criteria were: birth weight less than 1500 g, gestational age from 26 to 32 complete weeks, absence of congenital anomalies, severe perinatal asphyxia (as defined by 5-min Apgar score <5 or convulsions in the first 24 h) and bronchopulmonary dysplasia. Infants with sepsis or/and intraventricular hemorrhage grade III or IV (documented by ultrasound) were excluded. The eligible infants were recruited when they started oral feeding, were at least 32 weeks gestational age, and were clinically stable. They had been evaluated by the speech therapist as being ready to start oral feeding.

Informed consent was obtained from the parents or guardians of the patient prior to their inclusion.

During the development of a non-invasive technique, we used a resuscitation-type mask, a nasal prong (in different sizes) coupled to a pneumotachograph (Fleisch 00) and a differential pressure transducer (Validyne DP45). To measure respiratory flow during feeding we used the respiratory inductance plethysmography system (RIP) (Respiritrace) that consisted of a non-invasive monitor with two transduction bands wrapped circumferentially around the chest wall and abdomen (at the level of the axillae and umbilicus, respectively).

To record the movements of the oral muscles involved in feeding, electrodes for electromyography were attached to the buccinator and masseter muscles (bilateraly) and the mentalis muscle. The electrodes were then coupled to the electromyograph (Lab Linc V, Coulbourn Instruments). Electromyography was used to record when the infant was being fed and during pauses, in order to determine the moment in which changes in breathing occurred.

Safety during feeding is an aspect addressed in the literature and generally evaluated by oxygen saturation and heart rate (Marinelli et al., 2001; Sakalidis et al., 2012, 2013), thus, vital signs were monitored during feeding using a pulse oximeter and cardiac monitor (Massimo SET).

Thoraco-abdominal movements, electromyography, respiratory flow, and oxygen saturation were recorded simultaneously and saved to a computer for later analysis. PCLAB (Data Translations) software was used for analog signal transduction bands wrapped circumferentially around the chest wall and abdomen (at the level of the axillae and umbilicus, respectively).
acquisition, and a DT-2081 (Data Translation Systems) converter was used for the analog-to-digital signal conversion. Digital data analysis and processing was conducted with the ANADAT/LABDAT program (Meakies Christies, Montreal, Canada).

At the moment of evaluation the preterm infants were in a conscious state of 4 using the Brazelton scale (Brazelton, 1983) (alert, active or inactive), and in a semi-sitting position in an infant seat.

Statistical analysis was performed using T student test for unpaired samples following testing for normality using the One-sample Kolmogorov-Smirnov test.

Results

Development of technique

Respiratory flow and efforts
Initially we used nasal prongs in order to evaluate respiratory flow during feeding. However, the air flow escaped as a result of inadequate sealing and/or poor positioning of the prong during the testing, indicating that the recording of respiratory flow did not reliably reflect respiratory behavior. Thus, we used the RIP simultaneously with the nasal prongs in order to determine whether respiratory component measurements were consistent between these two methods. A qualitative analysis showed similarities between the traces obtained with the prong and the thoracic and abdominal movements (Fig. 1).

The prong use is therefore dispensable because the RIP allows both qualitative and quantitative analysis. Besides that, the elimination of the prong reduces the number of devices used, likely improving the comfort of the preterm infant during the procedure.

In addition, we compared the respiratory volume obtained using the RIP with that obtained using a mask which formed a good seal around the nasal and oral cavities. With this comparison, the tracings of thoracic and abdominal movements could be reliably correlated with the real respiratory flow, thus allowing its estimation during the test without use of the mask (Fig. 2). This comparison was necessary due to the fact that during feeding it is not possible to use the mask to evaluate breathing.

We initially placed the preterm infant in a semi-sitting position in the examiner’s lap, with the back resting on the examiner’s forearm and the head on her hands. Tracings of thoraco-abdominal movements taken in this position were not reliable (Fig. 3) and showed major interference when the preterm infant moved, making them unsuitable for further analysis.

We thus opted to put the preterm infants in a baby seat specially adapted for them, with the infant’s arms minimally contained with the aid of a sheet, and the examiner further stabilized the infant’s head and neck using her hands. This change in positioning led to a significant improvement in the tracings (Fig. 4) compared to those obtained with the infant positioned in the examiner’s lap (Fig. 3).

Oximetry
Oxygen saturation values were initially recorded manually by a researcher. We later switched to the data recording and storage system provided by the equipment itself, similar to that reported by Sakalidis et al. (2012), which enabled a continuous recording of oxygen saturation.

To record and store oxygen saturation values, we coupled a cable connecting the oximeter to the computerized system, allowing us to simultaneously record the oxygen saturation values and other parameters, further strengthening our analyses (Fig. 4).

When the recording was done manually, it was only possible to evaluate how many episodes of desaturation occurred during feeding. With the
change to continuous recording it was possible to assess how many episodes occurred and the specific time of which one during feeding.

Electromyography
To determine whether the changes observed in respiratory effort and oxygen saturation occurred during pausing or feeding we used electromyography.

We initially used the electrodes provided along with the electromyograph, but these electrodes were bulky, as it was necessary to attach them with bandaging tape, and the use of conductive gel was required. Due to these factors, the electrodes occasionally became loose before the end of the test, thus impeding data analysis and providing poor quality recordings (Fig. 3). As a solution, we opted to use self-adhering surface electrodes (3M), which are lighter and less bulky, improving their attachment to the skin and thus producing higher quality tracings. We reduced the diameter of the electrodes from 4.5 cm to 3.0 cm, as we were investigating preterm infants whose faces have only a small area available for electrode attachment, and encompassing a muscle group different from the preferable group studied during sucking (buccinator and masseter muscles). This did not alter the recording quality and allowed a more precise identification of pauses in feeding (Fig. 4).

Evaluation of technique
The methodology was applied in a pilot study in 8 preterm infants at two different times: at the start of the oral feeding and again at hospital discharge when feeding was fully established, totaling 16 tests. Demographic characteristics of the preterm infants are described in Table 1.

The tidal volume ($V_T$) obtained in the basal breathing (before administration of the feeding) was analysed and showed values within the normal range in both observations — at the beginning of oral feeding and at discharge (Chu et al., 1965) (6.8 ml/kg ± 1.72 and 6.25 ml/kg ± 1.12 respectively) (Table 2).

Since this methodology allows the distinction between the moment of feeding and pauses, it is possible to compare the $V_T$ during breathing to the $V_T$ obtained when the preterm infant was being fed. This way, it is possible to quantify the actual reduction in $V_T$ during sucking by removing the pause component ($V_T$ means during sucking = 1.88 ml/kg ± 1.43). When evaluating the whole process of feeding (sucking and pausing) this volume is 4.23 ml/kg ± 0.77 (Table 2).

The oximetry analysis showed there was desaturation (<85%) in 56.25% of the tests (9/16), totaling 44 episodes, with a mean of 4.8 (SD = 4.5) episodes per test. In most cases, the episodes of

Table 1: Population characteristics study. Instituto Nacional de Saude da Mulher, da Criança e do Adolescente Fernandes Figueira, Rio de Janeiro, Brazil, 2007. ($n = 8$).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>Birth weight (g)</td>
<td>1242.5</td>
<td>±207.3</td>
</tr>
<tr>
<td>Gestational age at birth (weeks)</td>
<td>30 6/7</td>
<td>±2 2/7</td>
</tr>
<tr>
<td>Duration of $O_2$ therapy (days)</td>
<td>2.87</td>
<td>±3.22</td>
</tr>
<tr>
<td>Duration of orotracheal tube use (days)</td>
<td>0</td>
<td>±0</td>
</tr>
<tr>
<td>Days of life until birth weight recovered</td>
<td>12.8</td>
<td>±1.95</td>
</tr>
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</table>

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desaturation were evident at the time of pause, when the lung volume had returned to values similar to baseline. This occurs due to the fact that the recording of oxygen saturation by pulse oximetry demonstrates the phenomena with a delay of 24–35 s (Soubani, 2001).

**Discussion**

The evaluation of the respiratory component during feeding has been investigated with different instruments in many studies over the last several decades. Daniels et al. (1986) and Mizuno and Ueda (2003) used nasal thermal sensors, however poor positioning of the sensor, differences in sensors and ambient air temperature often degraded the resulting signals. Koenig et al. (1990) used a nasal flowmeter, and Gewolb et al. (2001) used a prong positioned in the newborn’s nostrils, similar to the device used in our study.

One study, comparing nasal canullae and mask showed that both traces produced similar features during breathing, and the authors concluded that both methods similarly represented true airflow events and therefore, the mask is not necessary (Selley et al., 1994).

<table>
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<tbody>
<tr>
<td><strong>Start of oral feeding</strong></td>
<td><strong>Mean (SD)</strong></td>
<td><strong>P</strong></td>
</tr>
<tr>
<td>Weight (g)</td>
<td>1637 (±220.74)</td>
<td></td>
</tr>
<tr>
<td>Gestational age (weeks)</td>
<td>31 2/7 (±1/7)</td>
<td></td>
</tr>
<tr>
<td>VT in basal breathing (ml/kg)</td>
<td>6.82 (±1.64)</td>
<td></td>
</tr>
<tr>
<td>VT during sucking (S) (ml/kg)</td>
<td>1.88 (±1.43)</td>
<td>0.000</td>
</tr>
<tr>
<td>VT during pause (P) (ml/kg)</td>
<td>6.61 (±1.57)</td>
<td>0.799</td>
</tr>
<tr>
<td>VT during feeding (S+P) (ml/Kg)</td>
<td>4.23 (±0.77)</td>
<td>0.008</td>
</tr>
<tr>
<td><strong>Discharge</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (g)</td>
<td>2024 (±238.12)</td>
<td></td>
</tr>
<tr>
<td>Gestational age (weeks)</td>
<td>37 4/7 (±2/7)</td>
<td></td>
</tr>
<tr>
<td>VT in basal breathing (ml/kg)</td>
<td>6.25 (±1.08)</td>
<td></td>
</tr>
<tr>
<td>VT during sucking (S) (ml/kg)</td>
<td>2.95 (±1.58)</td>
<td>0.000</td>
</tr>
<tr>
<td>VT during pause (P) (ml/kg)</td>
<td>5.91 (±1.35)</td>
<td>0.272</td>
</tr>
<tr>
<td>VT during feeding (S+P) (ml/kg)</td>
<td>4.43 (±1.24)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

* T-Test (compare to basal breathing).
Mizuno and Ueda, 2003; Sakalidis et al., 2013), but our aim was to construct a model that would allow the use of different instruments for cup feeding. A cup is one of the most widely used feeding instruments but it does not allow pressure transduction measurement due to its lack of a nipple; therefore, we opted to use electromyography.

Electromyography is a commonly used technique for investigating the potential action of muscle fibers. In our study, it was used to obtain recordings of oral muscle activity, allowing us to determine whether the changes observed in respiratory effort occurred during feeding or pausing. Electromyography electrodes were attached to the buccinator and masseter muscles bilaterally and to the mentalis muscle (Gomes et al., 2006; Inoue et al., 1995; Sakashita et al., 1996). In a published review the authors describe that in bottle feeding, the buccinator and mentalis muscles are hyperfunctional and in cup feeding the masseter and temporal muscles function similarly to breastfeeding (Gomes et al., 2009). Thus, the electrodes attached were capable of capturing the action of muscles involved in both cup and bottle feeding.

The main challenge in this study was to develop a technique capable of recording the largest possible number of parameters, through a minimally invasive methodology providing infants with a relatively natural environment during monitoring.

This method allows the collection and analysis of respiratory flow and oxygen saturation data during the feeding process as well as identification of the moment in which changes in these values occur (during feeding or pausing). This methodology is currently being used in a clinical trial in the neonatology department of our hospital.

The technique proposed in this study evaluates the coordination of breathing with sucking directly. However, the coordination of these with swallowing is done indirectly — through the interpretation of physiological parameters, obtained by pulse oximetry. A strategy for a non-invasive technique to assess swallowing can be with the use of a laryngeal microphone positioned lateral to the larynx and coupled to the computer system. This strategy is being incorporated into this methodology for future studies.

In this study, we do not correlate episodes of brady/tachycardia observed to periods of feeding or pausing since it was not possible to obtain a continuous record of heart rate due to technical limitations of the equipment used.

This study makes an important contribution to the literature, highlighting the lack of studies and methodologies that can be used in preterm infants as a group. It was necessary to develop a method able to determine the safety of a cup or bottle to conduct clinical studies comparing the two techniques. This methodology is being used in a randomized clinical trial comparing the use of cup and bottle feeding in very low birth weight preterm infants.

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Conflict of interest statement

None.

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Respiratory efforts during feeding in preterm infants