Computerised determination of spontaneous inspiratory and expiratory times in premature neonates during intermittent positive pressure ventilation. II: results from 20 babies

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Abstract
Twenty premature infants ventilated for respiratory distress syndrome (RDS) were studied using a new computerised technique to determine spontaneous inspiratory and expiratory times. The technique is continuous and non-invasive. Infants were studied during intermittent positive pressure ventilation for periods of up to 45 minutes. Median birth weight and gestation were 1477 g and 30 weeks. The median number of breaths analysed for each baby was 925. The median (range) for spontaneous inspiratory time was 0.30 (0.26 to 0.34) seconds and for spontaneous expiratory time it was 0.46 (0.34 to 0.66) seconds. The spontaneous inspiratory and expiratory times were different from the ventilator settings.

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Most pre-term infants ventilated for respiratory distress syndrome (RDS) continue to breathe during ventilation. Data on their spontaneous inspiratory (Ti) and expiratory times (Te) may help select the appropriate ventilator settings to optimise the interaction between the infant and the ventilator.¹ There are no data on the spontaneous Ti and Te during ventilation, because there is no suitable continuous, non-invasive measurement technique.

Premature infants with RDS have highly

compliant chest walls and low compliance lungs. As a result, diaphragmatic contraction causes the lower chest wall to recess. Mechanical inflation of the lungs in the absence of spontaneous breathing does not. A Graseby pneumatic capsule (Graseby Medical, Hertfordshire, England), positioned in the subxiphisternal region, using medical adhesive tape and connected to a standard laboratory transducer, can be used to record recession and provide a signal of spontaneous respiratory activity that is scarcely affected by mechanical ventilation.²

A computerised system has been developed which can measure the median spontaneous inspiratory and expiratory times during intermittent positive pressure ventilation using the Graseby capsule.³ In outline this system works as follows:

1. A signal of spontaneous respiratory activity is acquired from the Graseby capsule and samples at 50 Hz.
2. High frequency noise is filtered.
3. Artefacts are rejected.
4. The onset of inspiration and expiration is identified.
5. Values for spontaneous Ti and Te are calculated and stored for averaging.
6. New median values for Ti and Te are calculated every 10 seconds from the most recent 100 breaths.

The computerised system has been validated using pneumotachography.³ The mean

Table 1 Individual infant data

Infant	Age (hours)	Birth weight (g)	Length of study (minutes)	Mean % time signal accepted	Number of breaths analysed	Inspiratory time (seconds) median (range)	Expiratory time (seconds) median (range)	Respiratory rate (bpm)
1	48	2892	19	39	580	0.28 (0.26-0.32)	0.48 (0.42-0.50)	79
2	2	1600	30	62	1510	0.28 (0.24-0.30)	0.46 (0.40-0.50)	81
3	8	767	45	44	1330	0.34 (0.30-0.36)	0.56 (0.48-0.68)	67
4	11	894	30	87	1570	0.34 (0.24-0.40)	0.66 (0.58-0.74)	60
5	36	1706	9	50	360	0.26 (0.24-0.28)	0.50 (0.48-0.52)	79
6	60	1556	15	85	1030	0.28 (0.26-0.32)	0.46 (0.44-0.68)	81
7	16	1950	8	71	390	0.30 (0.28-0.32)	0.60 (0.42-0.68)	68
8	7	1000	9	80	570	0.30 (0.29-0.32)	0.46 (0.42-0.48)	79
9	11	2000	30	39	1140	0.28 (0.26-0.32)	0.34 (0.28-0.40)	97
10	15	804	9	54	400	0.26 (0.26-0.28)	0.46 (0.30-0.46)	83
11	7	1995	30	34	900	0.26 (0.24-0.30)	0.42 (0.28-0.48)	88
12	7	1690	20	59	930	0.34 (0.30-0.36)	0.42 (0.40-0.46)	79
13	4	1180	11	51	470	0.32 (0.28-0.34)	0.40 (0.36-0.46)	83
14	10	1650	30	76	1800	0.28 (0.26-0.28)	0.48 (0.46-0.50)	79
15	52	1397	20	50	830	0.26 (0.22-0.28)	0.46 (0.40-0.52)	83
16	44	1170	29	41	920	0.32 (0.24-0.36)	0.46 (0.42-0.52)	77
17	22	681	30	39	780	0.30 (0.28-0.34)	0.60 (0.54-0.68)	67
18	8	1949	31	61	1490	0.30 (0.30-0.32)	0.46 (0.44-0.48)	79
19	10	892	29	70	1280	0.32 (0.30-0.36)	0.64 (0.54-0.68)	63
20	22	1370	30	66	1740	0.30 (0.26-0.34)	0.38 (0.36-0.42)	88
Group median (range)	20 hours (2-60)	1477 g (681-2892)	29 minutes (8-45)	57% (34-87)	925 (360-1800)	0.30 seconds (0.26-0.34)	0.46 seconds (0.34-0.66)	79/minute (60-97)

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Figure 1 Proportion of the Graseby signal accepted by the software as genuine breaths during a recording from one infant, over a period of 45 minutes.

difference between the values for T_i from the new technique and those measured with the pneumotachograph is -5.4% , with the technique underestimating T_i . For T_e , the mean difference is $+1.6\%$, with the technique slightly overestimating the value for T_e .

This paper describes the use of this technique in a group of pre-term infants to determine their spontaneous T_i and T_e during intermittent positive pressure ventilation.

Methods

Infants were studied if they were ventilated for clinically diagnosed RDS and had arterial blood gases in the normal range at the time of study. Infants with lethal congenital abnormalities or those receiving pancuronium were excluded. They were studied for up to 45 minutes and the ventilator settings were unchanged during each study. Data were stored on: the duration of each study; the percentage time the respiratory signal was accepted; and the median T_i and T_e for each 10 seconds. The median values for T_i and T_e during each 10 second epoch were used to calculate the median T_i and T_e for each study. These values were combined to calculate the

Figure 2 Variation over 45 minutes in spontaneous inspiratory time (T_i) and expiratory time (T_e) from one infant during intermittent positive pressure ventilation

T_i and T_e for the whole group. All the studies were carried out at the neonatal intensive care unit, Rosie Maternity Hospital, Cambridge, with permission from the Local Research Ethics Committee. Parents were asked for verbal consent for their infants to be studied and were present during most of the studies.

Results

Twenty spontaneously breathing ventilated babies were studied for a median (range) time of 29 minutes (eight to 45). Their median gestation and birth weight were 30 (23 to 35) weeks and 1477 (681 to 2892) g. The inspired oxygen was 0.50 (0.21 to 0.98) and the peak inspiratory pressure was 18 (14 to 24) cm H_2O . They were ventilated with inspiratory and expiratory times of 0.33 (0.30 to 0.45) and 0.43 (0.34 to 0.66) seconds. The data for the babies are shown in table 1.

The percentage of time (for each 10 second epoch) that the Graseby signal was accepted by the software as breaths varied for each infant during the study and between infants. The median (range) for the studies was 57% (34–87%). Figure 1 shows a frequency plot of the accepted signal from a typical infant. Epochs of respiratory signal that had 40–60% of the signal accepted by the software were the most common.

An estimate of the number of breaths analysed for each baby is shown in table 1. The median was 925, with a range of 360 to 1800.

The median (range) T_i for the group was 0.30 seconds (0.26 to 0.34) and for T_e it was 0.46 seconds (0.34 to 0.66) (table 1). Figure 2 shows the variation in T_i and T_e with time for the baby studied for the longest time – a period of 45 minutes.

The median T_i and T_e for each infant were used to calculate the median spontaneous respiratory rate (table 1). The median respiratory rate for the group was 79 breaths per minute (range 60 to 97).

Figures 3 and 4 compare the median spontaneous T_i and T_e for each infant with the ventilator inflation and deflation times, respectively. Points representing more than one infant are marked accordingly. The line of equality is indicated on the graph. There was no significant relationship between either T_i and ventilator inflation time ($p=0.126$) or between T_e and ventilator deflation time ($p=0.224$) using Spearman's correlation coefficient.

Discussion

The new technique for the continuous analysis of spontaneous inspiratory and expiratory times of ventilated premature babies reported here is non-invasive and can distinguish between the effect of the ventilator and that of spontaneous respiration on the chest wall of pre-term infants.

No infant breathed with a median inspiratory time greater than 0.34 seconds, or a median expiratory time greater than 0.66 seconds. The practice in Cambridge over the

Figure 3 Median spontaneous inspiratory time and set ventilator inflation time. The numbers next to some points indicate infants with identical results.

Figure 4 Median spontaneous expiratory time and set ventilator deflation time. The number next to one point indicates three infants with identical results.

past few years has been to ventilate infants with an initial ventilator inflation time of 0.32 seconds and a deflation time of 0.43 seconds. These times were derived from earlier work looking at spontaneous respiratory times in ventilated premature infants studied while receiving continuous positive airways pressure (CPAP).⁴ For the nine infants ventilated with inflation times of 0.32 seconds, the median spontaneous *Ti* varied from 0.26 to 0.34 seconds. Thus even where an attempt has been made to set ventilator inflation and deflation times close to spontaneous respiratory times commonly measured in this population, the infants continue to breathe with slightly different times. Furthermore, infants with RDS do not have fixed respiratory patterns (fig 2). The variability of *Ti* is less than that for *Te* in the data shown here; this was typical for the group as a whole. Short term variation in the spontaneous respiratory rate is therefore more likely to be a function of change in *Te* than in *Ti*.

One difficulty with using the Graseby capsule for the respiratory signal is that it is a movement detector and also records abdominal contraction, gross body movements, and heart beat. Algorithms have therefore been incorporated to reject non-respiratory movements. Continuous analysis of the respiratory signal, however, still allows the software to accept very large numbers of breaths which are all from periods of good quality respiratory signal. This ensures that the values determined for *Ti* and *Te* are calculated only from genuine breaths and are representative of the stable respiratory pattern. Inevitably there will be some genuine breaths that fulfil the criteria to be rejected; this is the cost of being as sure as

possible that only genuine breaths are accepted. Although the algorithms may also reject some breaths which occur at the same time as the other movements, there is no reason to believe that the inspiratory and expiratory times of these breaths would be significantly different from the breaths accepted for analysis. On average this technique determined that the respiratory signal could be analysed about half of the time in this study group. Even the rejection of half the signal still left an average of about 900 breaths per baby for analysis. This is more than has been analysed in any other study.

Another problem with using the Graseby capsule is that the technique will not produce an accurate signal if the baby is breathing so shallowly or without recession that there is no respiratory component to the Graseby signal. However, under these circumstances no other device would easily detect spontaneous respiration. A related concern is that the Graseby signal may simply reflect the mechanical effect of ventilator inflation and deflation on the chest wall. Figure 3 shows how the median spontaneous *Ti* differed from the ventilator inflation time. If the Graseby capsule was simply detecting the effect of mechanical inflation most of the points would lie on or close to the line of equality. This is clearly not the case, confirming that the Graseby capsule is detecting spontaneous respiratory movement even during intermittent positive pressure ventilation.

A comparison of the *Ti* and *Te* from this study has been made with previously published data on spontaneous respiratory timings (table 2). The reported values for *Ti* and *Te* vary widely, depending on the population studied

Table 2 Previous studies investigating inspiratory and expiratory times in babies

Year	Reference	Number studied	Characteristics of the infants	Method used	Inspiratory times (seconds)	Expiratory time (seconds)	Respiratory rate/minute
1960	5	15	Term, well, free breathing	Face mask pneumotach	I:E ratio 0.77	Not reported	37
1968	6	22	RDS, not ventilated	Nasal pneumotach	0.3	0.9	50
1985	7	6	RDS, free breathing	Nasal/oral air flow	0.35	Not reported	73
1986	8	24	RDS, intubated, CPAP	Pneumotach	0.48	0.59	63
1991	9	12	RDS, IPPV studied on CPAP	Oesophageal balloon Pneumotach	On CPAP 0.35 Disconnected 0.28	Not reported	
1992	4	76	RDS, IPPV studied on CPAP	Pneumotach	0.31	0.41	88.5
1992	10	22	RDS, IPPV studied on CPAP	Oesophageal balloon	On CPAP 0.29 Disconnected 0.34	On CPAP 0.38 Disconnected 0.43	

and the measuring technique. The Ti and Te reported by South⁴ and by Hird¹⁰ are similar but not exactly the same as those reported by our study. None of the studies determined Ti and Te during intermittent positive pressure ventilation itself, and this may explain the differences between our results and those from South and Hird, where similar populations of infants were studied. Respiratory reflexes may be involved in the interaction between the infant's spontaneous respiratory effort and ventilator cycling.¹¹ For example, disconnection from the ventilator in the studies of Hird *et al*^{9,10} will influence Ti and Te, because the infant may change its respiratory rate to preserve functional residual capacity.

Selecting the most appropriate ventilator settings for inflation and deflation times is difficult. When infants with RDS have been ventilated at rates adjusted to produce apparently synchronous ventilation, studies have shown benefit in oxygenation^{9,12} and a reduction in cerebral blood flow velocity variability.¹³ Other studies have shown a reduction in the incidence of air leak with ventilator rates of 60 inflations per minute compared with 40 inflations per minute.¹⁴⁻¹⁶ In these studies the fast rates were with inflation times of 0.5 seconds or less compared with inflation times of up to one second in the slower rate groups. The computerised system of monitoring spontaneous Ti and Te during intermittent positive pressure ventilation described here could be used to determine the most appropriate ventilator inflation and deflation times for infants with RDS undergoing intermittent positive pressure ventilation.

This system could be used to investigate how ventilated infants breathe and provide clinicians with information which may be helpful when setting ventilator parameters.

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