



HAL
open science

Measuring tidal breathing parameters using a volumetric vest in neonates with and without lung disease

Catherine Olden, Elizabeth Symes, Paul Christopher Seddon

► To cite this version:

Catherine Olden, Elizabeth Symes, Paul Christopher Seddon. Measuring tidal breathing parameters using a volumetric vest in neonates with and without lung disease. *Pediatric Pulmonology*, 2010, 45 (11), pp.1070. 10.1002/ppul.21272 . hal-00579482

HAL Id: hal-00579482

<https://hal.science/hal-00579482>

Submitted on 24 Mar 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Measuring tidal breathing parameters using a volumetric vest in neonates with and without lung disease

Journal:	<i>Pediatric Pulmonology</i>
Manuscript ID:	PPUL-09-0302.R1
Wiley - Manuscript type:	Original Article
Date Submitted by the Author:	06-Jan-2010
Complete List of Authors:	Olden, Catherine; Royal Alexandra Children's Hospital, Respiratory Care Symes, Elizabeth; Royal Alexandra Children's Hospital, Respiratory Care Seddon, Paul; Royal Alexandra Children's Hospital, Respiratory Care
Keywords:	infant, respiratory function, tidal breathing, chest wall



Review

1
2
3
4 Measuring tidal breathing parameters using a volumetric vest in
5
6
7 neonates with and without lung disease
8
9

10
11 Olden C RSCN, Symes E RSCN, Seddon P MB ChB.
12

13
14 Respiratory Research Unit, Royal Alexandra Children's Hospital, Brighton BN2 5BE, UK
15
16
17
18
19
20
21
22

23 C Olden and E Symes receive salary support from the Research for Patient Benefit scheme of
24 the National Institute for Health Research, UK. The authors gratefully acknowledge technical
25 assistance from Roy Norum of OKB Medical Ltd, UK, and from Kjell Øygarden and Morten
26 Eriksen of Volusense, Norway.
27
28
29
30
31
32
33
34

35 Correspondence to Dr Paul Seddon:
36

37 Respiratory Care, Royal Alexandra Children's Hospital, Brighton BN2 5BE, UK
38
39

40 Tel: +44 1273 696955
41

42 paul.seddon@bsuh.nhs.uk
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Running head: Measuring tidal breathing with a volumetric vest

Summary

Lung function measurement is difficult in unsedated infants; tidal breathing parameters are a useful non-invasive surrogate, but even these measurements cause disturbance from applying a facemask. We investigated a novel volumetric vest system (FloRight), which measures volume changes of the respiratory system from changes in the magnetic fields induced by current-carrying coils around the entire chest and abdomen.

Using a facemask and ultrasonic flowmeter as comparator, we assessed the validity and repeatability of tidal breathing parameters measured by FloRight in 10 healthy newborn infants during natural sleep. We also assessed the effect of a facemask on tidal volume and tidal expiratory flow parameters. To assess the ability of the FloRight system to detect disease, we compared the healthy infants with 11 infants suffering from bronchopulmonary dysplasia.

Tidal parameters with the FloRight vest corresponded closely with facemask measurements. Mean difference, mask minus vest, for tidal volume was 0.096mL ($p < 0.05$), with limits of agreement +4.5 to -4.3mL. Coefficient of repeatability was similar for mask and vest measurements. Tidal volume measured by FloRight with mask in place (20.6mL) was significantly higher than without mask (16.1mL), but tidal expiratory flow parameters were not altered. FloRight measurements of tidal parameters were markedly different between the two groups of infants, with tidal volume per Kg significantly higher and tidal expiratory flow parameters significantly lower.

Our findings suggest that the FloRight system is able to measure tidal breathing parameters accurately, in healthy newborn infants, without prior calibration on the infant. It appears to have at least sufficient sensitivity to detect severe respiratory disease.

Keywords: Infant, respiratory function, tidal breathing, chest wall.

Introduction

Assessing lung function in infants is difficult and time-consuming, and in certain situations virtually impossible with current techniques. Methods such as rapid thoracic compression and its raised volume refinement have advanced our understanding of infant lung disease¹.

Because of the need for sedation, however, they are only practicable in stable infants without severe or acute lung disease. The need for sedation and the time taken for measurements also limits their clinical applicability. Measurement of tidal breathing parameters²⁻⁴ is an attractive alternative, giving an indirect but non-invasive indication of lung function. They can be measured and repeated rapidly, and sedation is not always needed. However, the application of a facemask to capture respiratory airflow is problematic: it often causes disturbance or arousal, and there are suggestions^{3;5;6} that both the trigeminal stimulation and the deadspace of a mask may alter the pattern of tidal breathing.

To avoid these problems, attempts have been made to measure tidal breathing parameters at the chest wall using respiratory inductive plethysmography (RIP)⁷. However, this requires prior calibration with airflow measured at a facemask if absolute volumes are to be measured⁸, which negates most of the advantage of the technique. Using uncalibrated RIP has been advocated⁹, but the accuracy of tidal parameters measured in this way has been questioned¹⁰. Even when RIP is calibrated before use, changes in band position or in the pattern of breathing can invalidate the calibration. A method of measuring respiratory airflow accurately at the chest wall without mask calibration would be highly desirable.

1
2
3 The FloRight system (Volusense, Kongsvinger, Oslo, Norway) consists of two continuous wire
4 coils sewn into a vest worn over the entire chest and abdomen, the upper coil covering the
5 chest, the lower the abdomen. A weak (100mA) alternating current is passed through the
6 chest, the lower the abdomen. A weak (100mA) alternating current is passed through the
7 coils, resulting in a magnetic field around the child's torso which is detected by an external
8 magnetic field sensor. With breathing movements, the volume contained within the coils
9 expands and contracts, causing proportional changes in the magnetic field that is generated.
10
11 The device can therefore directly measure changes in the volume of the respiratory system,
12 and these volume changes can be differentiated digitally to yield a flow signal – and hence
13 measure tidal breathing parameters.
14
15

16
17
18 Basic laboratory studies (Unpublished observations, Volusense) have suggested that the
19 measurement of volume change is accurate and requires only electrical calibration with a
20 cylindrical volume reference coil. The primary aim of this study was to validate the
21 measurement system in healthy newborn infants – ie to demonstrate that it gives accurate
22 measurements of tidal breathing parameters without needing calibration on the infant
23 against airflow measured from a mask at the airway opening. Our primary hypothesis is that
24 in spontaneously breathing healthy term newborns, the FloRight vest gives estimates of
25 tidal volume which are similar to estimates measured from flow at the airway opening.
26
27 Secondary aims were to quantify and compare the repeatability of tidal breathing
28 measurements using the two methods – chest wall (vest) and airway opening (mask)
29 measurements - and to compare tidal breathing parameters (measured at the chest wall)
30 with and without a mask in place. A further aim was to assess whether it was possible, using
31 tidal parameters measured with the system, to distinguish between healthy newborn
32 infants and infants with bronchopulmonary dysplasia (BPD).
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Patients and Methods

The study protocol was approved by the East Sussex Research Ethics Committee and all parents gave written informed consent. In the first part of the study (validation), healthy newborn infants were studied simultaneously using the FloRight system and a system measuring airflow via a mask using an ultrasonic flowmeter (Exhalyzer D, EcoMedics AG, Duernten, Switzerland). Ten infants under a week of age and over 37 weeks gestation, without a history of respiratory symptoms or congenital abnormalities were studied on the postnatal ward of the Royal Sussex County Hospital, Brighton, UK.

Firstly, a FloRight vest of suitable size – fitting snugly but without constriction – was put on over a single thin layer of clothing. The correct size of vest was gauged by measuring the chest circumference at nipple level, and the vest was placed covering the infant from armpit to groin. In this position the junction between the upper and lower coils of the vest is approximately at the lower border of the ribcage. The FloRight system was calibrated with the magnetic field detector in place and the volume reference cylinder at the side of the infant. For measurement the magnetic field detector was positioned so that the vest was aligned with the two fins and equidistant between them, with the baby lying on a surface 40 cm below the fins. The EcoMedics system was calibrated with a 100 ml Hans Rudolph volumetric syringe (Hans Rudolph Inc, Shawnee, Kansas, US). Once the baby was in quiet natural sleep, a firm face mask with inflatable cushion rim was placed over the baby's nose and mouth, then collection of two minutes of tidal breathing data was commenced

1
2
3 simultaneously with the two systems. These recordings will be designated V1 (FloRight vest)
4
5 and M1 (EcoMedics mask). The mask was then removed, and a two minute epoch of tidal
6
7 breathing was recorded using FloRight alone, with no mask in place – designated V1A .
8
9
10 Finally, a further two-minute epoch was recorded using both systems for repeatability
11
12 measurements – designated V2 and M2. Figure 1 shows the mask and vest in place
13
14 simultaneously during data collection. The data sampling frequency was 200 Hz for the
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For calculation of the tidal breathing parameters, the traces were first inspected visually to select a 10-breath segment of stable tidal breathing with the following characteristics: no obvious artefacts, no sighs, no obvious changes in depth of breathing or baseline.

Simultaneous 10-breath segments from M1/V1, M2/V2, and from V1A were then analysed in detail to calculate the following parameters, measured breath-by-breath then averaged over the 10-breath segment:

1. Tidal volume (V_T) in ml, and per Kg body weight (V_T/Kg)
2. Time to peak tidal expiratory flow as a ratio of expiratory time (T_{PTEF}/T_E)

For the vest recordings only, the following additional tidal parameters were calculated from the traces:

3. Ratio of expiratory time to inspiratory time (T_E/T_I)
4. Expiratory flow at 50% of tidal volume as a ratio of peak tidal expiratory flow
 $(TEF_{50}/PTEF)^2$
5. Expiratory flow at 25% of tidal volume as a ratio of peak tidal expiratory flow
 $(TEF_{25}/PTEF)^2$

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
6. Centre of gravity along the volume axis for the tidal expiratory flow-volume curve (FVg). This is the dimensionless value along the volume axis (taking 0 as the start of expiration and 1 as the end of expiration) such that the areas under the curves to right and left of this point are equal. A symmetrical curve with peak flow occurring at mid-tidal volume would have $FVg=0.5$; any shift of peak tidal expiratory flow towards the start of inspiration will give values below 0.5.

19
20
21
22
23
24

The parameters were compared, using paired t-test and Bland-Altman analysis, between pairs of recordings as follows.

25
26
27

M1 and V1 were compared to assess the validity of the FloRight vest measurements.

28
29
30
31
32

M1 was compared with M2, and V1 with V2, to assess repeatability of both the mask and vest measurements.

33
34
35
36
37
38

V1 was compared with V1A to assess the effect of a facemask on tidal breathing parameters.

39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For the second part of the study, 11 oxygen-dependent infants with bronchopulmonary dysplasia (BPD, defined as persistent supplemental oxygen need beyond 36 weeks gestation, following neonatal respiratory failure) were measured, using the same protocol as above as far as possible. Mask measurements were not possible because of the nasal cannula oxygen (the oxygen flow caused a large baseline drift), so only V1 and V2 were recorded. The coefficient of repeatability of the vest measurements of tidal breathing parameters was calculated. In addition, the tidal measurements were compared with the 10 healthy term infants using two-sample t-tests.

1
2
3 The characteristics of the infants studied are summarised in Table 1. Although the weight
4
5 and length of the two groups is similar, the BPD infants, as would be expected, were short
6
7 and light for age even when corrected for prematurity.
8
9

10 11 Results

12 13 Validity

14
15
16
17
18
19 Figure 2 shows Bland-Altman plots of M1 vs V1 for V_T and for T_{PTEF}/T_E , with mean difference
20
21 and limits of agreement shown. There was no significant difference in either parameter, and
22
23 there was close correspondence between the paired measurements as shown by the small
24
25 mean differences (Mask minus Vest $V_T +0.096$ ml, $T_{PTEF}/T_E -0.01$) and narrow limits of
26
27 agreement ($V_T +4.5$ ml to -4.3 ml, $T_{PTEF}/T_E +0.32$ to -0.35).
28
29
30

31 32 Repeatability

33
34
35 Repeatability was expressed as the coefficient of repeatability (CR), defined as twice the
36
37 standard deviation of the differences between measurements¹¹. We have also expressed it
38
39 as a percentage of the mean value (CR%). Table 2 shows CR and CR% for: M1 vs M2 in
40
41 healthy infants, V1 vs V2 in healthy infants, and V1 vs V2 in BPD infants.
42
43
44
45

46 47 Effect of facemask

48
49
50 Table 3 shows mean difference, 95% confidence intervals of mean difference, and limits of
51
52 agreement for the tidal parameters, comparing V1 with V1A in the healthy infants. Tidal
53
54 volume is significantly higher with the mask in place, as would be expected because of the
55
56 additional deadspace. However, there was no significant difference in any of the tidal
57
58 expiratory flow parameters.
59
60

1
2
3 Changes with disease
4
5

6
7 Figure 3 shows typical flow-time and flow-volume traces recorded by the FloRight device in
8
9 a healthy infant and a BPD infant: a clear difference can be seen in the pattern of expiratory
10
11 flow (“sinusoidal” versus “quadrilateral” as originally described by Morris and Lane¹²). Table
12
13 4 shows mean difference and 95% confidence intervals of mean difference, comparing V_T in
14
15 healthy infants with V_T in BPD infants. There were significant differences in tidal volume
16
17 (corrected for body weight) and all tidal expiratory flow parameters. V_T per Kg was
18
19 significantly higher in BPD infants (as expected due to increased physiological deadspace),
20
21 while all the tidal expiratory flow parameters were significantly lower. Ratio of inspiratory to
22
23 expiratory time (T_I / T_E) showed only a non-significant trend to be lower.
24
25
26
27
28
29
30
31
32
33

34 Discussion

35
36
37

38 We have demonstrated that a novel volumetric vest system is able to measure both tidal
39
40 volume and tidal expiratory flow parameters in unsedated infants, without prior calibration
41
42 on the infant, and to yield values in healthy infants which are very close to those measured
43
44 directly from airflow at the airway opening. The measurements using the vest are as
45
46 repeatable as those measured at the airway opening. Furthermore, we have shown that
47
48 tidal measurements made using this system are able to differentiate infants with
49
50 bronchopulmonary dysplasia from healthy term infants.
51
52

53
54
55
56 Previous work using RIP has yielded conflicting results. Stick et al⁹, using uncalibrated RIP,
57
58 showed close agreement between T_{PTEF}/T_E values from RIP with those from mask and
59
60 pneumotachograph in unsedated healthy newborn infants. However, Jackson et al¹⁰, using

1
2
3 a different uncalibrated RIP system in unsedated newborns and sedated older infants were
4
5 unable to replicate this. In their study, RIP-measured T_{PTEF}/T_E was consistently lower, with
6
7 wide limits of agreement. Neither study was designed to measure tidal volume.
8
9

10
11 Our values for tidal parameters in the healthy infants, measured both by mask and by vest,
12
13 are very similar to published values in healthy term neonates measured by mask¹³⁻¹⁵. This,
14
15 as well as our finding that tidal expiratory flow parameters (unlike tidal volume) were not
16
17 altered by the presence of a mask, suggests that existing normative values are appropriate
18
19 in interpreting measurements made using this vest system. Our figures for repeatability of
20
21 T_{PTEF}/T_E , both with mask (CR 41%) and vest (CR 37%), are also similar to published values¹³,
22
23 and demonstrate how variable this parameter is in newborn infants. This is a significant
24
25 limitation of T_{PTEF}/T_E , however measured, and suggests that the parameters with better
26
27 repeatability such as FVg may be worth exploring .
28
29
30
31
32
33

34
35 Clearly caution is needed in applying our conclusions on the validity of the system. We were
36
37 not able to make mask measurements in our BPD infants because of the administration of
38
39 nasal cannula oxygen, and therefore were not able to show whether the Floright system
40
41 makes valid measurements in the presence of chest distortion. All our measurements were
42
43 made during spontaneous tidal breathing in infants lying supine, so that we cannot
44
45 comment on the validity of measurements in prone or side-lying infants, in older children
46
47 measured in a sitting position, or in artificially ventilated infants. All our healthy neonates
48
49 were above 2Kg weight: it is not yet clear whether the system will be accurate in small
50
51 preterm infants.
52
53
54
55
56

57
58 At the beginning of the study we encountered difficulty in calibrating the equipment in an
59
60 electrically “noisy” environment (eg near television screens): a software change was

1
2
3 required to resolve this problem. Interference from nearby devices producing a high
4
5 frequency changing magnetic field may still cause problems, in some settings, but would be
6
7 likely to produce a “noisy” trace, rather than inaccurate measurements. The equipment is
8
9 currently large and cumbersome, making its use in acute or intensive care settings difficult:
10
11 we understand that design changes to modify this problem are planned.
12
13
14
15
16

17 Despite these caveats, our findings suggest that this is an accurate technique for measuring
18
19 tidal breathing without the need for a face mask. This technique has the potential to
20
21 measure tidal flow parameters in situations where a mask is not tolerated (eg tachypnoea,
22
23 awake infants) or mask measurements are problematic (eg oxygen therapy, continuous
24
25 positive airway pressure, non-invasive ventilation). The volume changes can also be
26
27 partitioned into chest and abdominal components, giving the potential to measure
28
29 thoracoabdominal asynchrony in the context of acute respiratory disease or sleep-
30
31 disordered breathing. Further work is needed to validate the technique in these settings.
32
33
34
35
36
37
38
39
40
41

42 Reference List

- 43
44
45 (1) Gappa M, Ranganathan SC, Stocks J. Lung function testing in infants with cystic fibrosis:
46 lessons from the past and future directions. *Pediatr Pulmonol* 2001; 32(3):228-245.
47
48 (2) Lodrup Carlsen KC, Magnus P, Carlsen K-H. Lung function by tidal breathing in awake healthy
49 newborn infants. *Eur Respir J* 1994; 7:1660-1668.
50
51 (3) Bates JHT, Schmalisch G, Filbrun D, Stocks J. Tidal breath analysis for infant pulmonary
52 function testing. *Eur Respir J* 2000; 16:1180-1192.
53
54 (4) Seddon PC, Davis GM, Coates AL. Do tidal expiratory flow patterns reflect lung mechanics in
55 infants? *Am J Resp Crit Care Med* 1996; 153:1248-1252.
56
57 (5) Fleming PJ, Levine MR, Goncalves A. Changes in respiratory pattern resulting from the use of
58 a facemask to record respiration in newborn infants. *Pediatr Res* 1982; 16(12):1031-1034.
59
60

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
- (6) Dolfin T, Duffty P, Wilkes D, England S, Bryan H. Effects of a face mask and pneumotachograph on breathing in sleeping infants. *Am Rev Respir Dis* 1983; 128(6):977-979.
 - (7) Adams JA. Respiratory Inductive Plethysmography. In: Stocks J, Sly PD, Tepper RS, Morgan WJ, editors. *Infant Respiratory Function Testing*. New York: Wiley-Liss; 1996. 139-164.
 - (8) Sackner MA, Watson H, Belsito AE, Finerman D, Saurez M, Gonzalez G et al. Calibration of respiratory inductive plethysmography during natural breathing. *J Appl Physiol* 1989; 66:410-420.
 - (9) Stick SM, Ellis E, LeSouëf PN, Sly PD. Validation of respiratory inductance plethysmography ("Respirtrace") for the measurement of tidal breathing parameters in newborns. *Pediatr Pulmonol* 1992; 14:187-191.
 - (10) Jackson E, Stocks J, Pilgrim L, Dundas I, Dezateux C. A critical assessment of uncalibrated respiratory inductance plethysmography (Respirtrace) for the measurement of tidal breathing parameters in newborns and infants. *Pediatr Pulmonol* 1995; 20(2):119-124.
 - (11) Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; i:307-310.
 - (12) Morris MJ, Lane DJ. Tidal expiratory flow patterns in airflow obstruction. *Thorax* 1981; 36:135-142.
 - (13) Stocks J, Dezateux CA, Jackson EA, Hoo A-F, Costeloe KL, Wade AM. Analysis of tidal breathing parameters in infancy: how variable is $T_{PTEF}:T_E$? *Am J Resp Crit Care Med* 1994; 150:1347-1354.
 - (14) Lodrup Carlsen KC, Carlsen K-H. Lung function in awake healthy infants: the first five days of life. *Eur Respir J* 1993; 6:1496-1500.
 - (15) Stick SM. Measurements during tidal breathing. In: Stocks J, Sly PD, Tepper RS, Morgan WJ, editors. *Infant Respiratory Function Testing*. New York: Wiley-Liss; 1996. 117-138.

	Healthy	Bronchopulmonary Dysplasia
Number of infants	10	11
Weight (Kg)	3.7 (0.4)	4.0 (1.6)
Weight Z (SD) score	+0.13 (0.83)	-2.59 (1.11)
Length (cm)	52 (2.39)	52 (7.6)
Length SD Z (SD) score	+0.09 (0.82)	-2.17 (1.38)
Birth Gestation (weeks)	40 (1.3)	29 (4.6)
Age at test (days)	1.4 (0.5)	146 (71)

Table 1: Characteristics of infants studied, showing mean (SD). Z scores for weight and length are calculated as the number of SD above or below the predicted mean from growth charts; for the BPD infants, age is corrected for prematurity.

For Peer Review

	Healthy infants - Mask		Healthy infants - Vest		BPD infants - Vest	
	Mean value (SD)	CR (CR%)	Mean value (SD)	CR (CR%)	Mean value (SD)	CR (CR%)
V_T (ml)	20.66 (5.35)	7.2 (37%)	20.56 (4.10)	8.4 (41%)	26.84 (5.05)	6.6 (23%)
V_T (ml/Kg)	5.43 (1.53)	2.0 (37%)	5.40 (1.23)	2.2 (41%)	7.01 (1.32)	1.83 (23%)
T_{PTEF}/T_E	0.50 (0.09)	0.20 (41%)	0.51 (0.14)	0.18 (37%)	0.217 (0.094)	0.14 (65%)
T_E / T_I	1.07 (0.21)	0.43 (38%)	1.04 (0.18)	0.47 (45%)	1.30 (0.42)	0.89 (67%)
$TEF_{50}/PTEF$			0.920 (0.068)	13.3 (14%)	0.744 (0.125)	16.1 (22%)
$TEF_{25}/PTEF$			0.787 (0.116)	23.1 (30%)	0.457 (0.148)	15.5 (34%)
FVg			0.501 (0.028)	0.02 (8%)	0.430 (0.037)	0.04 (10%)

Table 2. Tidal breathing parameters, showing mean values, repeatability coefficient (CR) and CR as percent of mean value (CR%), for mask and vest measurements in healthy infants, and for mask measurements in BPD infants.

	With Mask Mean (SD)	Without Mask Mean (SD)	Mean Difference (95%Confidence Interval)
Tidal Volume (ml)	20.56 (4.10)	16.096 (3.79)	4.67 * (+1.64 to +7.29)
T_{PTEF}/T_E	0.51 (0.14)	0.53 (0.15)	0.01 (-0.09 to +0.06)
$TEF_{50}/PTEF$	0.918 (0.043)	0.849 (0.095)	0.069 (-0.010 to +0.148)
$TEF_{25}/PTEF$	0.776 (0.102)	0.772 (0.137)	0.004 (-0.038 to +0.047)
FVg	0.498 (0.020)	0.502 (0.028)	-0.005 (-0.02 to +0.01)

Table 3. Tidal breathing parameters in healthy newborn infants measured by volumetric vest, comparing values with and without face mask in place. * = $p < 0.05$

	Normal (n=10)	BPD (n=11)	p value
V_T / Kg (ml/Kg)	5.40 (1.23)	7.01 (1.32)	0.009
T_{PTEF}/T_E	0.506 (0.150)	0.217 (0.094)	0.00004
T_E / T_I	1.04 (0.18)	1.30 (0.42)	0.08
$TEF_{50}/PTEF$	0.920 (0.068)	0.744 (0.125)	0.009
$TEF_{25}/PTEF$	0.787 (0.116)	0.457 (0.148)	0.00002
FVg	0.501 (0.028)	0.430 (0.037)	0.00009

Table 4. Tidal breathing parameters measured by volumetric vest in healthy and BPD infants, showing mean (SD) values and p value for comparison (two-sample t-test).

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



Figure 1: Study setup, showing both FloRight vest and mask with ultrasonic flowmeter in place.
194x153mm (96 x 96 DPI)

Review

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

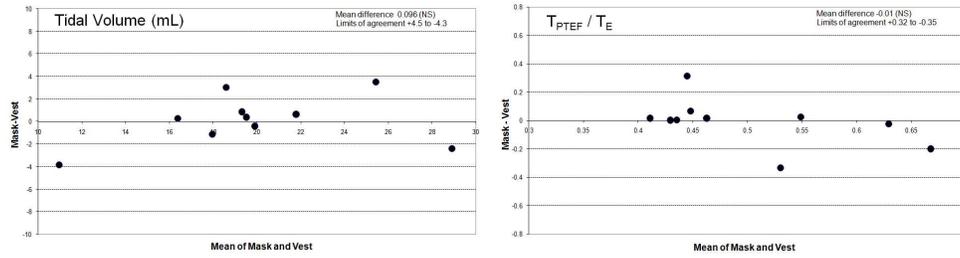


Figure 2: Bland-Altman plots comparing tidal parameters measured simultaneously with mask (ultrasonic flowmeter system) versus vest (FloRight system); tidal volume on left-hand plot, TPTEF/TE on right-hand plot. 533x144mm (96 x 96 DPI)

Peer Review

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

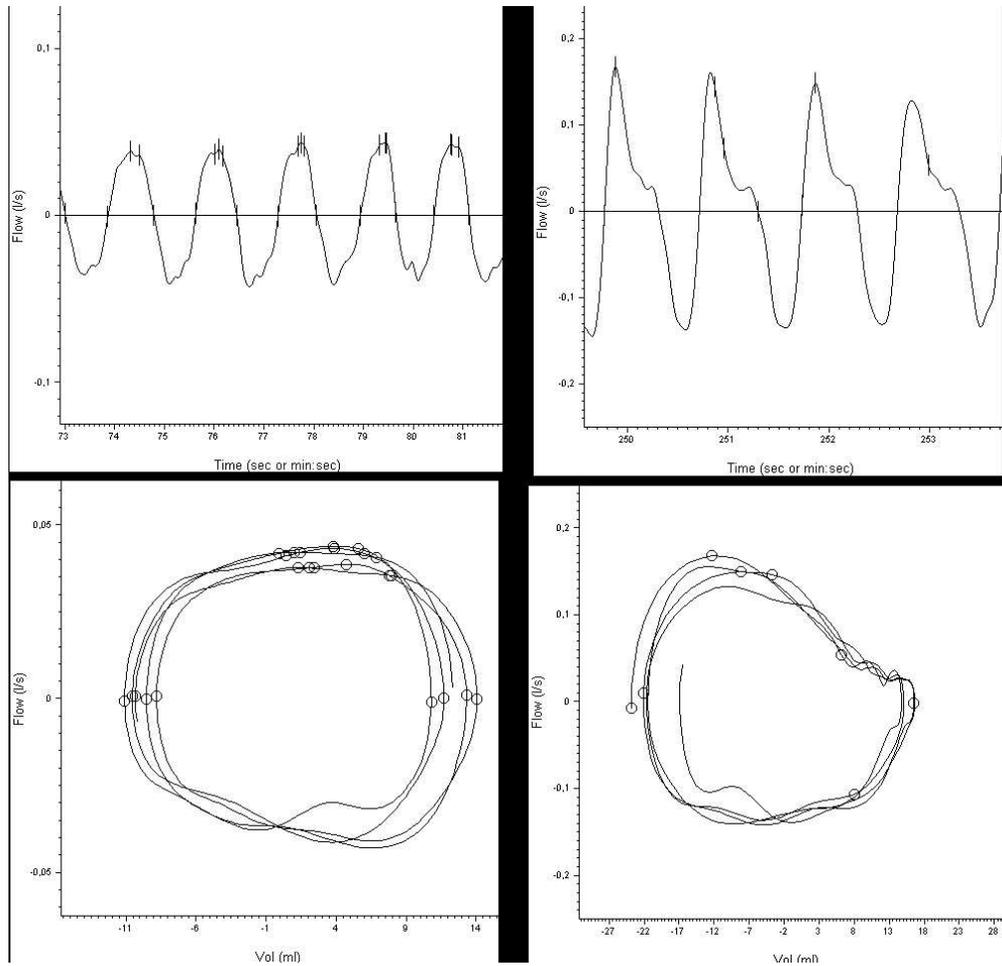


Figure 3: Sample flow-time (upper plots) and flow-volume (lower plots) for two infants: healthy newborn infant on the left, infant with bronchopulmonary dysplasia on the right. 262x252mm (96 x 96 DPI)

1
2
3
4 Measuring tidal breathing parameters using a volumetric vest in
5
6
7 neonates with and without lung disease
8
9

10 Olden C RSCN, Symes E RSCN, Seddon P MB ChB.

11
12
13
14 Respiratory Research Unit, Royal Alexandra Children's Hospital, Brighton BN2 5BE, UK
15
16
17
18
19
20
21

22
23 C Olden and E Symes receive salary support from the Research for Patient Benefit scheme of
24
25 the National Institute for Health Research, UK. The authors gratefully acknowledge technical
26
27 assistance from Roy Norum of OKB Medical Ltd, UK, and from Kjell Øygarden and Morten
28
29 Eriksen of Volusense, Norway.
30
31
32
33
34

35 Correspondence to Dr Paul Seddon:

36
37 Respiratory Care, Royal Alexandra Children's Hospital, Brighton BN2 5BE, UK
38
39

40 Tel: +44 1273 696955

41
42
43 paul.seddon@bsuh.nhs.uk
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Running head: Measuring tidal breathing with a volumetric vest

Summary

Lung function measurement is difficult in unsedated infants; tidal breathing parameters are a useful non-invasive surrogate, but even these measurements cause disturbance from applying a facemask. We investigated a novel volumetric vest system (FloRight), which measures volume changes of the respiratory system from changes in the magnetic fields induced by current-carrying coils around the entire chest and abdomen.

Using a facemask and ultrasonic flowmeter as comparator, we assessed the validity and repeatability of tidal breathing parameters measured by FloRight in 10 healthy newborn infants during natural sleep. We also assessed the effect of a facemask on tidal volume and tidal expiratory flow parameters. To assess the ability of the FloRight system to detect disease, we compared the healthy infants with 11 infants suffering from bronchopulmonary dysplasia.

Tidal parameters with the FloRight vest corresponded closely with facemask measurements. Mean difference, mask minus vest, for tidal volume was 0.096mL ($p < 0.05$), with limits of agreement +4.5 to -4.3mL. Coefficient of repeatability was similar for mask and vest measurements. Tidal volume measured by FloRight with mask in place (20.6mL) was significantly higher than without mask (16.1mL), but tidal expiratory flow parameters were not altered. FloRight measurements of tidal parameters were markedly different between the two groups of infants, with tidal volume per Kg significantly higher and tidal expiratory flow parameters significantly lower.

Our findings suggest that the FloRight system is able to measure tidal breathing parameters accurately, in healthy newborn infants, without prior calibration on the infant. It appears to have at least sufficient sensitivity to detect severe respiratory disease.

Keywords: Infant, respiratory function, tidal breathing, chest wall.

Introduction

Assessing lung function in infants is difficult and time-consuming, and in certain situations virtually impossible with current techniques. Methods such as rapid thoracic compression and its raised volume refinement have advanced our understanding of infant lung disease¹.

Because of the need for sedation, however, they are only practicable in stable infants without severe or acute lung disease. The need for sedation and the time taken for measurements also limits their clinical applicability. Measurement of tidal breathing parameters²⁻⁴ is an attractive alternative, giving an indirect but non-invasive indication of lung function. They can be measured and repeated rapidly, and sedation is not always needed. However, the application of a facemask to capture respiratory airflow is problematic: it often causes disturbance or arousal, and there are suggestions^{3;5;6} that both the trigeminal stimulation and the deadspace of a mask may alter the pattern of tidal breathing.

To avoid these problems, attempts have been made to measure tidal breathing parameters at the chest wall using respiratory inductive plethysmography (RIP)⁷. However, this requires prior calibration with airflow measured at a facemask if absolute volumes are to be measured⁸, which negates most of the advantage of the technique. Using uncalibrated RIP has been advocated⁹, but the accuracy of tidal parameters measured in this way has been questioned¹⁰. Even when RIP is calibrated before use, changes in band position or in the pattern of breathing can invalidate the calibration. A method of measuring respiratory airflow accurately at the chest wall without mask calibration would be highly desirable.

1
2
3 The FloRight system (Volusense, Kongsvinger, Oslo, Norway) consists of two continuous wire
4 coils sewn into a vest worn over the entire chest and abdomen, the upper coil covering the
5 chest, the lower the abdomen. A weak (100mA) alternating current is passed through the
6 chest, the lower the abdomen. A weak (100mA) alternating current is passed through the
7 coils, resulting in a magnetic field around the child's torso which is detected by an external
8 magnetic field sensor. With breathing movements, the volume contained within the coils
9 expands and contracts, causing proportional changes in the magnetic field that is generated.
10
11 The device can therefore directly measure changes in the volume of the respiratory system,
12 and these volume changes can be differentiated digitally to yield a flow signal – and hence
13 measure tidal breathing parameters.
14
15

16
17
18 Basic laboratory studies (Unpublished observations, Volusense) have suggested that the
19 measurement of volume change is accurate and requires only electrical calibration with a
20 cylindrical volume reference coil. The primary aim of this study was to validate the
21 measurement system in healthy newborn infants – ie to demonstrate that it gives accurate
22 measurements of tidal breathing parameters without needing calibration on the infant
23 against airflow measured from a mask at the airway opening. Our primary hypothesis is that
24 in spontaneously breathing healthy term newborns, the FloRight vest gives estimates of
25 tidal volume which are similar to estimates measured from flow at the airway opening.
26
27

28
29 Secondary aims were to quantify and compare the repeatability of tidal breathing
30 measurements using the two methods – chest wall (vest) and airway opening (mask)
31 measurements - and to compare tidal breathing parameters (measured at the chest wall)
32 with and without a mask in place. A further aim was to assess whether it was possible, using
33 tidal parameters measured with the system, to distinguish between healthy newborn
34 infants and infants with bronchopulmonary dysplasia (BPD).
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Patients and Methods

The study protocol was approved by the East Sussex Research Ethics Committee and all parents gave written informed consent. In the first part of the study (validation), healthy newborn infants were studied simultaneously using the FloRight system and a system measuring airflow via a mask using an ultrasonic flowmeter (Exhalyzer D, EcoMedics AG, Duernten, Switzerland). Ten infants under a week of age and over 37 weeks gestation, without a history of respiratory symptoms or congenital abnormalities were studied on the postnatal ward of the Royal Sussex County Hospital, Brighton, UK.

Firstly, a FloRight vest of suitable size – fitting snugly but without constriction – was put on over a single thin layer of clothing. **The correct size of vest was gauged by measuring the chest circumference at nipple level, and the vest was placed covering the infant from armpit to groin. In this position the junction between the upper and lower coils of the vest is approximately at the lower border of the ribcage.** The FloRight system was calibrated with the magnetic field detector in place and the volume reference cylinder at the side of the infant. For measurement the magnetic field detector was positioned so that the vest was aligned with the two fins and equidistant between them, with the baby lying on a surface 40 cm below the fins. The EcoMedics system was calibrated with a 100 ml Hans Rudolph volumetric syringe (Hans Rudolph Inc, Shawnee, Kansas, US). Once the baby was in quiet natural sleep, a firm face mask with inflatable cushion rim was placed over the baby's nose and mouth, then collection of two minutes of tidal breathing data was commenced

1
2
3 simultaneously with the two systems. These recordings will be designated V1 (FloRight vest)
4 and M1 (EcoMedics mask). The mask was then removed, and a two minute epoch of tidal
5
6 breathing was recorded using FloRight alone, with no mask in place – designated V1A .
7
8
9 Finally, a further two-minute epoch was recorded using both systems for repeatability
10
11 measurements – designated V2 and M2. Figure 1 shows the mask and vest in place
12
13 simultaneously during data collection. The data sampling frequency was 200 Hz for the
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For calculation of the tidal breathing parameters, the traces were first inspected visually to select a 10-breath segment of stable tidal breathing with the following characteristics: no obvious artefacts, no sighs, no obvious changes in depth of breathing or baseline.

Simultaneous 10-breath segments from M1/V1, M2/V2, and from V1A were then analysed in detail to calculate the following parameters, measured breath-by-breath then averaged over the 10-breath segment:

1. Tidal volume (V_T) in ml, and per Kg body weight (V_T/Kg)
2. Time to peak tidal expiratory flow as a ratio of expiratory time (T_{PTEF}/T_E)

For the vest recordings only, the following additional tidal parameters were calculated from the traces:

3. Ratio of expiratory time to inspiratory time (T_E/T_I)
4. Expiratory flow at 50% of tidal volume as a ratio of peak tidal expiratory flow
 $(TEF_{50}/PTEF)^2$
5. Expiratory flow at 25% of tidal volume as a ratio of peak tidal expiratory flow
 $(TEF_{25}/PTEF)^2$

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
6. Centre of gravity along the volume axis for the tidal expiratory flow-volume curve (FVg). This is the dimensionless value along the volume axis (taking 0 as the start of expiration and 1 as the end of expiration) such that the areas under the curves to right and left of this point are equal. A symmetrical curve with peak flow occurring at mid-tidal volume would have $FVg=0.5$; any shift of peak tidal expiratory flow towards the start of inspiration will give values below 0.5.

19
20
21
22
23
24

The parameters were compared, using paired t-test and Bland-Altman analysis, between pairs of recordings as follows.

25
26
27

M1 and V1 were compared to assess the validity of the FloRight vest measurements.

28
29
30
31
32

M1 was compared with M2, and V1 with V2, to assess repeatability of both the mask and vest measurements.

33
34
35
36
37
38

V1 was compared with V1A to assess the effect of a facemask on tidal breathing parameters.

39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For the second part of the study, 11 oxygen-dependent infants with bronchopulmonary dysplasia (BPD, defined as persistent supplemental oxygen need beyond 36 weeks gestation, following neonatal respiratory failure) were measured, using the same protocol as above as far as possible. Mask measurements were not possible because of the nasal cannula oxygen (the oxygen flow caused a large baseline drift), so only V1 and V2 were recorded. The coefficient of repeatability of the vest measurements of tidal breathing parameters was calculated. In addition, the tidal measurements were compared with the 10 healthy term infants using two-sample t-tests.

1
2
3 The characteristics of the infants studied are summarised in Table 1. Although the weight
4 and length of the two groups is similar, the BPD infants, as would be expected, were short
5 and light for age even when corrected for prematurity.
6
7
8
9

10 Results

11 Validity

12
13
14
15
16
17
18
19 Figure 2 shows Bland-Altman plots of M1 vs V1 for V_T and for T_{PTEF}/T_E , with mean difference
20 and limits of agreement shown. There was no significant difference in either parameter, and
21 there was close correspondence between the paired measurements as shown by the small
22 mean differences (Mask minus Vest $V_T +0.096$ ml, $T_{PTEF}/T_E -0.01$) and narrow limits of
23 agreement ($V_T +4.5$ ml to -4.3 ml, $T_{PTEF}/T_E +0.32$ to -0.35).
24
25
26
27
28
29
30
31

32 Repeatability

33
34
35 Repeatability was expressed as the coefficient of repeatability (CR), defined as twice the
36 standard deviation of the differences between measurements¹¹. We have also expressed it
37 as a percentage of the mean value (CR%). Table 2 shows CR and CR% for: M1 vs M2 in
38 healthy infants, V1 vs V2 in healthy infants, and V1 vs V2 in BPD infants.
39
40
41
42
43
44
45

46 Effect of facemask

47
48
49
50 Table 3 shows mean difference, 95% confidence intervals of mean difference, and limits of
51 agreement for the tidal parameters, comparing V1 with V1A in the healthy infants. Tidal
52 volume is significantly higher with the mask in place, as would be expected because of the
53 additional deadspace. However, there was no significant difference in any of the tidal
54 expiratory flow parameters.
55
56
57
58
59
60

1
2
3 Changes with disease
4
5

6
7 Figure 3 shows typical flow-time and flow-volume traces recorded by the FloRight device in
8
9 a healthy infant and a BPD infant: a clear difference can be seen in the pattern of expiratory
10
11 flow (“sinusoidal” versus “quadrilateral” as originally described by Morris and Lane¹²). Table
12
13 4 shows mean difference and 95% confidence intervals of mean difference, comparing V_T in
14
15 healthy infants with V_T in BPD infants. There were significant differences in tidal volume
16
17 (corrected for body weight) and all tidal expiratory flow parameters. V_T per Kg was
18
19 significantly higher in BPD infants (as expected due to increased physiological deadspace),
20
21 while all the tidal expiratory flow parameters were significantly lower. Ratio of inspiratory to
22
23 expiratory time (T_I / T_E) showed only a non-significant trend to be lower.
24
25
26
27
28
29
30
31
32
33

34 Discussion

35
36
37

38 We have demonstrated that a novel volumetric vest system is able to measure both tidal
39
40 volume and tidal expiratory flow parameters in unsedated infants, without prior calibration
41
42 on the infant, and to yield values in healthy infants which are very close to those measured
43
44 directly from airflow at the airway opening. The measurements using the vest are as
45
46 repeatable as those measured at the airway opening. Furthermore, we have shown that
47
48 tidal measurements made using this system are able to differentiate infants with
49
50 bronchopulmonary dysplasia from healthy term infants.
51
52

53
54
55
56 Previous work using RIP has yielded conflicting results. Stick et al⁹, using uncalibrated RIP,
57
58 showed close agreement between T_{PTEF}/T_E values from RIP with those from mask and
59
60 pneumotachograph in unsedated healthy newborn infants. However, Jackson et al¹⁰, using

1
2
3 a different uncalibrated RIP system in unsedated newborns and sedated older infants were
4
5 unable to replicate this. In their study, RIP-measured T_{PTEF}/T_E was consistently lower, with
6
7 wide limits of agreement. Neither study was designed to measure tidal volume.
8
9

10
11 Our values for tidal parameters in the healthy infants, measured both by mask and by vest,
12
13 are very similar to published values in healthy term neonates measured by mask¹³⁻¹⁵. This,
14
15 as well as our finding that tidal expiratory flow parameters (unlike tidal volume) were not
16
17 altered by the presence of a mask, suggests that existing normative values are appropriate
18
19 in interpreting measurements made using this vest system. Our figures for repeatability of
20
21 T_{PTEF}/T_E , both with mask (CR 41%) and vest (CR 37%), are also similar to published values¹³,
22
23 and demonstrate how variable this parameter is in newborn infants. This is a significant
24
25 limitation of T_{PTEF}/T_E , however measured, and suggests that the parameters with better
26
27 repeatability such as FVg may be worth exploring .
28
29
30
31
32
33

34
35 Clearly caution is needed in applying our conclusions on the validity of the system. We were
36
37 not able to make mask measurements in our BPD infants because of the administration of
38
39 nasal cannula oxygen, and therefore were not able to show whether the Floright system
40
41 makes valid measurements in the presence of chest distortion. All our measurements were
42
43 made during spontaneous tidal breathing in infants lying supine, so that we cannot
44
45 comment on the validity of measurements in prone or side-lying infants, in older children
46
47 measured in a sitting position, or in artificially ventilated infants. All our healthy neonates
48
49 were above 2Kg weight: it is not yet clear whether the system will be accurate in small
50
51 preterm infants.
52
53
54
55
56

57
58 At the beginning of the study we encountered difficulty in calibrating the equipment in an
59
60 electrically “noisy” environment (eg near television screens): a software change was

1
2
3 required to resolve this problem. Interference from nearby devices producing a high
4
5 frequency changing magnetic field may still cause problems, in some settings, but would be
6
7 likely to produce a “noisy” trace, rather than inaccurate measurements. The equipment is
8
9 currently large and cumbersome, making its use in acute or intensive care settings difficult:
10
11 we understand that design changes to modify this problem are planned.
12
13
14
15
16

17 Despite these caveats, our findings suggest that this is an accurate technique for measuring
18
19 tidal breathing without the need for a face mask. This technique has the potential to
20
21 measure tidal flow parameters in situations where a mask is not tolerated (eg tachypnoea,
22
23 awake infants) or mask measurements are problematic (eg oxygen therapy, continuous
24
25 positive airway pressure, non-invasive ventilation). The volume changes can also be
26
27 partitioned into chest and abdominal components, giving the potential to measure
28
29 thoracoabdominal asynchrony in the context of acute respiratory disease or sleep-
30
31 disordered breathing. Further work is needed to validate the technique in these settings.
32
33
34
35
36
37
38
39
40

41 Reference List

- 42
43
44
45 (1) Gappa M, Ranganathan SC, Stocks J. Lung function testing in infants with cystic fibrosis:
46 lessons from the past and future directions. *Pediatr Pulmonol* 2001; 32(3):228-245.
47
48 (2) Lodrup Carlsen KC, Magnus P, Carlsen K-H. Lung function by tidal breathing in awake healthy
49 newborn infants. *Eur Respir J* 1994; 7:1660-1668.
50
51 (3) Bates JHT, Schmalisch G, Filbrun D, Stocks J. Tidal breath analysis for infant pulmonary
52 function testing. *Eur Respir J* 2000; 16:1180-1192.
53
54 (4) Seddon PC, Davis GM, Coates AL. Do tidal expiratory flow patterns reflect lung mechanics in
55 infants? *Am J Resp Crit Care Med* 1996; 153:1248-1252.
56
57 (5) Fleming PJ, Levine MR, Goncalves A. Changes in respiratory pattern resulting from the use of
58 a facemask to record respiration in newborn infants. *Pediatr Res* 1982; 16(12):1031-1034.
59
60

- 1
2
3
4 (6) Dolfin T, Duffty P, Wilkes D, England S, Bryan H. Effects of a face mask and
5 pneumotachograph on breathing in sleeping infants. *Am Rev Respir Dis* 1983; 128(6):977-
6 979.
7
8 (7) Adams JA. Respiratory Inductive Plethysmography. In: Stocks J, Sly PD, Tepper RS, Morgan
9 WJ, editors. *Infant Respiratory Function Testing*. New York: Wiley-Liss; 1996. 139-164.
10
11 (8) Sackner MA, Watson H, Belsito AE, Finerman D, Saurez M, Gonzalez G et al. Calibration of
12 respiratory inductive plethysmography during natural breathing. *J Appl Physiol* 1989;
13 66:410-420.
14
15 (9) Stick SM, Ellis E, LeSouëf PN, Sly PD. Validation of respiratory inductance plethysmography
16 ("Respirtrace") for the measurement of tidal breathing parameters in newborns. *Pediatr*
17 *Pulmonol* 1992; 14:187-191.
18
19 (10) Jackson E, Stocks J, Pilgrim L, Dundas I, Dezateux C. A critical assessment of uncalibrated
20 respiratory inductance plethysmography (Respirtrace) for the measurement of tidal
21 breathing parameters in newborns and infants. *Pediatr Pulmonol* 1995; 20(2):119-124.
22
23 (11) Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of
24 clinical measurement. *Lancet* 1986; i:307-310.
25
26 (12) Morris MJ, Lane DJ. Tidal expiratory flow patterns in airflow obstruction. *Thorax* 1981;
27 36:135-142.
28
29 (13) Stocks J, Dezateux CA, Jackson EA, Hoo A-F, Costeloe KL, Wade AM. Analysis of tidal
30 breathing parameters in infancy: how variable is $T_{PTEF}:T_E$? *Am J Resp Crit Care Med* 1994;
31 150:1347-1354.
32
33 (14) Lodrup Carlsen KC, Carlsen K-H. Lung function in awake healthy infants: the first five days of
34 life. *Eur Respir J* 1993; 6:1496-1500.
35
36 (15) Stick SM. Measurements during tidal breathing. In: Stocks J, Sly PD, Tepper RS, Morgan WJ,
37 editors. *Infant Respiratory Function Testing*. New York: Wiley-Liss; 1996. 117-138.
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



Figure 1a: Study setup, showing both FloRight vest and mask with ultrasonic flowmeter in place. The two fins of the magnetic field detector are shown suspended above the infant.
105x72mm (150 x 150 DPI)