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TECHNICAL NOTE

Evaluation of three different techniques used to measure chest wall movements in children

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Evaluation of three different techniques used to measure chest wall movements in children. R.I. Ross Russell, P.J. Helms. ©ERS Journals Ltd 1994.
ABSTRACT: Several techniques exist for assessing chest wall movements in children, that incorporate different measurement principles. Although the output from such devices appears very similar, the comparability of data from different devices needs to be evaluated.

We have investigated the simultaneous measurement of chest wall movement using three different devices in 12 children recovering from intensive care. The devices used were inductance plethysmography (assessing thoracic cross-sectional area), magnetometers (assessing thoracic diameter), and a Hall device strain gauge (assessing thoracic circumference).

Measurements of respiratory timing and of phase angle between rib cage and abdomen in these patients showed a close agreement between devices in ventilated patients. However, occasional inconsistencies occurred in patients who were breathing spontaneously.

We suggest that it may not always be appropriate to directly compare data on chest wall movements in children recorded using different measurement techniques. The best method of measurement varies with the clinical picture.
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There is a increasing interest in the noninvasive monitoring of respiratory function, and particularly in the measurement of chest wall movements. Among these measures is the objective assessment of the asynchronous behaviour of the rib cage and abdomen during breathing, allowing qualification of chest wall distortion [1, 2]. Such asynchronous breathing patterns have implications for the ventilatory capacity and efficiency of the patient concerned. Different techniques that have been used include linear differential transducers and magnetometers measuring changes in anteroposterior (AP) diameter of the chest [3–6], respiratory inductance plethysmography (RIP) measuring cross-sectional area [7–10], and mercury-in-rubber strain gauges measuring abdominal circumference [11, 12]. These techniques have been used extensively [13–15], although their accuracy as quantitative measures of lung volume has been questioned [11, 16].

Experience with all these techniques, whether used qualitatively or semiquantitatively, has generally assumed them to be equivalent. However, as they all use different measurement principles, this may not necessarily be so [7, 17]. Only one previous study has compared these three techniques with respect to their use as semiquantitative measures of lung volume [17], and not in relation to measurements of respiratory timing or asynchrony.

We therefore compared the results of different methods embodying the three main measurement principles (linear distance, cross-sectional area and circumference) in order to evaluate any systematic differences in respiratory timing and indices of thoracoabdominal asynchrony.

Methods

Chest wall movements were measured using three types of device. Changes in cross-sectional area were estimated by inductance plethysmography (RIP, Respitrace, Respitrace Corp., Ardsley, NY, USA). Changes in thoracic (AP) diameter were measured with magnetometers. Circumferential changes were measured with a Hall device strain gauge (Densa Ltd, Clwyd, Wales). This latter device consists of a small 1.5 cm monitor that is secured by circumferential elasticated bands. Inward movement of the top part of the sensor with tightening of the band during inspiration, moves a magnet closer to a Hall sensor. This produces a small current, which is amplified to produce a respiratory signal.

Measurements were made in 10 patients, aged 1 month to 13 yrs, recovering from intensive care (table 1). Patients with asymmetrical chest walls or unilateral abnormalities on chest radiology were excluded. Five patients were studied whilst on full ventilation, and five during spontaneous breathing.

Elasticated straps were applied first, just above the

Table 1. – Clinical details of the 10 patients studied

Case No.	Age	Diagnosis
Ventilated		
1	1 month	Central hypoventilation
2	5 years	Leukaemia + pneumonia
3	3 months	Bronchiolitis
4	13 years	ASD repair
5	10 years	Congenital heart disease*
Spontaneous breathing		
6	3 years	Head injury
7	8 years	Leukaemia + pneumonia
8	1 month	Bronchiolitis
9	10 years	VSD repair
10	1.5 months	Preterm, bronchiolitis

*: postcardiac catheterization. ASD: atrial septal defect; VSD: ventricular septal defect.

nipple line and 1 cm above the umbilicus, with the Hall sensor placed randomly in either the left or right midclavicular line. Magnetometers were then placed under the straps in the opposite midclavicular line and taped into place. Finally, RIP bands were applied over the Hall sensors and magnetometers. Once in place, the straps and bands were gently stretched by hand, to ensure that there was no restriction to breathing. To assess possible interference between the monitors, traces were also obtained as each device was switched on and off. Children were then left for at least 5 min to adjust to the monitors, and the resultant signals recorded directly onto a computer using a data acquisition software (Snapshot, HEM Data Corp., Southfield, Michigan, USA, adapted by Densa Ltd, Clwyd, Wales). Data were collected over 10 min. Input gains were adjusted for all six channels, so that their amplitude was similar during tidal breathing. Hard copies of all traces were obtained as screen dumps and analysed manually. For each patient, a period of 2 min was selected during which there was minimal movement artefact. Respiratory rate (RR), inspiratory time (TI), and inspiratory time as a ratio of total respiratory cycle time (TI/Ttot) were measured from both the rib cage and abdominal traces. Phase angle between rib cage and abdominal motion was measured using Lissajou plots and previously described formulae [2]. Mechanically-ventilated and spontaneously breathing patients were analysed separately, as the chest wall mechanics and synchrony between rib cage and abdomen are known to be different between relaxed mechanically-ventilated patients and those who are spontaneously breathing.

Statistical analysis was performed using nonparametric techniques on paired samples (Wilcoxon matched pairs), and 95% confidence intervals of the measurements.

Results

Satisfactory traces were obtained from all patients, and no interference between devices could be detected. All signals remained unchanged as each separate device was turned on and off.

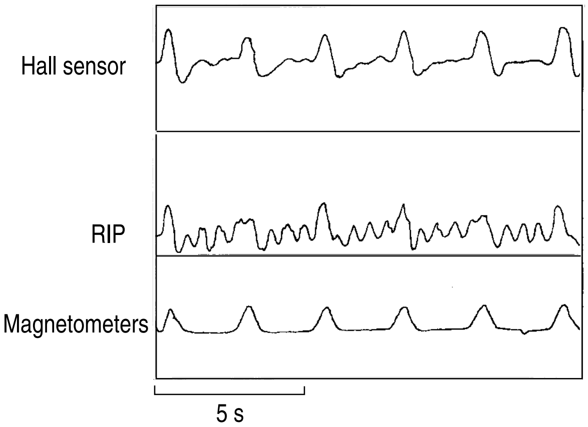

Fig. 1. – Traces from all three monitors showing rib cage movement in case No. 8. The (strain gauge) Hall sensor recording is shown at the top, respiratory inductance plethysmography (RIP) in the middle, and magnetometers at the bottom. The RIP trace shows marked artefact corresponding exactly with the heart rate, that is not seen in the other traces.

In two infants, aged 4 and 6 weeks, (cases No. 8 and 10), the RIP rib cage signal contained too much cardiac artefact to allow interpretation of the trace (fig. 1).

Respiratory rates were identical for all the devices. Measurements of TI and TI/Ttot over the 2 min period produced 40–118 data points for each patient for each device, depending on their respiratory rates. Pooled measurements from all 10 patients showed greater within-device variability and gave higher mean values for TI and TI/Ttot when measured from the rib cage than when measured from abdominal traces (table 2), although between-device variability appeared less. There was an apparent ordering effect, with RIP producing higher values than magnetometers, which in turn were higher than Hall sensor. Using paired analysis, these differences were statistically significant between all devices in the measurement of TI, but were arguably of little clinical significance. In the measurement of TI/Ttot, rib cage *versus* abdominal measurements were statistically different for both magnetometers and Hall sensor.

Phase angles from Lissajou plots of rib cage and abdominal movement were measured in 10 patients. In both patients with cardiac artefact (discussed above), it was not possible to measure phase angle from the RIP

Table 2. – TI and TI/Ttot from the 3 monitors comparing chest and abdominal signals

		RIP	Magnets	Hall
Mean TI	Rib cage	0.46*	0.43	0.41
		(0.083)	(0.092)	(0.107)
	Abdomen	0.44	0.39	0.36
		(0.061)	(0.057)	(0.067)
Mean TI/Ttot	Rib cage	0.29*	0.30	0.29
		(0.056)	(0.064)	(0.061)
	Abdomen	0.30	0.28	0.26
		(0.050)	(0.040)	(0.048)

Data presented as mean (SD) of pooled values for all patients. *: the traces of two patients were excluded due to poor signal. TI: inspiratory time; TI/Ttot: inspiratory time as a ratio of total respiratory cycle; RIP: respiratory inductance plethysmography; Magnets: magnetometers.

trace. As with other measurements, ventilated patients showed good agreement between devices, with any differences being small, and, despite any statistical significance, unlikely to be clinically important.

Discussion

All three types of respiratory movement monitor gave broadly similar wave-forms, although the derived measurements of respiratory timing and phase angle were not always interchangeable between devices, particularly in the patients breathing spontaneously. Such differences are to be expected, as all three devices use different methods for measuring thoracoabdominal movement. For example, RIP would be expected to detect global changes in chest wall size, but may fail to identify local distortion. Magnetometers, and other similar devices, reflect much more local changes in chest wall shape.

The commonest pattern in the Lissajou plots is of an ellipse with initial outward abdominal movement. During this early phase of inspiration, there may be little or no ribcage movement, which then becomes greater throughout inspiration and extends into early expiration. T_I may, thus, appear longer when measured from the rib cage than from the abdominal wall. RIP will reflect such changes best, but local chest wall distortion, especially a slight reduction in AP diameter of the chest during early inspiration, would minimize the changes seen if using magnetometry. The fact that the Hall sensor showed a further reduction in this measurement suggests that local, as well as circumferential changes, may affect the signal from this device.

Used as described, these devices have only measured two components of movement, and there is an implicit assumption that this is representative of the total movement of the chest wall. However, this is only true if one assumes that the chest wall has no more that two degrees of freedom. Such an assumption is probably justified in the healthy adult [3], but is less valid in infants [1, 12], and in any situation where there is significant chest wall distortion [14]. In the presence of chest wall distortion, some measurements (*e.g.* AP diameter of the chest) may be affected more than others (*e.g.* cross-sectional area).

One previous study in infants compared three similar devices, and looked at their accuracy in predicting lung volume changes in comparison to pneumotachography [17]. Respiratory timing and phase angle measurements were not assessed, and it is here that we feel that such devices have their greatest benefits. Objective data on respiratory timings and chest wall distortion, especially when it can be obtained noninvasively over time in individual patients, may prove to be of greater clinical benefit than changes in lung volume, especially when the accuracy of those volume measurements is questioned [11, 16]. In the present study, we found that abdominal signals were more consistent within methods than rib cage signals (table 2).

The difference between the signals seen in the children with marked cardiac artefact on RIP (fig. 1) is difficult to explain. In such children, the active heart produces visible movement of the chest wall, which one would expect to be reflected in the signal from all three devices. As discussed earlier, both magnetometers and the Hall sensor appear to measure more local changes, and this may explain their apparent insensitivity to the active precordium. Output from the RIP band is also dependent on the plane of the band relative to the chest (P. LeSouef, personal communication), and our artefact may have been due to an active precordium rotating the RIP band.

Each of the techniques has advantages in particular settings. In children, RIP is simple, well-validated, and is the most widely used method. However, in infants, devices such as the Hall sensor, which appear to be minimally affected by cardiac artefact, and can be easily applied, may be more practical. This particular system would benefit from lighter straps and cables for the neonatal population. In patients with unilateral abnormalities, such as hemidiaphragmatic paralysis, magnetometers probably offer the best technique. They may also be more sensitive at detecting configurational changes in the abdomen.

In most instances, all three of the techniques assessed gave similar measurements of respiratory timing and phase angle. However, in spontaneously breathing patients, there were occasional inconsistencies between the devices, which may be explained by their different methods of measurement, either in theoretical terms, or in the practical transference of movement to electrical signal. Further studies are needed to more clearly identify the relative merits and disadvantages of the different systems in particular clinical settings.

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