

# Estimation of lung volume in infants by echo planar imaging and total body plethysmography

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## Abstract

**Echo planar imaging (an extremely fast method of magnetic resonance imaging) was used to measure lung volume in a group of nine infants, all of whom had had respiratory problems. The mean echo planar imaging estimate of total lung volume was  $44 \pm 9$  ml/kg. In each case the right lung was larger than the left (ratio 52.8:47.2%). The mean thoracic gas volume was  $36 \pm 8$  ml/kg. The entire sequence of images of the thorax (about 400) takes five minutes to complete, infants require no sedation, and there are no side effects.**

Echo planar imaging is a form of nuclear magnetic resonance imaging that gives short image acquisition times and so permits a sequence of images to be obtained rapidly. Each image is displayed in transection as it is acquired in real time.<sup>1-3</sup>

We have used echo planar imaging to study the thoraxes of nine infants aged between 1 and 9 months, all of whom had had respiratory problems. The measurements were produced on our home built imaging machine operating at a field strength of 0.1 Tesla (T) which corresponds to an operating radio frequency of 4.0 MHz for protons.

We have compared the results of echo planar imaging for total and individual lung volumes with mean thoracic gas volume measurements. Measurement of thoracic gas volume in infancy by total body plethysmography after bronchiolitis has, however, recently been questioned by Godfrey *et al.*<sup>4</sup> The work described here is an extension of an earlier pilot study.<sup>5</sup>

## Patients and methods

Nine infants with recurrent attacks of wheezing were studied (table 1). Cases 8 and 9 had mild wheezes on auscultation; the other patients were clinically well when studied. Cases 2, 5, 7, and 8 were studied immediately before discharge from hospital after their wheezing had improved. Measurements of lung volume by plethysmography and by echo planar imaging were made on the same day in cases 4-9 and within two days of each other in cases 2 and 3. Case 9 was studied at 1 and 3 months of age. Case 1 did not have the thoracic gas volume measured.

Infants were sedated with chloral hydrate (120 mg/kg) to allow measurement of thoracic gas volume by total body plethysmography.<sup>6-9</sup> The total body plethysmograph had a capacity

Table 1 Details of patients studied

Case No	Age (months)	History of bronchiolitis
1	8	Yes
2	4	Yes
3	9	Yes
4	8	No
5*	6	Yes
6	6	No
7	10	Yes
8	10	Yes
9 (at 1 month old)	2	No
9 (at 3 months old)	4	No

\*Case No 5 was the only girl studied.

of 260 l and a servocontrolled heating system to maintain the face mask, shutter system, and rebreathing bag at 36°C. Thoracic gas volume was measured after inspiration, with subtraction of the tidal volume after calculation. Each child was nursed supine and a latex face mask was applied; this was smeared with petroleum jelly to help secure an airtight seal. The dead space of the mask was 55 ml for patients 1-8, but a 28 ml mask was used for patient 9. There was a bias flow of air to the face mask of 5 l/minute. Signals were relayed to the axes of a cathode ray oscilloscope, readings were taken by the same observer, and calculations made by standard techniques. From five to eight breaths were analysed in each case.

Infants required no sedation for echo planar imaging studies. The echo planar imaging technique is an extension of nuclear magnetic resonance imaging and the details of its develop-

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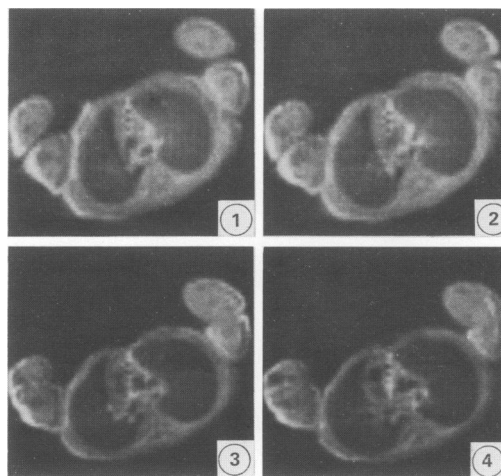
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Four contiguous echo planar transectional images through the mediastinum of an infant. The patient's left side is on the left.

Table 2 Comparison of measured thoracic gas volume by total body plethysmography with total lung volume measurement by echo planar imaging. Also shown is airways resistance

Case No	Thoracic gas volume (ml/kg)	Airways resistance (cm H <sub>2</sub> O/l/s)	Lung volume measured by echo planar imaging		
			Total volume (ml/kg)	Left lung (ml)	Right lung (ml)
1	Not measured	Not measured	29	50	54
2	29	60	50	200	161
3	37	27	45	110	113
4	37	21.7	43	120	195
5	34	33	36	136	145
6	34	19	38	159	185
7	60	60	69	154	155
8	27	45	41	110	138
9 (at 1 month old)	85	31.4	58	119	120
9 (at 3 months old)	70	55	55	156	205

ment and medical use may be found elsewhere.<sup>1-3</sup>

The procedure requires no gating, because each image is a snapshot acquired within 32 to 64 ms. It is therefore comparatively free of motional artefact from either cardiac or respiratory movement. Each transectional image is 6 mm thick. A 64×64 pixel display was used resulting in a true resolution within each slice of 3 mm. Consecutive images are acquired during the cardiac cycle with the first image of each sequence triggered by the QRS complex of the electrocardiogram.

A Winchester quart of known transectional area was used as the standard. The area obtained from this image was measured by planimetry and compared with the known area. A conversion factor was determined and used to convert image screen measurements of lung area to actual size. The same standard was repeated before each study.

The accuracy of area measurement had two components: an inherent error ( $\epsilon_i$ ), which is related to the pixel signal:noise ratio (R) and calculated by  $100/(R\sqrt{N})\%$ , where N is the number of pixels scanned in the area of interest, and an observer error ( $\epsilon_o$ ), which arises from errors in delineating the area of interest and reproducibility. The inherent error is usually around 1%, whereas the observer error is about 10%.

The initial transectional image was obtained at the apex of the lung and at 6 mm steps towards the base until lung was no longer seen. Numbers of slices ranged from 10–16, depending on the patient. The area of the lung at each stage was measured by planimetry, converted to actual area, and multiplied by the stage thickness to give total and individual estimates of lung volume. Each transectional image measured was a compilation of 16 snapshots taken in rapid succession (figure), so the lung volumes calculated tend to reflect volume in the middle of a tidal breath. All readings were made by the same observer.

This study was approved by the Nottingham ethics committee. Written parental consent was obtained for the observations.

## Results

None of the infants required sedation for echo planar imaging studies, each of which took less than five minutes to carry out.

The measurements of thoracic gas volume

and airways resistance, and measurements of individual and total lung volume using echo planar imaging, are shown in table 2.

The mean thoracic gas volume was  $36 \pm 8$  ml/kg. The estimate of total lung volume by echo planar imaging was  $44 \pm 9$  ml/kg.

Taking the group as a whole, 47.2% of the total lung volume was in the left lung and 52.8% was in the right lung according to the echo planar imaging. The coefficient of variation for intrasubject measurement of thoracic gas volume was 4.1%.

## Discussion

Measurement of thoracic gas volume in infants by total body plethysmography requires sedation and can be a lengthy procedure. In addition, measurement of thoracic gas volume when airways are closed,<sup>5</sup> and measurement in wheezy infants who have had bronchiolitis, has been questioned.<sup>4</sup> The use of an imaging technique to calculate total, and—for the first time—individual, lung volumes in this age group is appealing. Magnetic resonance imaging has no known hazards and studies of the thoraxes of infants using echo planar imaging can be completed within five minutes with no need for sedation.

The plethysmographic measurement and the echo planar imaging estimates differ. Measurements of lung volume obtained by echo planar imaging include volume taken up by lung tissue, hence they should be greater than measurements of thoracic gas volume. In addition measurements of thoracic gas volume were made after inspiration, with subtraction of the tidal volume after calculation, but echo planar imaging measurements were made at what we consider to be mid tidal volume. Thus, in addition to lung tissue volume, they may be expected to be half a tidal volume greater than thoracic gas volume. Using echo planar imaging, only part of the dead space is measured, which we ignore in these results. Dead space in infancy has been measured by various groups, and estimates range from 1.1–2.77 ml/kg.<sup>10-13</sup>

In cases 2–8 the lung volumes on echo planar imaging were between 2 and 21 ml/kg greater than the measurements of thoracic gas volume. Only in case 9 was the thoracic gas volume larger than the echo planar imaging estimation of total lung volume. In this patient a different face mask with a dead space of 28 ml (as

opposed to 55 ml) was used. When the infant was sedated it was impossible to obtain a complete seal with our standard mask. It is interesting that previous studies have shown that this mask gives measurements of thoracic gas volume up to a third higher than the mask we usually use, with a dead space of 55 ml. Whether the difference is the result of using the small face mask, or of some other effect, remains to be determined.

The right lung was of greater volume than the left lung in all cases except case 2, in whom the left lung was 39 ml larger. Echo planar imaging showed collapse and consolidation in the right lung, which was responsible for the reduced right lung volume. Omitting this patient's results, the mean right lung volumes of the group were between 50% and 62% of the total lung volumes. This finding is similar to the results of weighing normal lungs at necropsy. Emery and Mithal found the right lung weighed between 52–57% of the total lung weight in babies between the ages of 1–12 months.<sup>14</sup> Cases 8 and 9 had mild wheeze at the time of the study, and were clinically hyperinflated. Their lung volume estimates agree with the clinical assessment (table 2). The use of this method to study individual lung volumes will be of great interest in monitoring lung growth in infants with hypoplastic lungs and after repair of diaphragmatic hernias,<sup>15</sup> as well as in measuring the effects of scoliosis on lung volume, and in many other conditions.

The images obtained from the more hyperinflated babies seemed less dense than those from the other infants. With improvements in image quality it will be possible to measure the density of the lungs from the echo planar

images. Studies are being conducted in older subjects to equate the density reading with actual tissue volume.

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