Evaluation of infants by echo planar imaging after repair of diaphragmatic hernia

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SUMMARY   Three infants were studied by echo planar imaging after repair of congenital diaphragmatic hernias. Total lung volume and individual lung volumes were estimated using echo planar imaging. In the two patients with left sided hernias, the right lung was more than twice as large as the left. The patient with a right sided hernia had developed emphysema on the right side, and the right lung was twice as large as the left when estimated by echo planar imaging. Echo planar imaging studies took less than five minutes to perform and no sedation was required.

Echo planar imaging is a form of magnetic resonance imaging that gives short image acquisition times and that permits a sequence of images to be rapidly obtained. Each image is displayed in transection as it is acquired in real time. Images may be constructed from the data in the sagittal, coronal, or any other plane, and transformed into a film sequence if required.

We have used this technique to investigate three infants after repair of congenital diaphragmatic hernias. Necropsy studies of children with such hernias have shown pronounced hypoplasia of both lungs in those that died soon after birth.[1] Plethysmographic studies show that most babies achieve normal lung volumes in the first weeks of life after successful repair of diaphragmatic hernias.[2] The accuracy of the plethysmographic method of estimation of lung volumes in infants has recently been questioned, however.[3] Because echo planar imaging is not invasive and requires no sedation, the possibility of measuring individual and total lung volumes is practical and we present preliminary measurements.

Patients and methods

The principles of nuclear magnetic resonance imaging of discrete structures were first introduced by Mansfield and Grannell in 1973.[4] Echo planar imaging is an extension of these principles and the details of its development and use in medicine have been reported elsewhere.[5–7]

Echo planar imaging requires no gating because each image is a snapshot acquired in 64 milliseconds. Each image is therefore comparatively free of motional artefact caused by either cardiac or respiratory movement. It follows that echo planar imaging may be useful in infants who have high heart and respiratory rates.

Each transectional image is 7 mm thick and comprises an original image array of 64×64 pixels that correspond to a true in plane resolution of 3 mm. For display and photographic purposes the array is linearly interpolated up to 256×256 points. Consecutive images may be acquired prospectively by gating during consecutive cardiac cycles with the first image of each sequence triggered from the QRS complex. An alternative triggering mode uses a fixed delay from the R wave peak. This effectively freezes heart motion at a particular point in the cardiac cycle, but permits movement of the thorax to be seen in a film sequence. Film sequences may also be constructed of each slice showing patterns of blood flow. Blood at a standstill gives a relatively high signal and looks bright. Blood moving out of the imaging plane of the study yields little signal and looks black.

Additionally, constructions in the sagittal, coronal, or any other plane may be made and transformed into a film sequence. Each study of the thorax took less than five minutes and no sedation was required.

The initial transectional image was obtained starting at the apex of the lung and continuing in

6 mm steps towards the base until lung could no longer be seen. The area of the lung at each stage was measured by planimetry and multiplied by the stage thickness to give total and individual estimates of lung volumes. Each of the transectional images comprised an average of 16 snapshots taken in rapid succession over a 10 second period. Thus the lung volumes calculated tend to reflect the volume in the middle of a tidal breath.

Case reports

CASE 1

A 9 month old baby boy had been born at 38 weeks' gestation by caesarean section after an uneventful pregnancy. He had made no attempt to breathe and required intubation and ventilation. A right sided diaphragmatic hernia was diagnosed on chest *x* ray picture. Surgical repair was performed at 14 hours of age. The size of the defect necessitated the insertion of Xenoderm patches on the diaphragm and on the musculature of the abdominal wall. The skin was closed normally. The infant was ventilated for 23 days and required supplementary oxygen for 28 days. Tolazoline and dopamine infusions were given for six days and maximum ventilatory requirements were pressure 30/3, rate 90/minute in 100% oxygen.

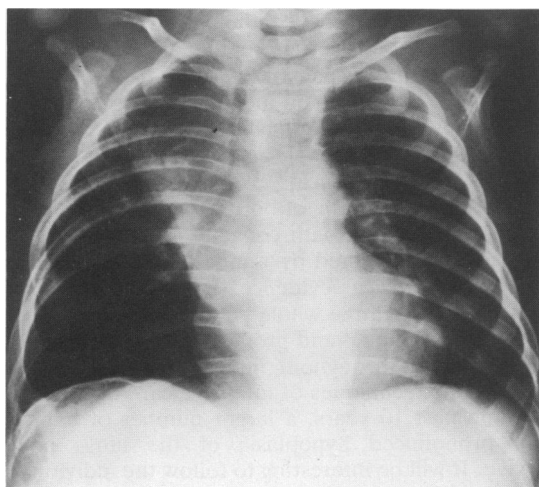Echocardiography showed that the heart was normal. After discharge his parents noted that he often became wheezy, and the wheeze was severe when associated with upper respiratory tract infections. On examination he was gaining weight along the third centile, developing normally, and had pectus excavatum and decreased air entry over the right lower lobe.

Radiological investigation showed intermittent shadowing of the right upper lobe and the most recent films show the right hemithorax to be almost filled by aerated middle and lower lobe. The bronchus of the right upper lobe arose at the carina (fig 1). Barium meal examination showed oesophageal reflux and a sliding hiatal hernia.

Figure 2 shows four echo planar imaging transections corresponding to planes 12, 14, 17, and 18 taken from a set of 18 contiguous slices starting at the apex of the lung. Figures 2(A) and (B) show the pectus deformity, over expansion of the lower zone of the right lung, and displacement of the heart into the left side of the thorax. Figures 2(C) and (D) show the Xenoderm patch. When lung volumes were estimated by our method, the right lung was 2·03 times as large as the left, and the total lung volume was 28 ml/kg (the baby's weight at the time of the study was 8000 g).

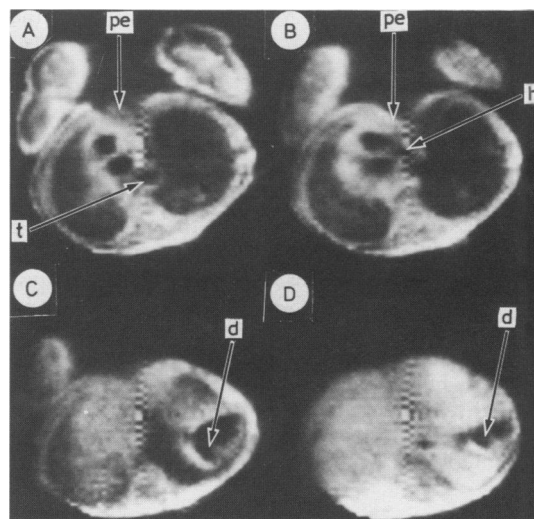### CASE 2

A 10 week old baby girl had been born at 37 weeks'

Fig 1   *Chest x ray picture of case 1 at the time of echo planar imaging. Note collapse of right upper lobe, deviation of trachea to right, and hyperinflation of right middle and lower lobes.*

Fig 2   *Transectional echo planar images through the thorax of case 1. (A) and (B) show sections through mediastinum at mid systole with heart mass and chambers (h). Trachea (t) is also visible in (A) as a bright ring structure posterior and right of heart. Note pectus excavatum deformity (pe) and hyperinflation of right lung. Diaphragmatic repair patch (d) is seen in (C) and (D).*

Table Total and individual lung volumes in three infants with diaphragmatic hernias

Case No	Side of hernia	Estimation of lung volumes		
		Left lung (ml)	Right lung (ml)	Total lung volume (ml/kg)
1	Right	71	149	28
2	Left	23·4	51·8	25
3	Left	62	110	43

gestation. Resuscitation, including ventilation, paralysis with pancuronium, infusion of dopamine, and drainage of a right sided pneumothorax had been required before operative repair of her diaphragmatic hernia when 12 hours old.

A large left posterior lateral defect had been found in the diaphragm with the stomach, spleen, left lobe of liver, and some small and large bowel in the chest.

Postoperatively she required ventilation with maximum pressures of 24/4, rate 60/minute, and oxygen of 100%. Dopamine and tolazoline were given for seven days. After discharge from hospital at 20 days of age she remained symptomless.

When lung volumes were estimated by our method, the right lung was 2·04 times larger than the left, and the total lung volume was 25 ml/kg (the baby's weight at the time of the study was 3000 g).

CASE 3
An 8 week old baby boy had been born at term and had required resuscitation at birth before being operated on at 7 hours of age. His left diaphragmatic hernia was closed easily and the volume of the left lung was reported as 'good' in the postoperative notes. Ventilation was required for six days and tolazoline and dopamine were given for five days. Maximum pressure was 20/4, rate 50/minute, and inspired oxygen 90%. He remained symptomless after discharge from hospital.

When lung volumes were estimated by our method, the right lung was 1·7 times larger than the left, and the total lung volume was 43 ml/kg. Estimated lung volumes are shown in the table.

Discussion

Magnetic resonance imaging is free of hazards, and the studies of the chests of these infants by echo planar imaging were completed within five minutes with no need for sedation.[8]

We have described a new method of calculating total and individual lung volumes in infants who have had diaphragmatic hernias repaired. Studies in which measurements were made by total body plethysmography have shown that after successful surgical repair of diaphragmatic hernias most babies achieve normal lung volumes in the first weeks of life.[2] Some infants had reduced lung volumes that tended to become normal later in the first year of life, and a small number were hyperinflated.

Plethysmographic studies in infancy require sedation, and because of the doubtful accuracy of estimates of thoracic gas volume in this age group, especially in infants with obstructed airways,[3] lung volume estimation by echo planar imaging will be clinically useful. Thoracic gas volume is an indication of aerated lung volume, and a measurement of total lung capacity would be a more accurate indication of the degree of lung hypoplasia.

The two patients with left sided hernias had right lungs that were twice as large as the left, suggesting decreased growth on the left. The total lung volume of 25 ml/kg measured by echo planar imaging in the second patient was small for her age when compared with published estimates of thoracic gas volume in normal infants (30–35 ml/kg). The difference would be even greater if tissue volume—which is included in estimation by echo planar imaging—were subtracted, and this might indicate hypoplasia of her lungs. Not all the dead space is measured by echo planar imaging but this is assumed to be comparatively small. Interestingly, the third patient, who was thought at operation to have a lung of good size on the side of the hernia, had a total lung volume of 43 ml/kg (table).

The first patient had radiological evidence of hyperexpansion of his right middle and lower lobes nine months after repair of his right diaphragmatic hernia. Measurement of individual lung volumes support this, his right lung being more than twice as large as his left.

There is pathological evidence that there is pronounced hypoplasia of both lungs in infants who die soon after birth with congenital diaphragmatic hernias.[1] As suggested by Landau et al,[2] however, and by radiological evidence, the ipsilateral lung may appear to fill the whole hemithorax within one week of operation,[9] and gross hypoplasia does not always persist throughout infancy.

Using the techniques of intensive care developed over the past 10 years, a larger number of babies with pronounced hypoplasia of the lungs now survive. It will be interesting to follow the individual growth of their lungs.

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