RESPIRATORY DISTRESS SYNDROME IN THE NEWBORN

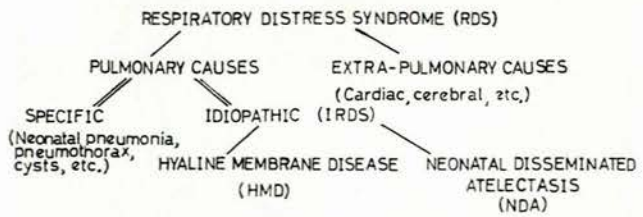
RADIOLOGICAL ASPECTS

R. E. KOTTLER, M.B., CH.B., M.MED. (RAD.D.), D.C.H. (R.C.P. & S.), in association with A. F. MALAN,* M.B., CH.B., M.MED. (PAED.), D.MID. C.O.G. (S.A.); AND H. DE V. HEESE, B.SC., M.D., M.R.C.P. (EDIN.), D.C.H. (R.C.P. & S.), *From the Departments of Diagnostic Radiology and Child Health, Groote Schuur Hospital and University of Cape Town*

Breathing difficulties occurring in a small proportion of infants continue to receive wide interest in many parts of the world. While being mainly, but not exclusively, a problem peculiar to premature infants, the presence of maternal diabetes, toxaemia of pregnancy, and some of the other conditions which necessitate caesarean section, are predisposing factors. The presence of any of these in the mother does not, however, allow it to be assumed that her distressed infant is suffering from the idiopathic respiratory distress syndrome (IRDS). In this condition, at a certain stage of the disease, the radiological features are as characteristic as in the histology. The purpose of this paper is to discuss some of the problems in radiological diagnosis which have been encountered locally with regard to IRDS.

Before doing so it is essential to clarify the field and terms of our study. Table I makes it clear that there are many clinically confusing conditions, which can be differentiated mainly by radiological means:

TABLE I. SCHEMATIC OUTLINE OF CAUSES IN THE RESPIRATORY DISTRESS SYNDROME



It is obviously very important to establish the local criteria for the diagnosis in IRDS and to try to differentiate true hyaline membrane disease (HMD) from neonatal disseminated atelectasis (NDA).

The decision to include any infant in the series with RDS rested on the presence of any two of the following:

(*i*) Respiratory rate greater than 60 per minute for more than 2 hours on the first day of life.
(*ii*) Expiratory grunting.
(*iii*) Cyanosis in room air.
(*iv*) Crepitations.
(*v*) Radiological evidence of the pathology.

Radiological Aspects

Pulmonary disease remains the most common cause of neonatal mortality and morbidity. The chest X-ray examination becomes obligatory in respiratory distress syndrome (RDS), since the radiological features are often diagnostic, regardless of the clinical findings.

*CSIR Senior Research Bursar, Department of Child Health, Groote Schuur Hospital, Cape Town.

Radiology Study and Material

One hundred cases of respiratory distress syndrome with available radiographs were studied for this paper, being highly selected material, influenced by our interest in neonatal chest conditions.[12]

A simplified, schematic outline of causes in the respiratory distress syndrome is given in Table I, while Table II refers to the conditions comprising our 100 selected cases. Referring to the data in Table II, the larger groups are hyaline membrane disease and neonatal disseminated atelectasis, which together form 80% of our total.

TABLE II. CONDITIONS PRESENT AND NUMBER OF CASES

Clinical hyaline membrane disease (HMD)	63
Neonatal disseminated atelectasis (NDA)	17
Massive meconium aspiration	2
Pulmonary infections	3
Spontaneous pneumothorax	2
Respiratory distress syndrome (RDS) with normal radiographs	7
Miscellaneous	6
	100

Only the two groups, HMD and NDA will be discussed in the text and radiographic illustrations are provided to demonstrate certain aspects.

Each radiograph in the study has been scrutinized with special attention to: (1) quality of radiograph, (2) position of diaphragm, (3) cardio-thoracic index, (4) lung translucency, (5) air-bronchogram, (6) reticular or granular lung pattern, (7) linear markings (atelectases), (8) emphysema, (9) interstitial air, and (10) pneumothorax (or pneumomediastinum).

38 patients with hyaline disease died. The radiological evidence was confirmed at 17 out of 18 autopsies. In the remaining one the finding was primary atelectasis with no hyaline membrane formation.

RADIOLOGICAL FEATURES OF HYALINE MEMBRANE DISEASE[1, 4, 6-11, 13, 14, 16, 19, 20]

The characteristic features depend on the stage and severity of the condition, though a definite sequence must not always be expected.

(*a*) *Diffuse pulmonary opacity.* Diffuse, homogeneous opacity of both lungs, in a thorax of diminutive volume (Fig. 1), may be seen sometimes soon after birth and is commonly referred to as 'ground-glass opacity'. As a result of partial and continuing failure of pulmonary aeration, the unexpanded lungs give rise to a striking resemblance to an 'expiratory film'. A trivial amount of air may be seen in the larger bronchi and will determine the presence of the next feature.

(*b*) *Air-bronchogram*. The air-filled bronchial tree is contrasted sharply against any adjacent lung tissue showing increased opacity (Fig. 2). The air bronchogram provides good evidence of consolidation in the corresponding region of the lung, whatever the cause, e.g. exudate, oedema, inflammatory tissue, atelectasis, etc. In HMD air-filled and *distended* bronchi can be clearly identified and can be seen to extend far into the periphery of the partially aerated lung. In normal infants air in the bronchus of the left lower lobe may be faintly visible through the heart and diaphragm and, therefore, an air-bronchogram should usually be assessed in the lung parenchyma beyond these structures.

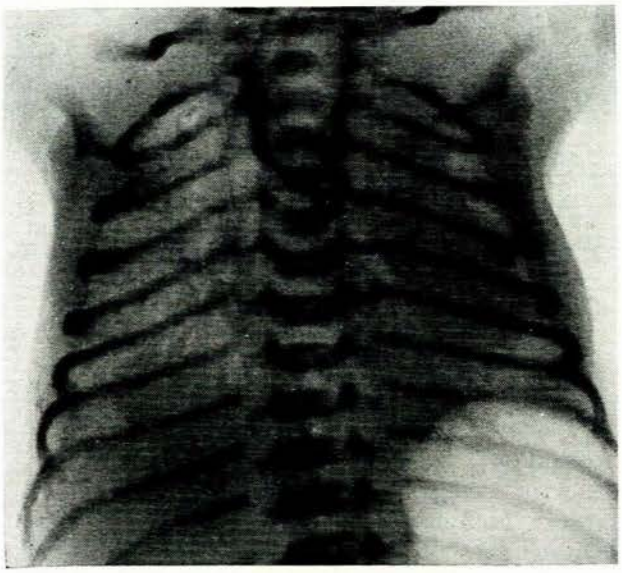


Fig. 1. Lungs and thorax are unexpanded. Minimal aeration, opacity of the lungs and prominent air-bronchogram, are shown (HMD).

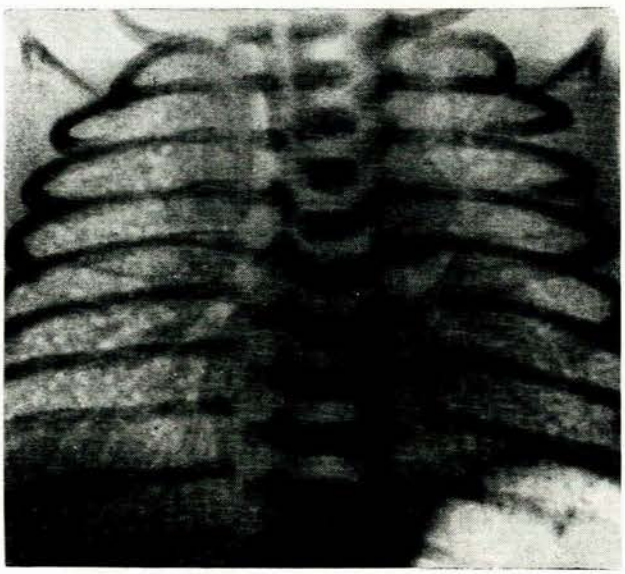


Fig. 2. Marked air-bronchogram present. Note the small cystic collections of 'interstitial air' (HMD).

(*c*) *Reticular-granular lung pattern*. This is probably the most typical feature in HMD and it may be seen shortly after birth (Fig. 3), though it usually appears during the first day of life. Following its appearance the reticular-granular pattern usually alters in degree, extent and composition. At first there appears to be a mass of small, faint, white stipples or granular opacities, which represent foci of atelectatic lung, having been rendered visible by the air contrast in the adjacent areas of partially aerated lung. The amount and distribution of this air will obviously determine the character of the pattern.

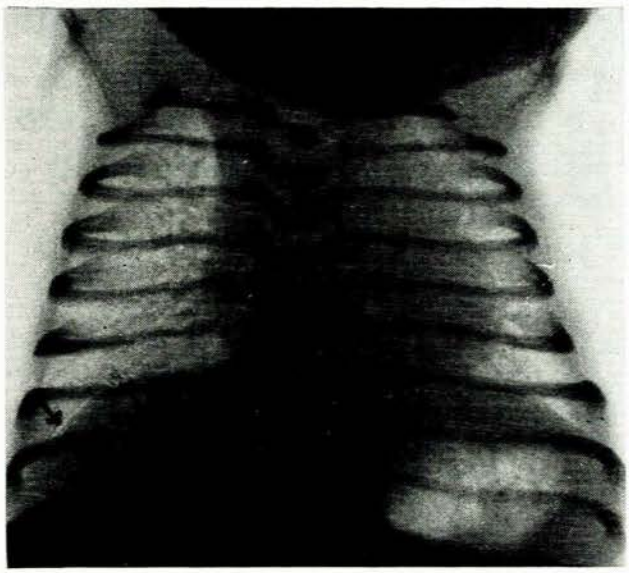


Fig. 3. Lungs well aerated. Extremely fine granular pattern causing reduction in normal lung translucency. Arrows indicate minute amount of air in pleura (HMD).

Sloughing of the epithelial cells at alveolar duct level produces obstruction and interference with aeration of the alveoli. In addition to simple mechanical obstruction, the formation of 'check-valves' in the terminal bronchioles are responsible for 'air-trapping'. This phenomenon, in well-established examples of HMD, has important effects and will influence the radiological features. The air-trapping leads to an increase in the amount of residual air and a further reduction in the amount of tidal air, and it is responsible for certain radiological features as described in (*d*), (*e*), (*f*) and (*g*).

(*d*) *Thoracic configuration*. The thoracic cage is often seen to be well filled and the lungs apparently well aerated, in spite of the gross atelectasis. The position of the diaphragm is relatively constant in such cases, and respiratory excursions are very small.

(*e*) *Interstitial air*. The gross over-distension and occasional rupture of the *alveolar ducts,* with formation of dissolution cysts and escape of air into the interstitial tissues of the lung, is a further consequence of air-trapping. The presence of interstitial air can often be

(*b*) *Air-bronchogram*. The air-filled bronchial tree is contrasted sharply against any adjacent lung tissue showing increased opacity (Fig. 2). The air bronchogram provides good evidence of consolidation in the corresponding region of the lung, whatever the cause, e.g. exudate, oedema, inflammatory tissue, atelectasis, etc. In HMD air-filled and *distended* bronchi can be clearly identified and can be seen to extend far into the periphery of the partially aerated lung. In normal infants air in the bronchus of the left lower lobe may be faintly visible through the heart and diaphragm and, therefore, an air-bronchogram should usually be assessed in the lung parenchyma beyond these structures.

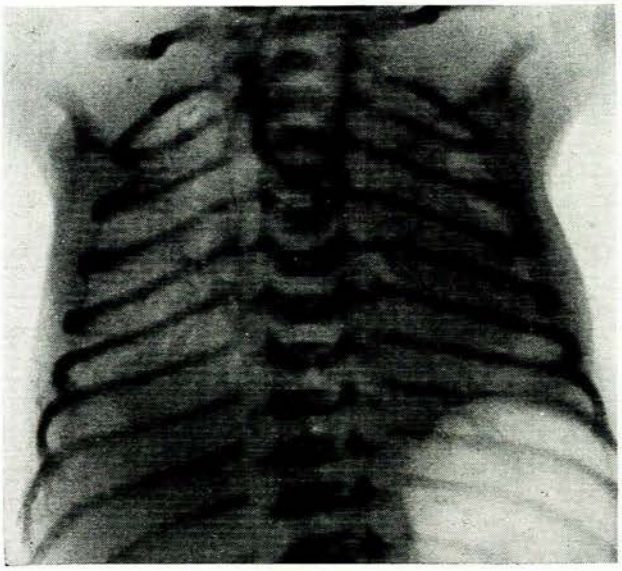


Fig. 1. Lungs and thorax are unexpanded. Minimal aeration, opacity of the lungs and prominent air-bronchogram, are shown (HMD).

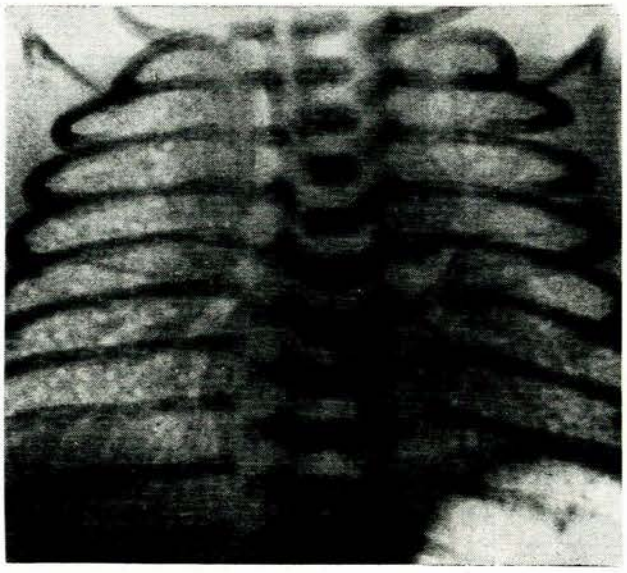


Fig. 2. Marked air-bronchogram present. Note the small cystic collections of 'interstitial air' (HMD).

(*c*) *Reticular-granular lung pattern*. This is probably the most typical feature in HMD and it may be seen shortly after birth (Fig. 3), though it usually appears during the first day of life. Following its appearance the reticular-granular pattern usually alters in degree, extent and composition. At first there appears to be a mass of small, faint, white stipples or granular opacities, which represent foci of atelectatic lung, having been rendered visible by the air contrast in the adjacent areas of partially aerated lung. The amount and distribution of this air will obviously determine the character of the pattern.

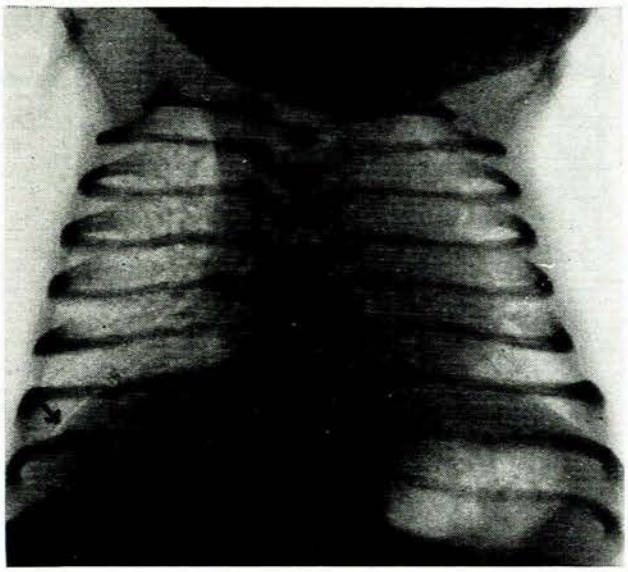


Fig. 3. Lungs well aerated. Extremely fine granular pattern causing reduction in normal lung translucency. Arrows indicate minute amount of air in pleura (HMD).

Sloughing of the epithelial cells at alveolar duct level produces obstruction and interference with aeration of the alveoli. In addition to simple mechanical obstruction, the formation of 'check-valves' in the terminal bronchioles are responsible for 'air-trapping'. This phenomenon, in well-established examples of HMD, has important effects and will influence the radiological features. The air-trapping leads to an increase in the amount of residual air and a further reduction in the amount of tidal air, and it is responsible for certain radiological features as described in (*d*), (*e*), (*f*) and (*g*).

(*d*) *Thoracic configuration*. The thoracic cage is often seen to be well filled and the lungs apparently well aerated, in spite of the gross atelectasis. The position of the diaphragm is relatively constant in such cases, and respiratory excursions are very small.

(*e*) *Interstitial air*. The gross over-distension and occasional rupture of the *alveolar ducts*, with formation of dissolution cysts and escape of air into the interstitial tissues of the lung, is a further consequence of air-trapping. The presence of interstitial air can often be

detected radiologically, and the air may track into the mediastinum or rupture into the pleural space.

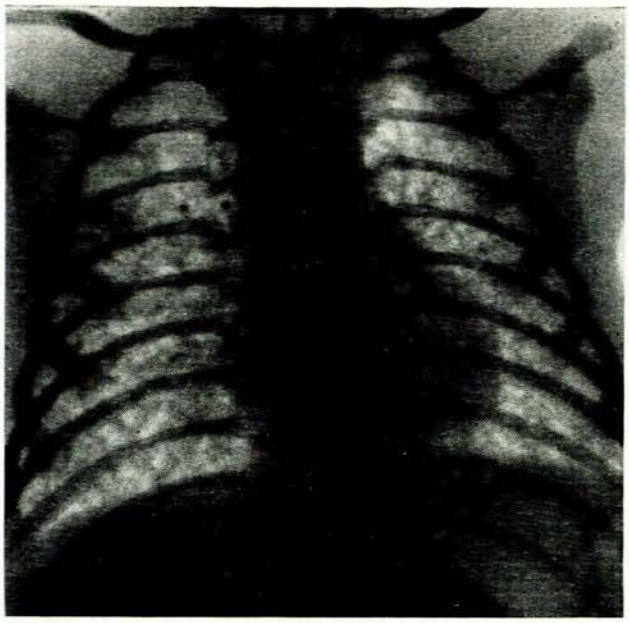


Fig. 4. The thorax is expanded and the diaphragm low in position (10 ribs shown). Note the small translucencies throughout the lungs (HMD).

The overdistension and then rupture of air-spaces are responsible for the small, pin-head translucencies and larger rounded, oval or linear translucencies.

A change, therefore, occurs from the stippled, granular islands of atelectatic lung tissue, surrounded by a filigree lacework of air in the bronchi and alveolar ducts, to a much coarser type of reticular-granular pattern, in which the translucencies may dominate the picture (Figs. 4, 5). However, the only distinction that has been made between reticular and granular, has been entirely for descriptive purposes.

(*f*) The marked sub-sternal and lower costal recession is often graphically demonstrated in the lateral projection.

(*g*) Pneumothorax and pneumomediastinum, occurring as a complication in HMD, will be discussed below.

(*h*) The size of the heart in HMD is also discussed separately.

NEONATAL DISSEMINATED ATELECTASIS

In the 17 examples of IRDS, in whom the clinical aspects were indistinguishable from HMD, there was a coarse irregular pattern (Fig. 6) quite unlike HMD.

(*a*) There was a tendency for all to have a moderate degree of general emphysema.

(*b*) A pattern of streaky or nodular opacities was present. These radiated outward in the direction of the bronchial tree and commenced in a central position. In some there was alternating segmental emphysema. These lesions were considered to represent atelectases.

(*c*) There had been a very mild air-bronchogram in some, though it had never been a prominent feature.

(*d*) Since the phase of respiration may be apparent from the degree of pharyngeal or tracheal distension, ob-

Fig. 5. The air-filled bronchi are distended. Note the pockets of interstitial air (retouched and enlarged).

struction to a bronchus may be suspected if during expiration there is excessive or asymmetrical pulmonary aeration.

Clinical Correlation in NDA

Although the radiological appearances in NDA were considered to be due to atelectasis and emphysema, occurring in lung segments as a result of lesser forms of foetal aspiration syndrome, the features are not specific and may be seen with infections in the neonate.

Fig. 7 shows a comparison of the relative incidence of radiological signs in HMD and NDA. The clinical features are initially very similar in these two conditions. The obstetrical history may provide evidence of aspiration. In NDA the onset of distress is earlier, recovery more rapid, and there was only one death.

Spontaneous pneumothorax[10, 17] was responsible for RDS in 3 cases, but occurred as a complication in no less than 13 of the 63 cases with HMD.

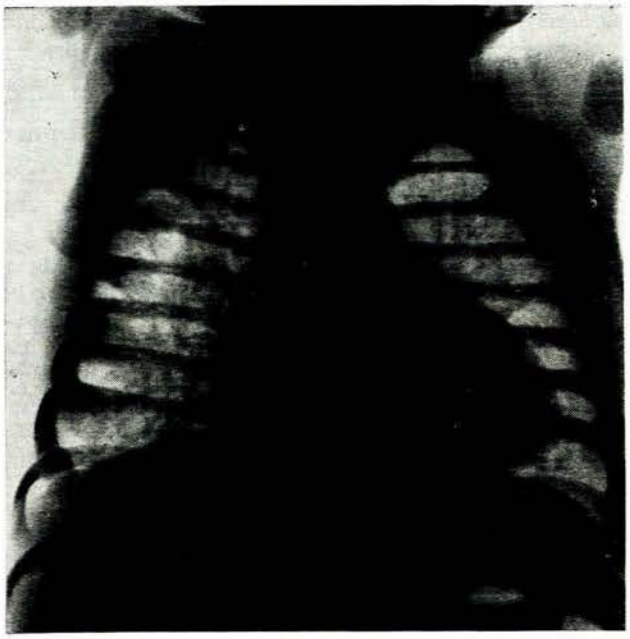


Fig. 6. Fairly severe example of aspiration syndrome atelectasis. Meconium-stained liquor was present at birth. Note atelectases and areas of focal emphysema (NDH).

PNEUMOTHORAX AND PNEUMOMEDIASTINUM IN IRDS

The lung in HMD is stiffened by the combination of atelectasis and trapped air[7] and tends to resist collapse. A small pneumothorax may therefore exist under tension, and its onset may cause sudden dramatic increase in distress with deterioration in the infant's condition. Since

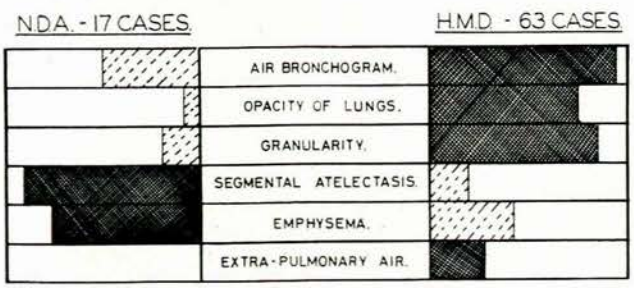


Fig. 7. Evidence of radiological signs. Cross hatching= prominent signs; faint hatching=doubtful signs.

immediate treatment may be required, all the films in RDS must be carefully scrutinized specifically for these minute pneumothoraces which often precede the larger event. Pneumothorax appears to be a more common complication in cases receiving assisted respiration.

The diagnostic difficulty is threefold: firstly, the smallness of the pleural collection; secondly, radiography in the supine position, if this applies; and thirdly, the difficult distinction, sometimes, between pleural, mediastinal and interstitial air collections, while all may be present simultaneously. The collection of pleural and mediastinal air, commonly found in the supine position, is shown in Fig. 8.

The usual familiar position in which pneumothorax is seen in the erect posture, i.e. the upper and outer portion of the thorax (Fig. 8E), occurs less frequently in the supine position, while the altered posture has created different situations in which air may collect. These situations have been noted in our series and in other cases, as indicated in Fig. 8.

They are noted adjacent to the upper mediastinum, occurring as a translucent band between mediastinum and medial lung edge (Fig. 8A); in an infrapulmonary position,

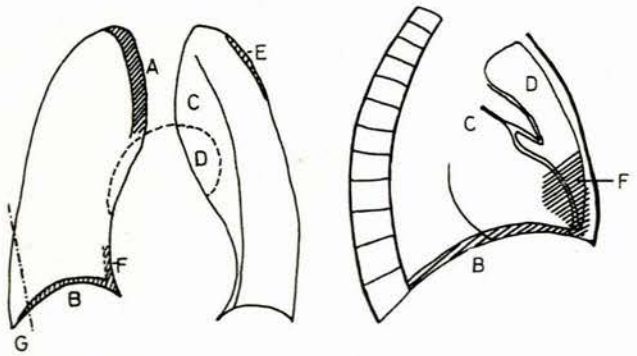


Fig. 8. Diagrammatic illustration of pneumomediastinum and pneumothorax in the supine position. A, B and E= pneumothorax; C, D=pneumomediastinum; F=air in the mediastinal pleura; G=skinfold.

it gives rise to a thin translucent crescent just below the base of the lung (Fig. 8B)—(the arrows in Fig. 3 show a minute crescent of air in this position and provide a strong indication for the routine use of a magnifying glass while inspecting X-ray films of the neonate); infrapulmonary air may also involve the mediastinal pleura anteriorly and in the lateral projection may be seen in relation to the heart and anterior mediastinum though occupying the lower part of the thorax (Fig. 8F); this appearance may be mistaken for a true pneumomediastinum, but the mediastinal air involves mainly the upper regions of the anterior mediastinal compartment (Fig. 8C, D).

The appearances of pneumomediastinum need no elaboration. Air in the anterior mediastinal compartment has a distinctive appearance, especially when loculated (Fig. 8D). It is easily identified in the lateral projection while air tracking mainly in the posterior mediastinum is more easily identified in the anterior view. Pneumomediastinum is very frequently associated with unilateral or bilateral pneumothoraces.

The incidence of pneumothorax[1, 8, 11, 17] in HMD and also the relative incidence of pneumomediastinum in these, have been variably stated in reports.[1, 8, 11, 17] Our own numbers being 13 of 63 cases of HMD would suggest an overall incidence of 20% in HMD.

The Size of the Heart in IRDS (NDA and HMD)

The findings[21] and suggestion that there was an increase in the heart size during perinatal asphyxia and a corresponding reduction following recovery, was the reason for

our measuring the cardio-thoracic ratio. However, the irregularity in the sequence of radiographic examination and also the small numbers and absence of control do not permit proper analysis of the data which follow:

Cardio-thoracic Index

63 cases with HMD	Mean CTI = 0·60
17 cases with NDA	Mean CTI = 0·63
25 cases surviving HMD	Mean CTI = 0·62
38 cases dying from HMD	Mean CTI = 0·63

In 45 cases serial radiographs were available. Our analysis did not show any significant difference between the CTI in the first and last examination. No trend could be detected as regards any increase or decrease in cardiac size, while comparing deaths and survivors. (It must be stressed, however, that these values have no statistical significance.)

DISCUSSION

The question often arises whether certain radiographic appearances in the neonatal chest are normal, physiological or pathological. The physiological changes described[3] in the neonatal chest film include even a reticular-granular pattern. That there are increased lung markings visible after birth,[9] will probably be accepted by most, but the absence of significant features in the normal has been confirmed by many. The serial radiographic studies made by Petersen and Pendleton,[11] in normal neonates, showed absence of radiographic changes, and their findings are important with regard to the problem studied here.

There are numerous causes of the respiratory distress syndrome and many of them of *non-respiratory* origin.[6, 15, 10] The warning given by Schultze[4] and reiterated by Baghdassarian[5] is important, that 'there is a tendency to over-read neonatal chest films, especially in the presence of a convincing history of respiratory distress, . . . (since) . . . there are many extrapulmonary conditions that can cause respiratory distress'. Schultze's 47 infants with 'respiratory distress', however, would have hardly fulfilled the criteria commonly accepted for the respiratory distress syndrome, and few would have been included in this series. These figures may exaggerate the extrapulmonary and non-specified causes of RDS.

The distinction between a film taken in expiration and one in which the diffuse opacity of the lungs is caused by failure of aeration, may not always be easy. The shape of the thorax, direction and slope of the ribs, position and shape of the diaphragm and amount of air in the respiratory passage may provide the answer; the X-ray beam, if centred incorrectly, may alter the shape of the thorax.

The air bronchogram may be very helpful, since a *prominent* air-bronchogram is not seen normally even during expiration.

Radiological assessment of 'emphysema' and of pulmonary 'aeration' is fraught with fallacy. Good pulmonary 'aeration', radiographically, does not imply adequate pulmonary ventilation. The seemingly good aeration in HMD, in spite of widespread alveolar atelectasis, provides an example, since the loss of lung volume is made up for by the overdistension of the alveolar ducts, bronchioles and bronchi.[7]

Apparent emphysema may be due to extrapulmonary causes, e.g. metabolic and other disturbances, which may lead to production of hyper-ventilation. The air in the upper respiratory tract, often shown on the lateral film, may indicate the phase of respiration. Occasionally, some discrepancy in the phase of respiration may be detected and the aeration present may provide a clue to airway obstruction.

During inspiration the diaphragm is usually related to the 8th rib posteriorly. Hyper-aeration is indicated if the diaphragm is seen below the 8th rib,[2, 6] while if situated as low as the 10th rib, it is frankly pathological (Fig. 4). In our cases with HMD the diaphragm showed an average relationship to the 8th rib and there was small diaphragmatic excursion. There was a slight tendency to lowering of the diaphragm and an increase in 'aeration' during serial films. The features indicated a relatively well-filled thorax in HMD even though widespread atelectasis exists.

Our series show a tendency for opacified lungs to become more translucent and never the reverse. Reports[4, 8, 9] indicate that HMD is associated with a loss in lung volume leading to opacification. No trend in this direction or a single example was encountered, although it was seldom possible to take films within the hour after birth and this may provide the reason. Harris[1] states that the change from translucency to opacity is a rare sequence.

Interstitial air arises from the rupture of distended air spaces, in particular from alveolar ducts and probably alveoli.[1, 10, 18, 22, 7]

The translucencies which are visible radiographically probably represent pockets of air in 'dissolution cysts' as a result of rupture of alveolar ducts.

There are several features of clinical and radiological similarity which occur in the aspiration syndromes commonly reported[4, 11, 6] and in our group with NDA, and the differences which do exist mainly concern the birth weight and the obstetrical background.

We regard neonatal disseminated atelectasis as an aspiration syndrome, the distinction being made purely on radiological grounds in the first instance, while supported by the clinical course of the illness. Any further attempt at correlation of data, to substantiate the concept, falls outside the scope of this paper and will be the subject of a future report.

SUMMARY

Our criteria, terminology and classification of the respiratory distress syndrome in the newborn, are presented.

In cases with the idiopathic respiratory distress syndrome, a radiological differentiation has been made between hyaline membrane disease and neonatal disseminated atelectasis.

The radiological aspects are outlined and the X-ray features in hyaline membrane disease are described. An attempt is made to correlate the features with the pathology of the condition, being subject to a personal interpretation of the radiographic signs.

Special attention is drawn to the importance and incidence of pneumothorax as a complication of hyaline membrane disease, and to the difficulties which may sometimes be encountered with regard to its radiological diagnosis.

We wish to record our special thanks to Prof. F. J. Ford for the facilities provided in the Department of Child Health, for his critical review of this paper and for the most helpful suggestions given.

We also wish to thank Dr. J. G. Burger (Medical Superintendent, Groote Schuur Hospital) for permission to publish.

REFERENCES

1. Harris, C. G. B. (1963): Radiol. Clin. N. Amer., **1**, 497.
2. Burnard, E. D. and James, L. S. (1961): Pediatrics, **28**, 545.
3. Caffey, J. (1956): *Paediatric X-Ray Diagnosis*, 3rd ed., p. 269. Chicago: The Year Book Publishers.
4. Schultze, G. (1958): Radiology, **70**, 230.
5. Baghdassarian, O. (1964): *Op cit*,[6] p. 56.
6. Avery, M. E., ed. (1964): *The Lung and Its Disorders in the Newborn Infant*. Philadelphia: Saunders.
7. Claireaux, A. E. (1953): Lancet, **2**, 749.
8. Gregg, R. H. and Bernstein, J. (1961): Amer. J. Dis. Child., **102**, 871.
9. Feinberg, S. B. and Goldberg, M. E. (1957): Radiology, **68**, 185.
10. Driscoll, S. G. and Smith, C. A. (1962): Pediat. Clin. N. Amer., **9**, 325.
11. Petersen, H. G., jnr. and Pendleton, M. E. (1955): Amer. J. Roentgenol, **74**, 800.
12. Heese, H. de V., Wittman, W. and Malan, A. F. (1963): S. Afr. Med. J., **37**, 126.
13. Donald, I. (1954): Brit. J. Radiol., **27**, 500.
14. Steiner, R. E. (1954): *Ibid.*, **27**, 491.
15. Hanley, W. B., Braudo, M. and Swyer, P. R. (1963): Canad. Med. Assoc. J., **89**, 375
16. Singleton, E. B., Rosenberg, H. M. and Samper, L. (1961): Radiology, **200**, 76.
17. Lubchenco, L. O. (1959): Pediatrics, **24**, 996.
18. Macklin, C. C. (1939): Arch. Intern. Med., **64**, 913.
19. Martin, J. and Griedell, H. L. (1952): Amer. J. Roentgenol, **67**, 905.
20. Donald, I. and Steiner, R. E. (1953): Lancet, **2**, 846.
21. Burnard, E. D. (1959): Brit. Med. J., **1**, 1495.
22. Landing, B. H. (1955): Amer. J. Roentgenol, **74**, 796.