Diffuse lung disease of infancy: a pattern-based, algorithmic approach to histological diagnosis

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ABSTRACT

Diffuse lung disease (DLD) of infancy has multiple aetiologies and the spectrum of disease is substantially different from that seen in older children and adults. In many cases, a specific diagnosis renders a dire prognosis for the infant, with profound management implications. Two recently published series of DLD of infancy, collated from the archives of specialist centres, indicate that the majority of their cases were referred, implying that the majority of biopsies taken for DLD of infancy are first received by less experienced pathologists. The current literature describing DLD of infancy takes a predominantly aetiological approach to classification. We present an algorithmic, histological, pattern-based approach to diagnosis of DLD of infancy, which, with the aid of appropriate multidisciplinary input, including clinical and radiological expertise and ancillary diagnostic studies, may lead to an accurate and useful interim report, with timely exclusion of inappropriate diagnoses. Subsequent referral to a specialist centre for confirmatory diagnosis will be dependent on the individual case and the decision of the multidisciplinary team.

INTRODUCTION

Diffuse lung disease (DLD) of infancy can be confronting to the pathologist who is not specialised in paediatric pulmonary pathology. The spectrum of disease and its aetiology is substantially different from that of adults and older children, and its pathological diagnosis invariably has a profound impact on clinical management. DLD of infancy presents with symptoms of impaired gas exchange that are more prevalent in infancy and other conditions that can occur at any age, such as disorders due to systemic disease (eg, collagen vascular disorders), infectious and other environmental agents, hypersensitivities and disorders of the immunocompromised host (box 1).2–4 The approach described will deal primarily with diagnosis of DLDs that are more specific to infancy, previously reported to constitute 60% of lung biopsies taken at <2 years of age for symptoms of DLD.4 Lung pathology, which is not specific to infancy and lung pathology in the immunocompromised host, will not be addressed, and such disease has been comprehensively described and reviewed.2–4 When using the approach described herein, the pathologist should be aware that the biopsy may exhibit a combination of infant-specific and non-specific disease (eg, alveolar growth abnormality (AGA) combined with infection).

Pulmonary hypertensive disease and its possible aetiology have been included in the diagnostic algorithm since histological changes of pulmonary hypertension are commonly encountered as a secondary event in DLD of infancy and clinically, pulmonary hypertension may be a prominent feature of DLD of infancy. For completion, aetiological causes of pulmonary hypertension other than DLD of infancy have also been included, particularly because these non-pulmonary causes have to be considered in any condition when lung biopsy is taken in the setting of pulmonary hypertension.

Normal anatomy

Diagnosis should not be attempted without a working knowledge of the normal anatomy of the neonatal lung. Gas exchange takes place in the acinus, that is, the functional unit of the lung, comprising the respiratory bronchiole, alveolar ducts and alveoli (figure 1). Several acini are present within a lung lobe, with lung lobules separated by interlobular septa. The walls of the alveoli are necessarily thin, with the air spaces primarily lined by squamous type I pneumocytes. Type II pneumocytes are cuboidal and are not obvious in normal lung. They produce surfactant, are the progenitors of type I pneumocytes and hence proliferate to colonise the alveolar walls following type I pneumocyte damage.

The anatomy of the vasculature of the lungs is unique. It is important to note that the pulmonary venous network does not run with the pulmonary arteries and also that the lung has a dual arterial blood supply. It is essential to accurately identify...
Box 1 Classification of diffuse lung disease in children under 2 years of age (modified from Deutsch et al4 and Langston and Dishop2)

Disorders more prevalent in infancy:
- Diffuse developmental disorders
  - Acinar dysplasia
  - Congenital alveolar dysplasia
  - Alveolar capillary dysplasia with misalignment of pulmonary veins
- Growth abnormalities
  - Prenatal conditions: secondary pulmonary hypoplasia
  - Postnatal conditions: chronic neonatal lung disease
  - Prematurity related
  - Term infants with chronic neonatal lung disease
  - Associated with chromosomal disorders
  - Associated with congenital heart disease
- Specific conditions of undefined aetiology
  - Neuroendocrine cell hyperplasia of infancy
  - Pulmonary interstitial glycosigenesis
- Surfactant dysfunction disorders
  - Surfactant protein B genetic mutations
  - Surfactant protein C genetic mutations
  - ABCA3 genetic mutations
- Histology consistent with surfactant protein dysfunction
  - with no genetic confirmation

Disorders not specific to infancy
- Previously normal hosts
  - Infection/postinfectious disease
  - Related to environmental agents
    - Hypersensitivity pneumonitis
    - Toxic inhalation
  - Aspiration syndromes
  - Eosinophilic pneumonia
  - Acute interstitial pneumonia
  - Non-specific interstitial pneumonia
  - Idiopathic pulmonary haemosiderosis
  - Others
- Disorders of the immunocompromised host
  - Opportunistic infections
  - Disorders related to therapy
  - Disorders related to transplantation and graft rejection
- Disorders relating to systemic disease
  - Immune-mediated disorders
  - Storage disease
  - Sarcoidosis
  - Langerhans cell histiocytosis
  - Malignant infiltrates
- Other
  - Disorders masquerading as interstitial lung disease
    - Arterial hypertensive vasculopathy
    - Congestive changes relating to cardiac dysfunction
    - Veno-occlusive disease
    - Lymphatic disorders
  - Pulmonary oedema
  - Unclassifiable
    - Includes end-stage lung disease, non-diagnostic, inadequate biopsies

To prevent a missed diagnosis of these conditions, the pulmonary arteries carry deoxygenated blood from the right ventricle and accompany the bronchi and bronchioles down to the level of the respiratory bronchioles, progressing from elastic to muscular arteries. The latter have a characteristic, well-formed internal and external elastic lamina, demonstrable with elastic stains, such as Elastic Van Gieson (EVG, figure 2) and should be similar in calibre to the accompanying bronchoile. The walls of the muscular pulmonary arteries undergo modification following birth due to the decrease in pulmonary arterial pressure. During the first few weeks of life, the media is relatively thick and the lumen narrow. However, by approximately 1 year of age, the muscular pulmonary arteries are thin-walled compared with those of the systemic circulation due to the reduced pressure within the pulmonary circulation. The muscular pulmonary arteries lead to arterioles that diverge from the respiratory bronchioles and travel within the intra-acinar connective tissue and thence to alveolar capillaries. The larger arterioles are muscular at birth, but lose this muscularisation with postnatal life.6

As noted above, the pulmonary venous network does not run with the pulmonary arteries in the bronchovascular bundles, but travels to the main pulmonary veins via venules and small veins within the inter-lobular septa. These vessels are thin-walled and have a single elastic lamina, but can be difficult to distinguish from arterioles, particularly in diseased states, unless the position of the vessel is noted. Pulmonary lymphatics are present within the bronchovascular bundles, in the pleura and adjacent to the pulmonary veins in the inter-lobular septa.

The bronchial arteries arise from the systemic circulation (via the thoracic aorta) and distribute oxygenated blood to the bronchi and connective tissue of the lungs. The bronchial arteries travel with the connective tissue of the bronchovascular bundles and are recognisable to the level of the terminal bronchioles. These vessels are relatively small-calibre, have a relatively thick media and no external elastic lamina. Beyond the terminal bronchiole, the bronchial circulation is difficult to identify; the bronchiol and pulmonary vessels anastomose and the majority of the bronchial arterial blood flow is returned via the pulmonary veins.

**APPRAOCH TO DIAGNOSIS OF DLD OF INFANCY**

A multidisciplinary approach to diagnosis of DLD of infancy is necessary, with appropriate input from clinical and imaging teams. Additionally, a pre-biopsy consultation with an expert pathologist at a specialist centre regarding possible aetiologies, appropriate sampling, biopsy technique and ancillary analyses may be appropriate. In all cases, whenever a paediatric lung biopsy is received, adequate specimen handling and processing is necessary for optimal diagnosis (see Langston et al5).

The current literature describing DLD of infancy takes a predominantly aetiological approach to classification (box 1). However, pathological diagnosis is necessarily pattern based. DLD of infancy exhibits a limited number of primary disease patterns and can be accompanied by additional histological features due to associated diseases. We propose an algorithm using histological, pattern-based appearances, to determine the probable cause of the DLD (figure 3). This algorithmic template can be used in conjunction with the more detailed information concerning clinical presentation, appropriate ancillary studies and outcome as described in the subsequent text and table 1.
nuclear glycogen vacuoles, which imparts a glandular epithelium of the distal airways is simple columnar with sub-nuclear glycogen. The descriptive term development is limited to the bronchial and bronchiolar structures. The term ‘glandular’ is used since the epithelium is columnar with sub-nuclear glycogen vacuoles, which imparts a glandular appearance. There is abundant mesenchyme surrounding the airways resulting in lobular architecture, and the airways lie at some distance from the capillary bed. Respiration is, therefore, impossible. AD is exceptionally rare and has been previously classified with the congenital pulmonary airway malformations (CPAM; type 0). AD is bilateral, and the lungs are characteristically very small (figure 4A). Infants with AD are refractory to ventilator support and usually die shortly after birth. For this reason, AD is more likely to be encountered at autopsy than biopsy.

Congenital alveolar dysplasia
Congenital alveolar dysplasia (CAD) is diagnosed when the lung development is arrested in the late canalicular or early saccular stage (figure 5). Here the low-power, lobular architecture is less pronounced, airspaces are more numerous with irregular outlines, the airspaces are lined by cuboidal epithelium and sub-nuclear glycogen is lost. Secondary mesenchymal crests containing capillaries are present within the airspaces, which divide them into saccules. The changes of CAD are present diffusely throughout the biopsy, and no normal lung tissue is present. This generalised growth abnormality is important to document since changes similar to CAD may be seen in other conditions, although they are then only focally present. In contrast to infants with AD, infants with CAD present with respiratory failure and pulmonary hypertension during the early neonatal period and can be successfully ventilated. Hence, biopsy is more likely for this condition. Nonetheless, these infants are ventilator-dependent and die due to respiratory failure.

Arrested alveolar development
Rarely, term neonates develop respiratory failure due to lung maturation arrest. The lung histology is developmentally primitive.

Acinar dysplasia
When the lung histology is reminiscent of either the pseudoglandular or early canalicular stage of fetal lung differentiation, acinar dysplasia (AD) is diagnosed (figure 4). In AD, the airway development is limited to the bronchial and bronchiolar structures. The descriptive term ‘pseudoglandular’ is used since the epithelium of the distal airways is simple columnar with sub-nuclear glycogen vacuoles, which imparts a glandular appearance.

Figure 1 The functional unit of the lung: terminal bronchiale (bottom right), alveolar ducts and alveoli within a lung lobule bounded by an inter-lobular septum (top left to centre). Note the artery accompanying the bronchiolre: the vein lies separately in the inter-lobular septum. Note also how thin the alveolar septa are: they contain a single capillary. Connective tissue is largely confined to the sheath around the bronchiole and artery and to the interlobular septum.

Figure 2 A muscular pulmonary artery with well-formed internal and external elastic lamina, demonstrable by elastic stains (Elastic van Gieson). The artery has a thick collagenous adventitial coat that merges with the collagen around the accompanying bronchiolre seen in part at top right (the pulmonary veins have a much thinner collagenous adventitia). Note that there is a layer of elastic tissue present in the mucosa of the bronchiolre. The bronchiolre and artery should generally be about equal in diameter.

Figure 3

Review


Figure 3  An algorithmic, histological, pattern-based approach to diagnosis of diffuse lung disease of infancy. IHC, immunohistochemistry; PAS, periodic acid Schiff; SpB, surfactant protein B; SpC, surfactant protein C.
significant alveolar structural simplification with fibrosis. CNLD is now more common in premature neonates than HMD/BPD due to the advent of prenatal steroid administration, surfactant replacement therapy and more refined ventilatory support. Therefore, HMD/BPD is now rarely seen in premature neonates.

**Table 1** Age at presentation, histological patterns, ancillary studies and mortality rate of DLD specific to infancy

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Age at presentation</th>
<th>Primary pattern</th>
<th>Possible associated conditions</th>
<th>Ancillary studies</th>
<th>Mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acinar dysplasia</td>
<td>Newborn</td>
<td>Delayed alveolar development</td>
<td>Pulmonary interstitial glycosgenosis</td>
<td>EVG, CD34 IHC, SMA IHC, FOXF1 mutation analysis</td>
<td>100%</td>
</tr>
<tr>
<td>Alveolar dysplasia</td>
<td>&lt;2 months</td>
<td>Delayed alveolar development</td>
<td>Pulmonary interstitial glycosgenosis</td>
<td>EVG, CD34 IHC, SMA IHC, FOXF1 mutation analysis</td>
<td>100%</td>
</tr>
<tr>
<td>Alveolar capillary dysplasia with misalignment of pulmonary veins</td>
<td>Newborn</td>
<td>Pulmonary hypertensive changes Interstitial thickening and congestion</td>
<td>AGAs Lymphangiectasia</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Congenital pulmonary lymphangiectasia</td>
<td>Newborn</td>
<td>Delayed alveolar development</td>
<td>Pulmonary interstitial glycosgenosis</td>
<td>EVG, D2–40 IHC</td>
<td>100%</td>
</tr>
<tr>
<td>Pulmonary hypoplasia, prematurity term; no specific factors</td>
<td>0.3–22 months</td>
<td>Alveolar simplification</td>
<td>Pulmonary interstitial glycosgenosis</td>
<td>Broad spectrum anticytokeratin IHC (eg, MNF116 antibody), EVG</td>
<td>34% overall, depending on cause of AGA</td>
</tr>
<tr>
<td>Congenital heart disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alveolar growth abnormalities</td>
<td>0.3–3 months not &gt;6 months</td>
<td>Interstitial thickening with non-inflammatory cells</td>
<td>AGAs Congenital alveolar dysplasia Alveolar capillary dysplasia</td>
<td>PAS, electron microscopy</td>
<td>0%</td>
</tr>
<tr>
<td>Neuroendocrine cell hyperplasia of infancy</td>
<td>2.7–24 months</td>
<td>Normal-appearing lung biopsy</td>
<td></td>
<td>Bombesin IHC</td>
<td>0%</td>
</tr>
<tr>
<td>Surfactant deficiencies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABAC3 deficiency</td>
<td>0.2–3.0 months</td>
<td>Interstitial thickening with prominent type II pneumocytes, PAP, DIP</td>
<td>CPI, NSIP</td>
<td>Broad spectrum anticytokeratin IHC (eg, MNF116 antibody), electron microscopy, ABAC3 mutation analysis</td>
<td>100% (improved survival when later presentation)</td>
</tr>
<tr>
<td>SpB</td>
<td>Newborn</td>
<td>Interstitial thickening with prominent type II pneumocytes, PAP</td>
<td>CPI, NSIP, DIP</td>
<td>Broad spectrum anticytokeratin IHC (eg, MNF116 antibody), anti-SpB IHC, electron microscopy, SpB mutation analysis</td>
<td>100%</td>
</tr>
<tr>
<td>SpC</td>
<td>2–22 months</td>
<td>Interstitial thickening with prominent type II pneumocytes, DIP, CPI</td>
<td>NSIP, PAP</td>
<td>Broad spectrum anticytokeratin IHC (eg, MNF116 antibody), SpC</td>
<td>0%</td>
</tr>
</tbody>
</table>

AGA, alveolar growth abnormality; CPI, chronic pneumonitis of infancy; DIP, desquamative interstitial pneumonia; DLD, diffuse lung disease; EVG, Elastic Van Gieson; IHC, immunohistochemistry; NSIP, non-specific interstitial pneumonitis; PAP, pulmonary alveolar proteinosis; PAS, periodic acid Schiff; SpB, surfactant protein B; SpC, surfactant protein C; SMA, smooth muscle actin.

**Figure 4** Acinar dysplasia. (A) Thoracic contents from a 24-week fetal death in utero showing bilateral, extremely small, granular lungs. The lungs are scarcely bigger than the atrial appendages. (B) Microscopic appearance of acinar dysplasia with airway development limited to bronchial and bronchiolar structures only, with no distal airways development. This imparts a distinctly lobular appearance, reminiscent of the pseudoglandular stage of fetal lung development. These lobules are surrounded by abundant loose mesenchyme.
bral dysgenesis, thyroidal dysfunction and severe pulmonary insufficiency which characterise the phenotype of this genetic disorder.\(^\text{10}\)

In contrast, the alveolar simplification is characteristically subpleural. One study showed that prematurity or congenital heart disease was highly predictive of AGA as the primary histological pattern of DLD.\(^\text{4}\) AGA can also occur in term infants who develop early postnatal infections which inhibits appropriate postnatal lung development. AGA has also been described in otherwise normal term neonates.\(^\text{2}\) A small proportion of these are infants of diabetic mothers. In other cases, it is presumed that undetected fetal hypoxia prevented normal alveolar growth.\(^\text{2}\) More recently, both AGA and extensive emphysematous change have been described in infants with TTF-1 (NKX2.1) deficiency, as part of the triad of cerebral dysgenesis, thyroidal dysfunction and severe pulmonary insufficiency which characterise the phenotype of this genetic disorder.\(^\text{10}\)

The outcome of AGA is variable depending on the underlying aetiology, the severity of the alveolar simplification and the presence of pulmonary hypertension. In one cohort, the overall mortality was 34%.\(^\text{4}\)

**Non-inflammatory interstitial thickening**

Interstitial thickening can be the main histological pattern of a number of disparate causes of DLD and also is commonly admixed with other disease patterns. The cause of the interstitial thickening should be carefully noted (eg, due to an inflammatory infiltrate, oedema and other causes) to facilitate assessing the cause of the lung pathology.

**Pulmonary interstitial glycogenosis**

The most common cause of a non-inflammatory, cellular interstitial infiltrate is PIG, which occurs in very young infants, usually <2 months of age and rarely in infants >6 months of age.\(^\text{2,4}\) The characteristic feature is diffuse (more rarely focal) expansion of the interstitium due to vimentin-positive, mesenchymal, oval to spindle cells with cytoplasmic clearing (figure 6). Somewhat confusingly, glycogen is not demonstrated following periodic acid Schiff stain on light microscopy in the majority of cases and hence lack of glycogen identified on light microscopy should not preclude this diagnosis.\(^\text{2}\) Perhaps for this reason PIG is said to be underdiagnosed.\(^\text{9}\) Glycogen droplets are more readily identified by electron microscopy.\(^\text{11}\) Interstitial fibrosis and an inflammatory infiltrate are minor, if present, in PIG and type II pneumocyte hyperplasia is not a feature of this condition.

PIG is commonly seen on a background of AGA, particularly when due to prematurity, and PIG has been noted to occur in more than 50% of cases of AGA presenting in infants below 6 months of age.\(^\text{2}\) PIG has also been documented in conjunction with CAD, ACD, persistent pulmonary hypertension and congenital lobar emphysema.\(^\text{3}\) The aetiology of PIG is poorly understood, but it may represent a persistence of embryological mesenchymal cells.\(^\text{3}\) In one series, there were no deaths due to PIG and the prognosis is generally good, depending on the severity of any associated lung conditions.\(^\text{4,12}\)

**ACD and misalignment of pulmonary veins**

The prominent low-power histological pattern of this complex developmental disease of pulmonary vasculature is interstitial thickening (figure 7). The alveolar capillaries are abnormally placed and central within the thickened alveolar septa and are not closely opposed to the lining pneumocytes. These abnormally placed capillaries can be advantageously visualised with antibodies to endothelial antigens such as CD31 (figure 7B). There is accompanying misalignment of pulmonary veins, which

![Figure 5](image-url)  
**Figure 5** Congenital alveolar dysplasia in a 2-month-old infant, born at 37 weeks gestation. The lung abnormality is diffuse and shows development reminiscent of the late canalicular/early saccular stage of fetal lung maturation. There are angulated distal airspaces, and mesenchymal crests are present. Many of the epithelial cells lining the airspaces are columnar. The neonate was ventilated and subsequently died. The abnormality must be diffusely present throughout the lungs to make the diagnosis.

![Figure 6](image-url)  
**Figure 6** Alveolar growth abnormality with pulmonary interstitial glycogenosis. (A) There is diffuse enlargement and simplification of alveolar spaces. The interstitium is thickened. In addition, there is oedema of the interlobular septum, with distension of the veins and lymphatics and focal deposition of haemosiderin. (B) Thick alveolar septae due to oval and spindle cells with cytoplasmic glycogen demonstrated by periodic acid Schiff. There is no significant interstitial inflammatory cell infiltrate.

run within the bronchovascular bundles, alongside the pulmonary arteries (figure 7A), although larger pulmonary veins occasionally may be normally placed within the inter-lobular septa. Due to this abnormal venous drainage, the capillaries within the alveolar septa are often congested and there are changes of pulmonary arterial hyperplasia, which are seen as medial hypertrophy of small muscular pulmonary arteries and muscularisation of the arterioles. Lymphangiectasia is usually prominent, and ACD may be associated with AGA and PIG. Importantly, neither type II pneumocyte hyperplasia nor inflammation is present in this disease and there is no significant debris or cellular material within the alveolar spaces.

The clinical history is important when considering a diagnosis of ACD. These neonates are usually born at term and develop early symptoms of severe pulmonary hypertensive disease, hypoxia and progressive respiratory failure which begin a few hours after birth. Most biopsies for this condition are therefore taken within the first month of life. The neonate often has other congenital abnormalities, particularly including the cardiac, gastrointestinal or renal systems. ACD has been associated with heterozygous FOXF1 gene mutations. These mutations are usually sporadic, although rare cases appear maternally inherited due to imprinting of the paternal allele.13 ACD is fatal in early infancy.

Interstitial thickening with a mild inflammatory interstitial infiltrate and type II pneumocyte hyperplasia
Surfactant protein deficiencies
In infancy, interstitial thickening due to a mild interstitial inflammatory infiltrate and oedema is often accompanied by prominent, uniform and diffuse type II pneumocyte hyperplasia (figure 8). This histological pattern is known as chronic pneumonitis of infancy (CPI) and is most commonly associated with congenital surfactant protein deficiency, particularly deficiency of surfactant protein C (SpC), which has autosomal-dominant inheritance. Type II pneumocytes are readily demonstrated by broad-spectrum anticytokeratin antibodies, such as MNF116. This histological appearance is different to that of the subacute/fibroproliferative phase of HMD, when type II pneumocytes may also be prominent, since in HMD evidence of severe acute lung damage is present, including resolving hyaline membranes. Nonetheless, these two conditions may coexist.

In addition to the interstitial inflammatory infiltrate and type II pneumocyte hyperplasia characteristic of surfactant protein deficiency, two further features may also be observed in differing proportion, that is, pulmonary alveolar proteinosis (PAP) and numerous macrophages within the alveolar spaces, that is, desquamative interstitial pneumonia (DIP). Depending on the prominence of these features, it is possible to suggest the specific genetic aberration that has led to the surfactant protein deficiency.

PAP is diagnosed when eosinophilic proteinaceous debris is prominent within the alveolar spaces (figures 9 and 10). The histological appearance of PAP occurring in infants and adults is similar. However, their aetiology is different. PAP in infancy is invariably combined with interstitial thickening and type II pneumocyte hyperplasia and is most likely due to recessively inherited mutations in the surfactant protein B (SpB) gene or ATP-binding cassette transporter A3 (ABCA3) gene. Further,
ABCA3 deficiency is said to confer characteristic ‘glassy’ intra-alveolar proteinaceous deposits, which can be useful to direct genetic investigations (figure 9). The alveolar protein in SpB deficiency tends to be more granular. Anti-SpB antibodies can be used to demonstrate absent SpB expression within the pneumocyte population and intra-alveolar debris in SpB mutation (figure 10). SpB and ABCA3 deficiency can also be inferred by their characteristic ultrastructural appearance; deficient mature lamellar bodies with SpB deficiency compared with absent mature lamellar bodies and the presence of distinctive electron-dense bodies within small lamellar bodies (‘fried egg’ appearance) in ABCA3 deficiency.

As with PAP, DIP-like changes in infant lungs are usually a manifestation of surfactant protein deficiency, including ABCA3 deficiency and SpC deficiency. The characteristic feature is the presence of numerous foamy macrophages within the alveolar spaces, sometimes containing cholesterol clefts, together with interstitial thickening, and type II pneumocyte hyperplasia. There may be overlap with PAR particularly with ABCA3 deficiency and CPI with SpC deficiency. No characteristic ultrastructural findings have been described with SpC deficiency.

SpB deficiency presents in newborns and is invariably fatal.16 ABCA3 deficiency presenting at a young age (0.2–3 months) is also a fatal disease.4 However, there is accumulating evidence that ABCA3 deficiency may present in later childhood as non-specific interstitial pneumonitis with less severe lung disease and an improved outcome.17 18 In contrast with SpB deficiency and ABCA3 deficiency presenting in infancy, SpC deficiency has a relatively good outcome.

Miscellaneous causes of interstitial thickening and PAP

Similar PAP changes as those seen with surfactant protein deficiencies can be seen in older infants as a response to infection, particularly viral infection. In this clinical setting, viral inclusions are occasionally visible and appropriate molecular or culture investigations for viral infection should be performed. PAP has also been described in infancy in the absence of a surfactant protein deficiency in conditions such as malignancy, immunodeficiency and in the rare autosomal-recessive condition: lysinuric protein intolerance.19

Interstitial thickening with prominent interstitial inflammatory cells and fibrosis

A prominence of chronic inflammatory cells as a cause of interstitial thickening is relatively rare in this age group and is termed non-specific interstitial pneumonia (NSIP). The inflammatory infiltrate is usually composed of lymphocytes and plasma cells and is characteristically temporally uniform across the biopsy. Cellular expansion of the interstitium is also the main histological feature of PIG and PIG is much more common than NSIP in this age group. However, PIG should not be diagnosed if the interstitial cells are inflammatory. There may be type II pneumocyte hyperplasia in NSIP and minor interstitial macrophages, but these findings are not as strikingly diffuse as in CPI, DIP and PAP. Fibrosis may be present, but is patchy and mild. Organising pneumonia also can be seen. As its appearance implies, NSIP is non-specific as to aetiology and can remain idiopathic, despite extensive investigation. While older children with surfactant protein deficiency, including SpC and ABCA3 deficiency, can show NSIP on biopsy, NSIP is not the usual presentation of surfactant protein deficiency in children <2 years of age. Other causes are not specific to this age group and include infections and hypersensitivity pneumonitis.

Pulmonary hypertensive disease

Histological changes of pulmonary hypertension are relatively common in lung biopsies in infants, but are usually secondary to other disease. Nonetheless, the hypertensive changes may be the most striking histological feature identified within a biopsy.

**Figure 9** ABCA3 deficiency. Interstitial thickening with florid type II pneumocyte hyperplasia and pulmonary alveolar proteinosis due to genetically proven ABCA3 deficiency. The eosinophilic debris within the alveolar spaces has a characteristic ‘glassy’ appearance. There are abundant intra-alveolar macrophages. There is also hyperplasia of smooth muscle in the interstitium.

**Figure 10** Surfactant protein B deficiency. (A) Interstitial thickening, and a striking quantity of granular, proteinaceous debris within alveolar spaces. Macrophages are not especially prominent, and there is little type II pneumocyte hyperplasia evident in this field. (B) Immunohistochemical staining with antibody to surfactant protein B is negative. Type 2 pneumocyte hyperplasia is more evident than in the H&E section. (C) Immunohistochemical staining with antibody to surfactant protein B in control lung tissue. Staining of surfactant protein B is present in type II pneumocytes lining the alveolar walls, and to a lesser extent, in the alveolar spaces.
In order to determine the cause of the hypertensive change, clinical history is paramount, together with identification of any other lung histopathology. Pulmonary hypertensive changes can primarily affect the arterial vasculature or affect both the arterial and venous systems. The causes are usually distinct.

In all biopsies where vessel abnormality is considered, an EVG histochemical stain is essential. CD34 or CD31 immunohistochemistry (IHC) is also useful to highlight the entire vascular component of the biopsy, and smooth muscle actin IHC will highlight abnormally muscularised vessels.

Pulmonary arterial hypertension
Pulmonary arterial hypertension is seen as medial hyperplasia of small muscular pulmonary arteries and muscularisation of arterioles. The more severe forms show cellular and fibrous intimal proliferation (figure 11A) and there may be deposition of fibrinoid, foam cells or plexiform lesions in the most severe cases (figure 11B). Additionally, elastic pulmonary arteries may show atheromatous intimal plaques, although these vessels are rarely seen on lung biopsy.

Pulmonary venous hypertension
Pulmonary venous hypertension will occur with any disease that increases pulmonary venous pressure due to left-sided obstruction. Histologically there is muscularisation of pulmonary veins together with variable intimal proliferation. There is congestion of alveolar capillaries, intra-alveolar haemosiderin-laden macrophages and occasionally calcification or ossification of the pulmonary interstitium. In pulmonary veno-occlusive disease, the septal veins show prominent intimal cellular proliferation, which can

Figure 11 Pulmonary arterial hypertension. (A) Cellular intimal thickening of small muscular pulmonary arteries. (B) Plexiform lesion. The parent artery is present to the left of the field and shows only mild intimal thickening. Several branches are present in its adventitial coat, and these show severe concentric, fibrous and myxoid intimal thickening with deposition of fibrinoid. Within the lumen of one vessel (3 o’clock), there is cellular proliferation with the formation of slit-like vascular lumina, creating a plexiform lesion. Surrounding this there are thin-walled dilated vessels, the whole forming a complex vascular lesion.

Pulmonary arterial hypertension (without significant venous pathology) most commonly occurs with congenital heart disease with significant, uncorrected left-to-right shunts (e.g., truncus arteriosus, transposition of great arteries, complete atrial ventricular septal defects). However, lung biopsy is now rarely performed in this clinical setting. Infrequently, pulmonary hypertensive disease may be idiopathic, either sporadic or familial.\textsuperscript{20}

Pulmonary venous hypertension
Pulmonary venous hypertension will occur with any disease that increases pulmonary venous pressure due to left-sided obstruction. Histologically there is muscularisation of pulmonary veins together with variable intimal proliferation. There is congestion of alveolar capillaries, intra-alveolar haemosiderin-laden macrophages and occasionally calcification or ossification of the pulmonary interstitium. In pulmonary veno-occlusive disease, the septal veins show prominent intimal cellular proliferation, which can

Figure 12 Pulmonary veno-occlusive disease. A large septal vein is shown in semi-longitudinal section. The original muscular media is evident as a thin cuff around the vessel, and the lumen is occluded by myxoid and fibrous and cellular intimal proliferation. There is a residual narrow and tortuous lumen. There is surrounding severe alveolar capillary congestion. There is also lymphatic dilatation.

Figure 13 Persistent pulmonary hypertension of the newborn. The lung is immature (thickened interstitium with double capillary loops). There are multiple profiles of an artery accompanying a respiratory bronchiole. The artery is thick-walled and muscular and is contracted—the endothelial cells are crowded together and pushed into the lumen in a hobnail pattern (Elastic Van Gieson). After birth, under the influence of increasing oxygen tension these arteries should normally dilate. In persistent pulmonary hypertension of the newborn, the majority of intra-acinar arteries in the lung have this constricted appearance.
Lymphangiectasia
Lymphangiectasia is seen as dilated lymphatic channels in the bronchovascular bundle, interlobular septa and pleura (figure 14). The lymphatics can be specifically identified with the antibody D2–40, a marker of lymphatic endothelium. There can be accompanying chylothorax, leading to pulmonary hypoplasia. Lymphangiectasia is common as a secondary phenomenon with chronic heart failure, venous obstruction, chronic lymphatic obstruction and ACD. Similar changes can also be seen in chronic heart failure.

Lymphangiectasia presents in newborns and is uniformly fatal.22,23

The normal-appearing lung biopsy
Occasionally, infants who present with persistent tachypnoea and hypoxia indicative of DLD have a biopsy that appears relatively normal on routine H&E staining or may contain non-specific minor changes such as a mild increase of airway-associated lymphoid tissue and mild hyperplasia of airway smooth muscle. A proportion of these cases will have neuroendocrine cell hyperplasia of infancy (NCHI), a relatively recently described entity. The diagnosis can be made on biopsy due to increased neuroendocrine cell numbers in small airways identified by IHC with antibodies to bombesin (figure 15). Infants diagnosed with this condition are usually born at term and may not present until 1 year of age.4,12,23 Symptoms may be precipitated by lung infection. This condition is said to have characteristic imaging, that is, central and right middle lobe and lingula ground glass densities seen on high-resolution CT.24 NCHI was found in 3.2% of biopsies taken for symptoms of interstitial lung disease in childhood in one retrospective institutional study.3 The outcome is generally good, with no reported cases of respiratory failure or death due to this condition.

DLD not specific to infancy
As seen in box 1, infants may present with DLD not specific to this young age group. Infection is commonly seen and has been documented to constitute 17% and 18% of DLD of infancy in two separate studies.4,24 Other relatively common DLDs in this age group are immune-mediated or collagen vascular diseases affecting the lungs, aspiration syndromes and hypersensitivity pneumonitis. The histological appearance of these conditions does not vary significantly from that seen in older children and adults. Of note, usual interstitial pneumonia, characterised as temporally heterogeneous fibrosis, is not seen in infants.

CONCLUSION
DLD of infancy has many aetiologies. Some diseases are specific to this young age group, while others are not. Recently published series of DLD of infancy, taken from the archives of specialist centres, indicate that many cases are referred for expert opinion from more generalist pathologists. We present an algorithmic approach to the diagnosis of DLD of infancy which may be of use to the non-specialist pathologist. As with any suggested algorithmic approach to diagnosis, practical common sense is necessary when faced with paediatric lung biopsies and expedient referral to a specialised centre, for either primary or confirmatory diagnosis, may often be required. In all cases, ultimate diagnosis is necessarily based on a multidisciplinary approach, including clinical, radiological and pathological input.
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