Abstract
Atelectasis can result from obstruction of bronchial airflow, compression of the lung or surfactant dysfunction. Middle lobe (ML) or lingula atelectasis in children is often due to asthma and usually resolves spontaneously, but in cases of more extended or prolonged atelectasis, bronchoscopy provides clinically useful information. Bronchoscopy allows direct airway inspection or potential pathogenic micro-organism isolation, whereas repeated lavage may be beneficial for mucus plug removal; foreign-body removal is therapeutic and may be even life saving. The anatomy of the ML bronchus creates conditions for poor secretion drainage, resulting in impaired ventilation and eventually alveolar collapse; repeated episodes of infection, inflammation and obstruction may eventually lead to bronchiectasis. Plastic bronchitis is characterized by the formation of large gelatinous or rigid branching airway casts. These casts are larger and more cohesive than those seen in ordinary mucus plugging; removal of central casts should be attempted before medical therapy to mobilize the casts.

Atelectasis
The term ‘atelectasis’ describes incomplete expansion or complete collapse of part of the lung parenchyma [2]. Atelectasis can result from obstruction of bronchial airflow, compression of the lung or surfactant dysfunction. Segmental, lobar or whole-lung collapse is associated with absorption of air in the alveoli. The developing lung is particularly predisposed to atelectasis once airway obstruction develops. In early childhood, the airways are smaller and more collapsible, the chest wall is more compliant, and the collateral ventilation through bronchiole-alveolar pores (the canaliculi of Lambert) is not completely developed [1, 2].

History and clinical examination are insensitive to detect atelectasis. The clinical manifestations depend on the underlying cause, the degree of volume loss within the lung, and how quickly volume loss develops. A slowly developing atelectasis of a lobe may produce no symptoms. Most children with atelectasis that occurs during the course of common diseases, such as asthma or infection, do not have many symptoms unless the obstructed area is large [1].
Classification

Obstructive Atelectasis
Obstructive atelectasis is the most common type and results from absorption of gas from the alveoli when communication between the alveoli and major airways is obstructed. Intrabronchial obstruction can be exogenous, as in foreign-body aspiration or recurrent aspiration of either gastric or oral contents due to a swallowing disorder, or endogenous, as is the case with tumours, mucus plugging or tracheo- or bronchomalacia.

Compression of Bronchi or Parenchyma
Compression atelectasis is caused by the inability to expand the lung due to any space-occupying lesion of the thorax: (a) tumours, cysts, enlarged lymph nodes, cardiomegaly or a vascular ring may compress the adjacent bronchi or parenchyma; (b) increased intrapleural pressure as with chylothorax, haemothorax, pneumothorax, and (c) chest wall defects and neuromuscular diseases may, directly or indirectly, result in alveolar hypoventilation and alveolar collapse.

Surfactant Deficiency or Dysfunction
Surfactant dysfunction has been reported in respiratory distress of the preterm newborn with inadequate surfactant production and in babies with meconium aspiration and surfactant destruction [3]. There is also surfactant breakdown in older patients with pneumonia and severe dysfunction in patients with the acute respiratory distress syndrome. Surfactant dysfunction causes increased alveolar surface tension as well as failure to maintain small airway patency.

Bronchoscopy for the Diagnosis of Atelectasis
Flexible bronchoscopy (FB) allows direct airway inspection and thus differentiation between obstructive and non-obstructive types of atelectasis and definition of the nature of obstruction when it occurs. Atelectasis is the second most frequent radiological sign of foreign-body aspiration in children after localized air-trapping, with fairly good diagnostic sensitivity, but low specificity [4]. In atelectasis caused by foreign-body aspiration, bronchoscopy is required for definitive diagnosis and identification of the type of foreign body and its integrity. In a series of 2,165 children with foreign-body aspiration, atelectasis and pneumonia (n = 362) were more commonly seen in patients with delayed diagnosis; however, only 15.7% of all foreign bodies were radio-opaque, and much fewer were opaque in children with delayed diagnosis [5]. By performing bronchoscopy, the presence of an endobronchial mass can often be confirmed. In a case series of 17 children with carcinoma or muco-epidermoid tumours, 12 presented with evidence of bronchial obstruction. FB confirmed the presence of a bronchial tumour in all cases, and endobronchial biopsies were diagnostic in 11 of 12 cases [6].

Extrinsic or intrinsic bronchial obstruction may lead to loss of integrity of the bronchial wall cartilage, and bronchiectasis with bronchial collapse may occur. Consequently, bronchial obstruction could be either the cause or the result of atelectasis [7; chapter 12, this vol., pp. 130–140] (fig. 1, 2; online suppl. video 1). A typical example is children with heart disease and vascular anomalies who are at increased risk of airway obstruction and atelectasis. In these children, FB can be both diagnostic and often therapeutic [8, 9]. In a study of 72 patients (mean age 21 months) with acquired and congenital heart disease (CHD), most underwent FB assessment for atelectasis (35%), pneumonia (14%) or stridor (14%). Airway malacia was the most common finding, primarily left main bronchus malacia (24%) with the second most common finding being stenosis by extrinsic compression, again mostly of the left main bronchus [8].

Chronic atelectasis of any aetiology can become a nidus of chronic purulent infection with bronchial wall damage leading to bronchiectasis. Isolation of pathogenic micro-organisms by FB and protected specimen brush or lavage can help to direct appropriate antibiotic therapy [chapter 15, this vol., pp. 156–172]. Bronchoscopic bronchoalveolar lavage (BAL) allows direct sampling of the involved lobe [10].

Value of Bronchoscopy in the Treatment of Atelectasis
In an attempt to re-inflate an atelectatic lobe, repeated ‘therapeutic’ small-volume lavage is sometimes used although a
benefit has not been clearly established (fig. 3). In pneumonia, if secretions completely occlude the airway and cannot be cleaned by coughing, suctioning or physical therapy, rigid bronchoscopy has been effective as a therapeutic procedure. In a study of 33 Taiwanese children with atelectasis caused by pneumonia, rigid bronchoscopy with lung lavage for removal of the mucus plugs or foreign bodies was performed. Twenty-one (64%) children had significant improvement in either oxygen saturation or chest radiography within 72 h [11]. Obviously, removing a foreign body obstructing the airway by using a bronchoscope can be therapeutic and even life saving. For safety, this should usually be performed with the rigid bronchoscope [chapter 8, this vol., pp. 83–94].

Other bronchoscopic interventions for treatment of persistent atelectasis such as instillation of acetylcysteine, antibiotics, dornase alfa, surfactant preparations and sodium bicarbonate [chapter 5, this vol., pp. 54–63] have also been reported but for the most part, results are poor or inconclusive [1, 2]. In a recent study [12] of 35 paediatric intensive-care patients with 51 episodes of atelectasis who received intratracheal dornase α, 67% of patients showed radiological signs of improvement after 24 h; however, there was no control group. In another paper [13], 5 children (7 months to 15 years of age) with heterogeneous lung diseases requiring mechanical ventilation were treated with a diluted surfactant preparation (Curosurf®) in a concentration of 5–10 mg/ml (total dose 120–240 mg) which was instilled into the

**Fig. 2.** Near total occlusion of the subsegmental medial basal bronchus (B7) of the right lower lobe in an 8-year-old girl with chronic wet cough (online suppl. video 1).

**Fig. 3.** Superior segmental bronchus (B6) with thick, tenacious purulent mucus plug, before and after repeated ‘therapeutic’ small-volume lavages.