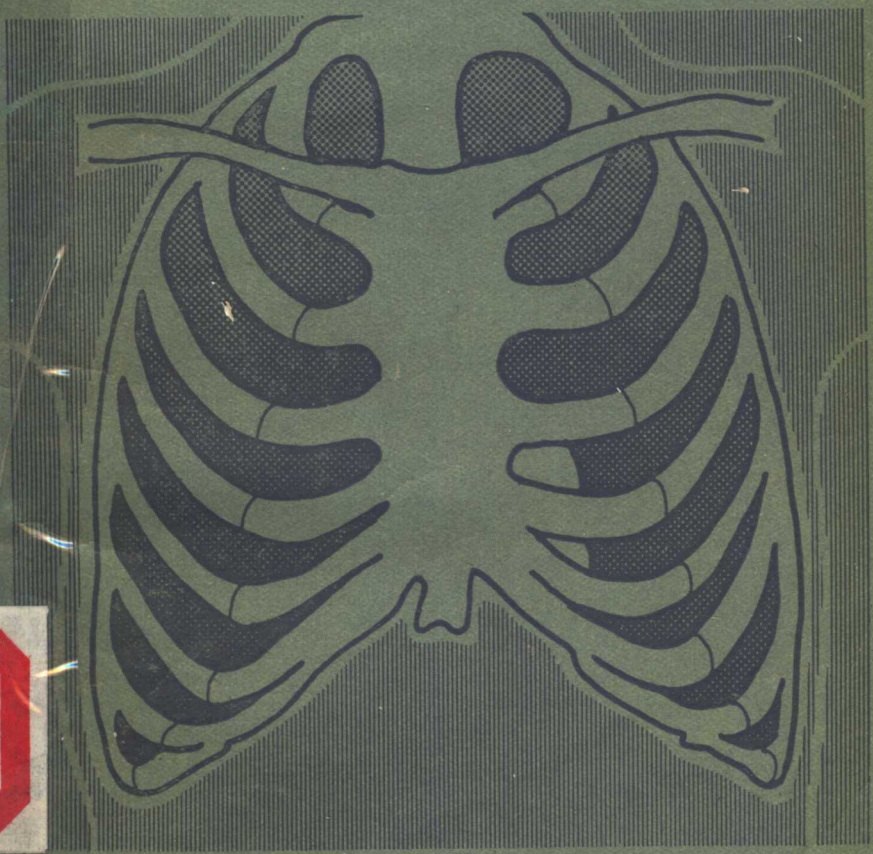
R. A. L. Brewis

Lecture Notes on Respiratory Disease



LECTURE NOTES ON

RESPIRATORY DISEASE

WRITTEN AND ILLUSTRATED BY

R. A. L. BREWIS

MD, FRCP

Senior Lecturer in Medicine,
University of Newcastle upon Tyne
Consultant Physician,
Royal Victoria Infirmary,
Newcastle upon Tyne

BLACKWELL SCIENTIFIC PUBLICATIONS

OXFORD LONDON EDINBURGH MELBOURNE

Osney Mead, Oxford,
85 Marylebone High Street, London W1M 3DE,
9 Forrest Road, Edinburgh,
P.O. Box 9, North Balwyn, Victoria, Australia.

ISBN 0 632 00651 X

First published 1975

Printed in Great Britain by
Western Printing Services Ltd,
Bristol
and bound by
The Western Book Co. Ltd.,
Maesteg, Glamorgan

PREFACE

The aim of this book is to present a concise review of respiratory disease. In addition to offering the medical student an alternative to attending lectures it is hoped that this book might provide the MRCP candidate with his basic minimum requirements in the respiratory field and the more mature general medical reader with a painless refresher course.

The emphasis throughout is on information which is useful and relevant to everyday clinical medicine. In reviewing pulmonary physiology and the assessment of pulmonary function all unnecessary complexities, symbols and equations have been avoided and attention has been focused on concepts and investigations which are in everyday use. A number of rare conditions receive little or no mention but the practical aspects of management of the commoner disorders are dealt with in some detail.

Numerous teachers, colleagues, students and patients have played a part in the development of my interest in respiratory disease but I owe a particular debt to Professor Jack Howell for opening my eyes to some of the special fascinations of the subject. I am grateful to Miss Veronica Downey for help with typing; without her watchful eye on my other commitments it would have been impossible to attend to the business of writing. I am grateful to Dr Martin Farebrother for reading parts of the manuscript and to Mr Per Saugman for his encouragement and courtesy. I hope to express my gratitude to my wife and family by seeing a little more of them.

R.A.L.B.

Newcastle upon Tyne, 1974

CONTENTS

CHAPTER 1 · REVIEW OF ANATOMY OF THE LUNG

Surface anatomy

The position of the lungs and some useful external landmarks are indicated in Fig. 1.1. A few points are worthy of special mention:

1 The apices of the lungs extend well above the clavicles.

2 The posterior surface of the lungs extends further downwards than the anterior surface.

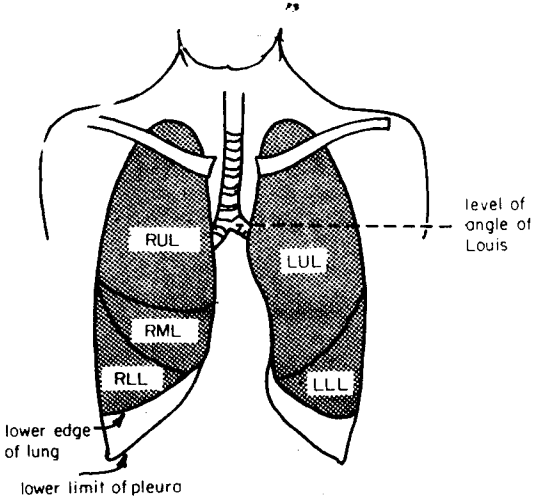
3 The upper lobes are situated *in front of* the lower lobes so that the lung immediately below the anterior chest wall is largely derived from the upper lobe and that beneath the posterior chest wall is mainly lower lobe.

Subdivisions of the lung

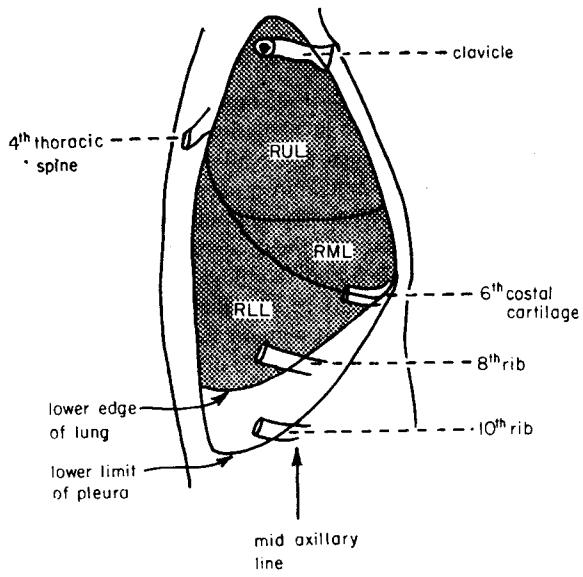
The lungs are divided into **lobes**—three on the right and two on the left—which are separated by slit-like invaginations of the pleural space. Each lobe has its own lobar bronchus. Each lobe is further subdivided by incomplete fibrous septa which extend inwards from the pleural surface into **bronchopulmonary segments.** Each bronchopulmonary segment is supplied by its own segmental bronchus and the usual arrangement of the segmental bronchi is shown in Fig. 1.2. Some pathological processes may be limited to particular segments which may be identified radiologically. Smaller incomplete fibrous septa are present within each segment which outline individual **lobules.** Lobules are about 1 cm in diameter and of variable shape but generally they are pyramidal with the apex towards the bronchiole which supplies them. The anatomy of the lobule is illustrated in Fig. 1.3. Each lobule contains 3 to 5 **acini,** each supplied by a terminal bronchiole. Acini are sometimes visualised on the chest X-ray when they are filled with secretions or bronchographic contrast medium producing a blotchy appearance sometimes referred to as acinar pattern.

Branching of the airways

The trachea divides into two main bronchi. The left main bronchus is longer than the right and comes off at a more abrupt angle. The right main bronchus is more directly in line with the trachea so that inhaled material tends to enter the right lung more readily than the left. The main bronchi



(a)



(b)

Fig. 1.1. ***Surface anatomy.*** **(a) Anterior view of the lungs. (b) Lateral view of right side of chest at resting end-expiratory position. RUL: right upper lobe; RML: right middle lobe; RLL: right lower lobe; LUL: left upper lobe; LLL: left lower lobe.**

divide into lobar and then segmental bronchi as shown in Fig. 1.2. Further divisions occur in an uneven dichotomous fashion; that is the branches at a division are not necessarily of the same size.

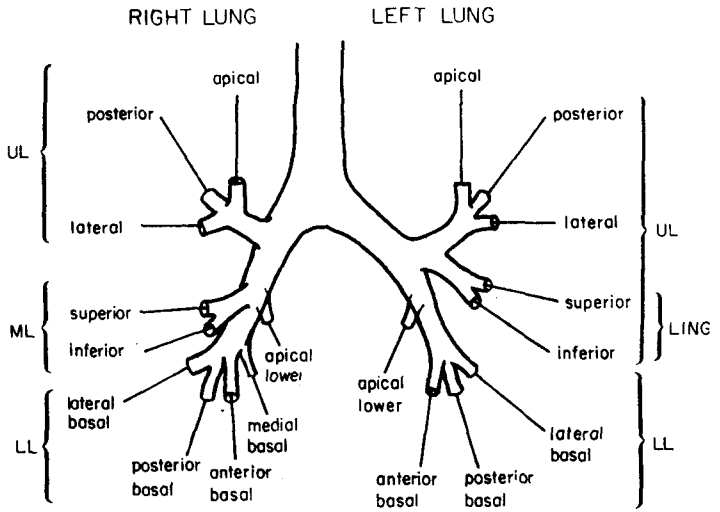


Fig. 1.2. *Diagram of bronchopulmonary segments.* UL: upper lobe; ML: middle lobe; LL: lower lobe; LING: lingula.

Bronchi

Bronchi are airways with cartilage in their walls. There are about 10 divisions of bronchi beyond the tracheal bifurcation. Smaller airways without cartilage in their walls are referred to as **bronchioles**. The term **respiratory bronchiole** refers to the peripheral bronchioles with alveoli in their walls. The bronchiole immediately proximal to the appearance of alveoli is known as the **terminal bronchiole**. The number of divisions between the bifurcation of the trachea and the terminal bronchiole varies between about 9 and 32. In general there are fewer branches to acini near the hilum and more branches to the peripherally situated acini.

Collateral ventilation

Holes in the alveolar walls known as pores of Kohn allow communication between parts of the lobule supplied by different respiratory bronchioles. There is a variable degree of communication at alveolar level between neighbouring lobules. Collateral ventilation through these communications is of importance in panacinar emphysema. In this condition they are

increased in size and number as part of the parenchymal destructive process.

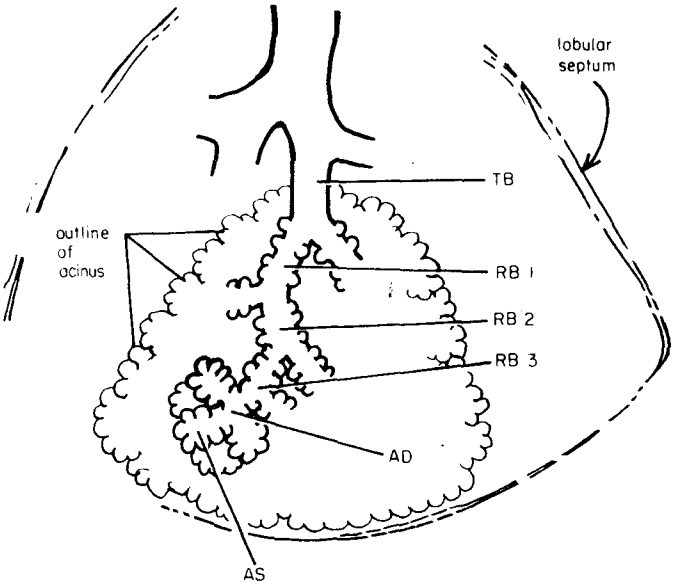


Fig. 1.3. *Diagram of the anatomy of the lobule.*
The lobule lies within incomplete fibrous septa and contains several acini. The borders of individual acini are not normally discernible. Each acinus is supplied by a terminal bronchiole (TB). There are about three orders of respiratory bronchioles with alveoli in their walls (RB1, RB2, RB3) which lead to alveolar ducts (AD) which are formed from the mouths of alveoli and alveolar sacs (AS).

Pulmonary vasculature

Pulmonary artery

The pulmonary artery divides into left and right pulmonary arteries which provide branches accompanying the branches of the bronchial tree. The arteries accompanying bronchi are elastic but have only thin muscular coats. The arteries accompanying bronchioles have well-developed medial muscular coats which become thinner peripherally. The **arterioles** accompanying terminal and respiratory bronchioles are thin walled and contain little smooth muscle.

Capillary network

The capillary network in the alveolar walls is very dense and provides a very large surface area.

Pulmonary venules

The pulmonary venules do not accompany the arterioles but drain laterally to the periphery of lobules and then pass centrally in the interlobular and intersegmental septa ultimately joining to form the four main pulmonary veins which empty into the left atrium.

The bronchial circulation

Small bronchial arteries usually arise from the descending aorta and travel in the outer layers of the bronchi and bronchioles supplying the tissues of the airways down to the level of the respiratory bronchiole. Bronchial veins drain into radicles of the pulmonary vein. They thus contribute a small amount of desaturated blood which accounts for part of the 'physiological shunt' observed in normal individuals. The bronchial arteries may be much enlarged in some diseases (e.g. severe bronchiectasis, pulmonary fibrosis).

Structure of the airways

Trachea

The trachea has cartilaginous horseshoe-shaped 'rings' supporting anterior and lateral walls. The posterior wall is flaccid and during coughing, when intrathoracic pressure is raised and the glottis opens, this soft posterior segment billows forwards reducing the lumen of the trachea to a U-shaped slit. This results in a high linear velocity of air-flow which produces a shearing effect which hastens the clearance of any excess of secretions. The trachea is lined with ciliated epithelium which contains goblet cells.

Bronchi

The bronchi have irregular plates of cartilage in their walls. Smooth muscle is arranged in spiral fashion internal to the cartilaginous plates and attached to them. The muscle coat becomes more complete distally as the cartilaginous plates become more fragmentary.

The epithelial lining is ciliated and includes goblet cells which become less numerous peripherally. Larger bronchi also have acinar mucus-secreting glands in the sub-mucosa. Hypertrophy of these glands is one of the more striking features of chronic bronchitis.

Bronchioles

The bronchioles have no cartilage in their walls. The muscular layer becomes progressively thinner peripherally but some strands of smooth muscle persist to the level of respiratory bronchioles and possibly beyond. The epithelium is made up of a single layer of ciliated cells with only very occasional goblet cells. A granulated cell known as the Clara cell appears in the wall of distal bronchioles and this cell is suspected of possessing secretory properties. It may contribute mucus to alveolar fluid making up the foundation of the mucous blanket which is propelled upwards by ciliary action.

Ciliated epithelium

Ciliated epithelial cells possess about 200 cilia each 3 to 6 μ in length. Cilia beat with a whip-like action very rapidly (the beat frequency is probably of the order of 1,000 per minute). Organised waves of contraction pass regularly from cell to cell. The cilia beat in a layer of thin fluid beneath a more viscous layer of mucus. The mucous sheet is about 5 μ thick and carries a load of macrophages, cellular debris, inhaled particles etc. In the trachea the mucous sheet moves upwards at about 1·5 cm per minute. Ciliary action is impaired by drying of the secretions, increase in thickness of the mucous sheet and by inhaled noxious agents such as cigarette smoke.

Alveolar structure

Alveoli are about 0·1 to 0·2 mm in diameter and take up a variety of shapes depending on the arrangement of adjacent alveoli. The structure of the alveolar wall is represented diagrammatically in Fig. 1.4. The capillaries are completely lined by flattened endothelial cells resting on a complete basement membrane. The alveoli are completely lined by a layer of alveolar cells which are of two types.

Type I pneumocyte

These cells have extensive flattened processes which extend to cover most of the internal surface of the alveoli. Only the nuclei of these cells are evident on light microscopy.

Type II pneumocyte

These cells are less numerous and more globular than the type I pneumocytes. Electron microscopy reveals that these cells contain bodies with a concentric lamellated structure. There is evidence which suggests that these

bodies are concerned with the manufacture or storage of surfactant (p. 27).

Alveoli contain phagocytic macrophages (p. 214).

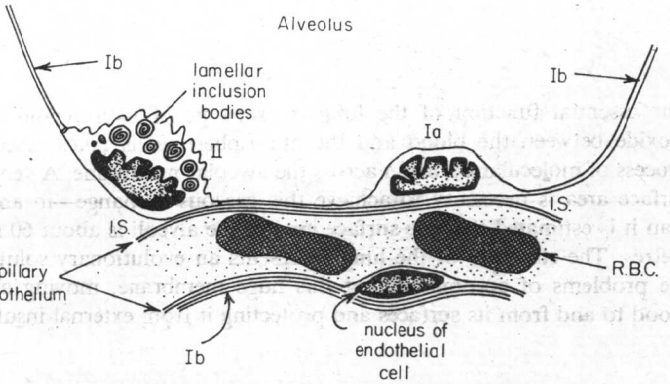


Fig. 1.4. Diagram of structure of alveolar wall as revealed by electron microscopy. Ia Type I pneumocyte; Ib Flattened extension of Type I pneumocyte covering most of the internal surface of the alveolus. II Type II pneumocyte with lamellar inclusion bodies which are probably the site of surfactant formation. I.S. Interstitial space. R.B.C. Red blood corpuscle. Pneumocytes and endothelial cells rest upon thin continuous basement membranes which are not shown.

Interstitial space

There is a potential space between the alveolar cells and the capillary basement membrane which is only apparent in disease states. It is continuous with the interstitial space surrounding bronchi and blood vessels.

Lymphatic vessels

Lymphatic channels are present in the interstitial space. They accompany the bronchial tree at least as far as the level of the respiratory bronchioles and supply the walls of the airway as well as the pulmonary interstitium. Lymphatics are also found in the interlobular septa and are abundant beneath the pleural surface. Drainage of lymph is towards the intrapulmonary lymph nodes adjacent to the proximal bronchi and thereafter to the mediastinal lymph nodes.

CHAPTER 2 · REVIEW OF RESPIRATORY PHYSIOLOGY

The essential function of the lung is exchange of oxygen and carbon dioxide between the blood and the atmosphere. This takes place by a process of molecular diffusion across the alveolar membrane. A very large surface area is necessary to achieve this gaseous exchange—in an adult man it is estimated that the surface area of the alveoli is about 60 square metres. The structure of the lung represents an evolutionary solution to the problems of accommodating this huge membrane, moving air and blood to and from its surfaces and protecting it from external insults.

MECHANICAL CONSIDERATIONS

Breathing

Inspiration is brought about by descent of the diaphragm and movement of the ribs upwards and outwards under the influence of the external intercostal muscles. Expiration is the consequence of gradually lessening contraction of the intercostal muscles allowing the lungs to collapse under the influence of their own elastic forces. This pattern of breathing—active inspiratory muscle contraction and passive expiration—is that normally encountered in quiet breathing at rest but other mechanisms are involved in other breathing patterns. In particular abdominal muscle contraction is brought into play during very rapid breathing and in breathing out to a position of full expiration (residual volume).

Lung compliance

The inherent elastic property of the lungs causes them to tend to retract from the chest wall causing a negative intrapleural pressure. The strength of the retractive force is related to the degree of stretching of the lung tissue—that is to lung volume. At high lung volumes the intrapleural pressure is more negative than at low lung volumes. The term lung compliance refers to the relationship between this retractive force and lung volume. Lung compliance is expressed as the change in lung volume brought about by unit change in transpulmonary (intrapleural) pressure and the units employed are litres per cm of water. Fig. 2.1 shows intra-

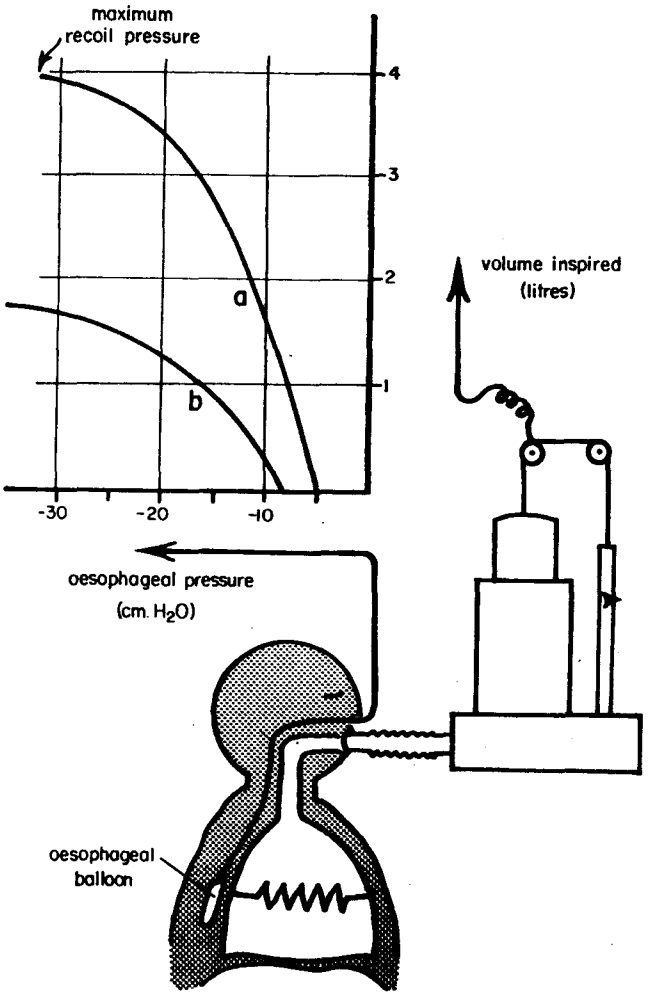


Fig. 2.1. *Lung compliance.* Oesophageal pressure is noted at a number of different volumes (each held momentarily with glottis open). The relationship between transpulmonary pressure and volume of air inspired is plotted for 2 individuals a and b. Lung compliance is an expression of the change in lung volume which accompanied unit change in transpulmonary pressure. In the case of a, lung compliance is normal (= 0·25 l/cm H_2O approx.). In the case of b, a smaller change in volume accompanies each unit change in pressure and compliance is low (= 0·1 l/cm H_2O approx.). Note that lung compliance becomes progressively less as lung volume increases.

pleural pressure at varying lung volumes. The slope of the line represents lung compliance. It will be seen that compliance becomes less at high lung volumes (i.e. smaller volume changes follow changes in pressure at high lung volume).

The retractive forces of the lung are balanced by the semi-rigid elastic structure of the thoracic cage and the action of the respiratory muscles. At the end of a quiet expiration the retractive force exerted by the lungs is nicely balanced by the tendency of the chest wall to spring outwards and the respiratory muscles are at rest.

Airways resistance

During breathing bigger changes in intrapleural pressure are observed than would be explained by lung retractive forces alone and this is because of the resistance to airflow offered by the respiratory passages (Fig. 2.2).

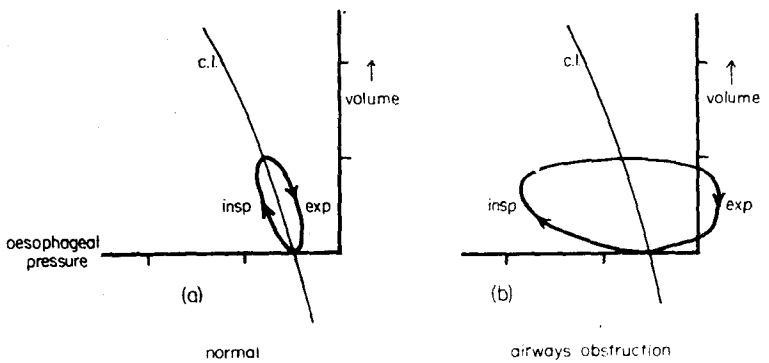


Fig. 2.2. Changes in intrapleural (oesophageal) pressure during quiet breathing. (a) in a normal individual. During inspiration the pressure is more negative and during expiration more positive than would be expected from consideration of lung compliance. c.l.: compliance line. The excessive pressure change is that required to overcome the resistance of the airways. (b) an individual with airways obstruction. Here the pressure changes are even more marked. During expiration oesophageal pressure is actually above atmospheric indicating compression of the lungs by expiratory musculature.

The additional pressure change depends upon the calibre of the airways and also upon the rate of airflow. The greater part of the total airways resistance is situated in the large airways—main bronchi, trachea and larynx—but in disease the increase in resistance generally involves the much smaller distal airways. The airways behave differently during inspiration and expiration. During inspiration pulmonary elastic recoil causes the

airways to open. During expiration the pull on the walls of the airways diminishes so that there is an increasing tendency towards closure of the airways.

The flow-limiting mechanism

Consider the model of the lung described in Fig. 2.3. During expiration the resistance of the distal airway (Res) will cause a drop in pressure between a and b so that the floppy segment will tend to collapse. It will be protected

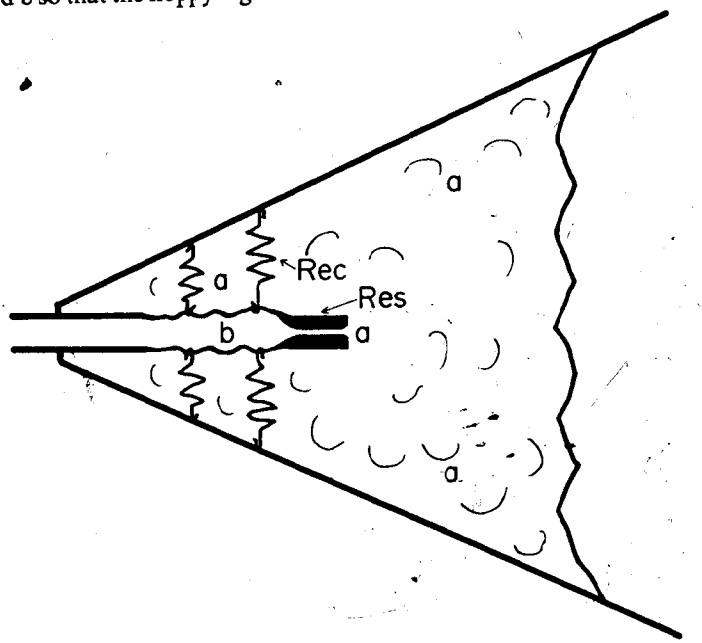


Fig. 2.3. Diagram of a model of the lung to demonstrate the flow-limiting mechanism (see text). The chest is represented as a bellows. The airways of the lungs are represented collectively as having a distal resistive segment (Res) and a more proximal collapsible or 'floppy' segment. The walls of the floppy segment are kept apart by the retractive force of lung recoil (Rec).

from collapse by the retractive force of the surrounding lung parenchyma (Rec). The extent of the pressure drop from a to b is proportional to the rate of air-flow. There will be a critical rate of air-flow which results in b being so much lower than a that the retractive force of the lung is overcome and the floppy segment closes. The closure limits the air-flow leading to less dramatic pressure drop from a to b which permits some re-opening of the floppy segment. It will be apparent that the system will control the

maximum rate of air-flow to a level determined by lung recoil (assuming that the resistance of the upstream segment (Res) remains constant). Lung recoil depends upon how stretched the lungs are and it should now be clear why high expiratory flow rates are obtainable at high lung volumes, but as lung volume decreases during expiration the maximum flow rate becomes progressively less and less. For each lung volume there is a particular maximum flow rate which cannot be exceeded no matter how great the expiratory effort.

The shape of the forced expiratory spirogram (Fig. 6.4) is thus determined by inherent mechanical properties of the lung and is to a large extent independent of effort above a certain level. This explains its very remarkable reproducibility.

When airways resistance is increased in disease a much greater pressure-drop occurs between a and b so that the supporting effect of recoil pressure (Rec) tends to be overcome at more modest rates of expiratory air-flow than in the normal. In this situation there is obvious advantage in breathing at a high lung volume which results in a greater lung recoil (Rec).

Where does the air go?

During an inspiration the distribution of air within the lungs is uneven because the compliance of different parts of the lungs is not uniform and because the resistance of the airways is also uneven. One of the most obvious causes of the uneven distribution of lung compliance is the effect of gravity. The weight of the lungs causes the upper parts to be kept under a greater stretch than the more dependent zones and the upper parts are thus less compliant. During inspiration more air tends to pass into the lower zones. The uppermost parts of the lungs may be regarded as already almost fully stretched and thus less 'receptive'. The analogy of a suspended spring may help to make the effect of gravity clearer (Fig. 2.4). The greater ventilation of the lower zones during quiet breathing is not inappropriate because gravity also directs pulmonary blood flow preferentially to the lower zones.

Unevenness of ventilation is also present within the lungs on a more miniature scale—adjacent lobules and even adjacent alveoli may have different compliances and, in response to a change of intrapleural pressure, may accept more or less air than expected. Local differences of airways resistance will also cause some unevenness in the distribution of inspired air. The effect of an increase in airways resistance is to reduce the rate of air-flow produced by a given change in intrapleural pressure—that is to delay filling of the lung or part of the lung. During extremely slow breathing the effect of increased airways resistance will be very small and air will pass into the most receptive (most compliant) parts of the lungs. But when breathing is more rapid, local increase in airways resistance will