Mechanics of mammalian lung

The mammalian lung consists essentially of two functional components; alveoli which provide a large (70 - 80 M^2 in man) surface area for exchange of O_2 and CO_2 between gas and blood, and a system of conducting airways through which the alveolar spaces are ventilated. Airways branch from the single trachea by asymmetrical dichotomy, to yield some 30,000 terminal bronchioles of 0.6 mm diameter. Because of asymmetry, the number of divisions (generations) varies from 7 to 29, and the distance from 7 to 22 cm from the carina. The terminal bronchiole is the last purely conducting airway and gives rise to three generations of respiratory bronchioles on which alveoli appear in increasing numbers. Finally, one or more wholly alveolated alveolar ducts arises and completes the airway system.

The structure of the airways also varies with size, the large bronchi being supported by complete rings of cartilage. These rings become incomplete in smaller bronchi and cartilage is lacking in the bronchioles where the wall consists of fibrous and elastic tissue and smooth muscle. The last smooth muscle is encountered in the alveolar ducts and distally, support is provided solely by collagen and elastic fibres and by the very thin epithelial and endothelial cells lining alveoli and blood capillaries. Alveoli and the smaller airways are lined and wetted by a mucoprotein layer, the surface tension of which, because of the small radii of curvature involved and the large liquid-air interface, contributes significantly to the overall mechanical properties of the lung.

There are some 300 million (3.0×10^8) alveoli with an average diameter of 0.25 mm, and these constitute the vast bulk of the total 5 to 7 litre volume of the lung, the conducting airways contributing a mere 150 ml or so. Thus, the lung's mechanical properties are governed to a large extent by the mechanical properties of the alveolar wall and lining, though the support which may be offered by the more rigid airways cannot be ignored.

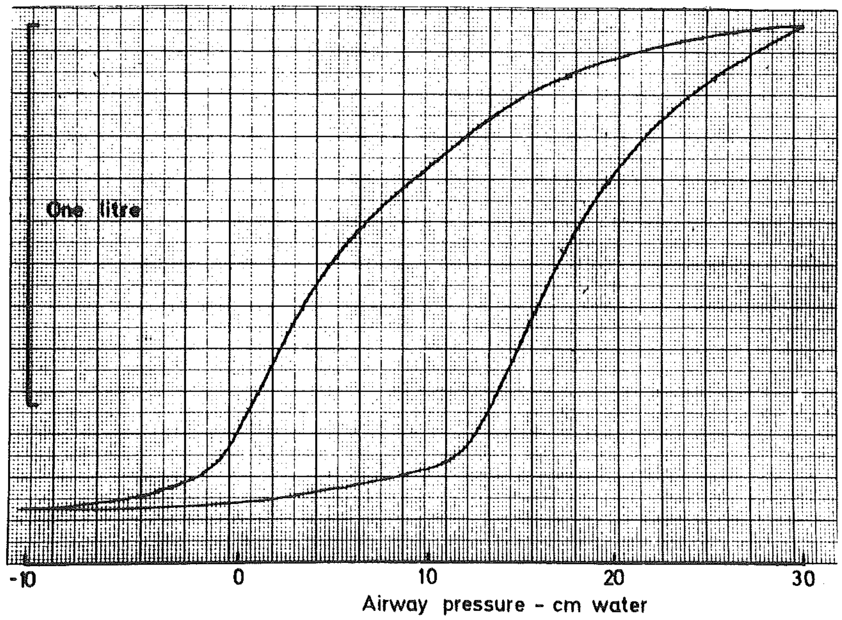

Fig. 1. Pressure-volume curve for isolated dog lung slowly inflated (lower curve) and deflated (upper curve) over a pressure range of -10 to +30 cm water.

When a lung is removed from the thorax it collapses to a minimal volume - about 20% of its maximum volume in life. This minimal volume is determined by closure of small airways, probably at bronchiolar level, and attempts to reduce lung volume further by suction merely increase the extent of airway closure. If the lung is then connected to a pump and inflated slowly (quasi-statically), the airway pressure first rises steeply until airways open, then the pressure rises more gradually as alveoli expand, and finally the pressure again rises more steeply as total lung capacity (TLC) is approached. (Fig. 1). TLC is obtained at about 30 cm water. The latter part of the inflation pressure-volume curve is an exponential function. In slow deflation from TLC, the pressure-volume curve again follows an exponential form (though with different constants) until, near zero airway pressure, the curve breaks away and the volume levels off at the lung's minimal volume. The pressure-volume curve for the whole lung thus shows marked hysteresis; that is, mid-range volumes are obtained at considerably greater airway pressures during inflation than during deflation.

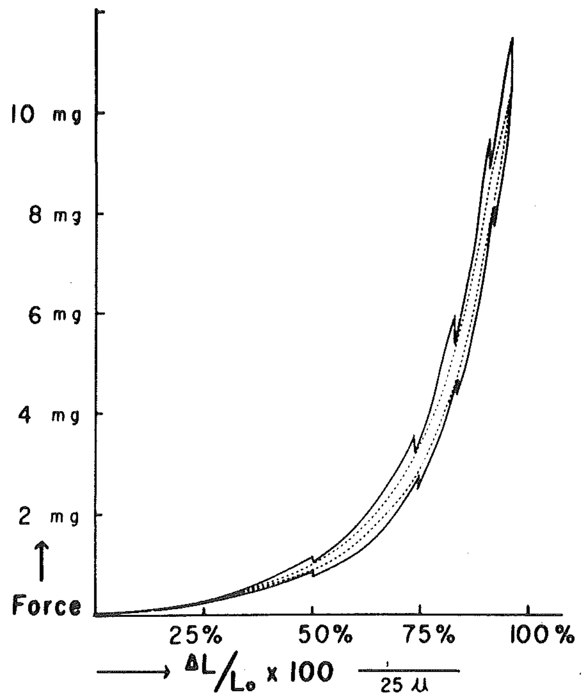

Fig. 2. Length-tension characteristics of cat alveolar wall, with 60 sec pauses to allow stress relaxation and recovery, though some hysteresis remains. (From Fukaya).

The chief components of the lung have been studied separately. Alveolar wall, when stretched in saline to eliminate surface tension effects, has a length-tension curve which approximates to the latter part of the lung's inflation curve. However, both stress relaxation and hysteresis are seen, though their magnitudes are small (Fig. 2). Surface active extracts obtained from lungs (and presumably representative of the alveolar lining) exhibit profound changes in surface tension when the areas of films are changed by more than 50%. Thus, as the area decreases below 50%, the tension falls to a lower limit of 10 to 15 d/cm, but returns to an upper limit of 40 to 50 d/cm upon re-expansion. Hysteresis is, therefore, very pronounced (Fig. 3). Summation of these two components can account