ELASTIC TISSUE OF NORMAL AND EMPHYSEMATOUS LUNGS

A Tridimensional Histologic Study

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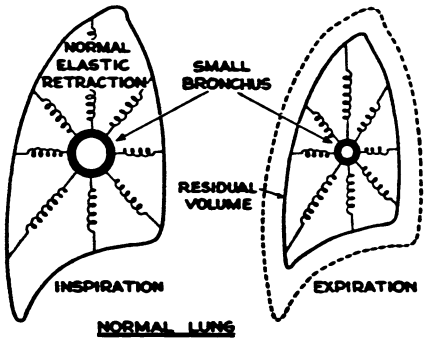
The elastic properties of the lung are of major importance in pulmonary ventilation. The lung is normally in a state of inflation and stretch within the thorax, and because of the elastic character of the lung tissue, this stretch tension is maintained during ventilatory inflation and deflation of the lung. Thus a radial type traction on the walls of the small airways and alveoli is continuously provided to maintain their patency (Text-fig. 1). The elastic character of the lung and the ability of the opposing pleural surfaces to slide one upon the other during breathing result in continuous adjustments and uniform distribution of these intrapulmonary stretch tensions. This uniform tension probably helps to distribute the inspired air evenly throughout the lung.



Text-figure 1. Diagram showing the contributory role of the radial traction forces of the lung parenchyma in maintaining the patency of the medium and smaller airways (including the bronchioles).[8]

It seems likely that the elastic characteristics of the lung are in large part provided by the elaborate framework of elastic fibers. These fibers unite the bronchi, alveoli, vessels, interlobular septums and pleura into an elastic continuum. Each of these structures possesses a rich supply of

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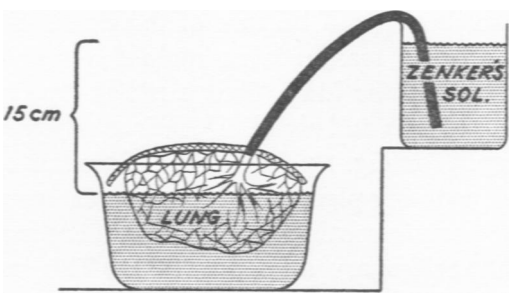
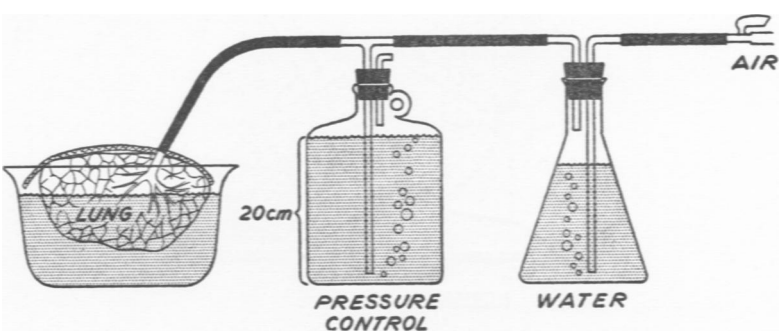
elastic fibers which branch and intermesh as previously described by Orsós,[1,2] and recently restated by Krahl.[3] Orsós also showed that pathologic alterations of this elastic framework occurred in emphysematous lungs. The purpose of this study was to describe the morphology of the elastic tissue of the normal and emphysematous lung with the use of a new tridimensional microscopic technique.

Material and Methods

Pulmonary tissue was obtained from necropsy and surgical material and consisted of 24 normal lungs from individuals aged 8 to 93 years, and 11 lungs with morphologically apparent emphysema from individuals aged 29 to 73 years.



Text-figure 2. Diagram demonstrating the method of infiltrating the lung with Zenker's solution.



Text-figure 3. Diagram demonstrating the method of replacing excess Zenker's solution by air without drying the specimen.

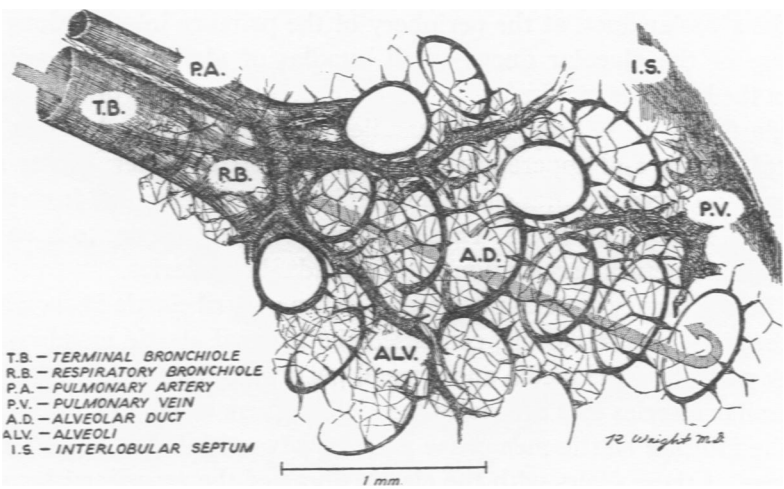
This tissue was studied in the following manner: An intact lobe was selected and filled through the bronchus with Zenker's solution at 15 cm. of water pressure and maintained in this distended state, partially submerged in Zenker's solution for approximately 2 hours (Text-fig. 2). The bronchus was then connected to a source of compressed air which was saturated with water and maintained at a pressure of 20 cm. of water (Text-fig. 3). Moistened gauze was placed over the partially submerged lung, and air leaks in the specimen were avoided to prevent the drying which occurs if air is allowed to flow through the specimen. The air was forced into the lung for approximately 12 hours, permitting the excess Zenker's solution to be replaced by air. At the end of this period the lung was well fixed, fully and uniformly

inflated, and rigid enough for tridimensional histologic preparations. The tissue remained wet enough to produce excellent microscopic detail with conventional histologic stains. Blocks of lung tissue 2 to 3 cm. wide and 3 to 4 mm. thick were then cut from selected areas of the lobe with a razor blade and washed in distilled water for 12 hours. Frozen sections 200 to 300 μ thick were prepared freehand with a stiff razor blade. The standard freezing microtome blade was unsatisfactory since it produced tears and distortions of the delicate elastic fibers when the blade passed directly through the tissues rather than slicing them like the manually operated razor blade.

The sections were then treated with Lugol's iodine solution, alcohol and distilled water to remove the Zenker solution; stained with orcein elastic and Gomori's trichrome connective tissue stains; and mounted in Permount on glass slides with a ring of plastic cement around the margin to support the cover slip and prevent crushing of the tissue.

The slides were viewed with the standard light microscope by which low power magnification provided 3-dimensional viewing for orientation, and high power magnification proved excellent for studying fine detail. Constant focusing was necessary at high magnification because of the short depth of focus.

The best results were obtained when the lung specimens were fixed within 6 hours post mortem.



TEXT-FIGURE 4. Drawing of the elastic tissue of the normal adult lung lobule, demonstrating the exchange of fibers composing an "elastic continuum."

OBSERVATIONS

Normal Lungs

The elastic fibers provided the major supporting framework of the primary lobule of the lung which includes the terminal bronchiole, respiratory bronchioles, alveolar ducts and alveoli (Text-fig. 4 and Figs. 1 to 4). The elastic fibers were also an important constituent of the larger pulmonary structures such as bronchi, vessels, interlobular septums and pleura. The majority of the elastic fibers in a large bronchus were longitudinally arranged in a layer within the submucosa. Occasional

small, delicate elastic fibers were arranged circumferentially and intermeshed with the thick longitudinal fibers. This arrangement extended to the respiratory bronchiole where the longitudinal fibers divided into poorly defined bundles. The circular fibers were abundant in the bronchioles and formed bundles which interlaced with the longitudinal bundles. Rudimentary alveoli, supported by a few fine elastic fibers, appeared between these crossing elastic bundles. The longitudinal and circular bundles became progressively better defined and more compact, and the alveoli became larger and better developed toward the end of the respiratory bronchiole.

Distal to the respiratory bronchiole, the dense bundles of elastic fibers ceased to crisscross and instead assumed circular and helical configurations with prominent decussations showing an exchange of fibers at points of contact between the bundles. The passageways defined by these bundles of elastic tissue were the alveolar ducts. The fibers in the bundles decreased in number and appeared less dense toward the end of the alveolar duct, at the periphery of the primary lobule. Along the course of the alveolar ducts, small bundles of elastic fibers radiated from the large coarse bundles to form the circular ostiums of the alveoli. Single fibers arose from these smaller bundles, branched across the alveolar walls and apparently helped to support the interalveolar septums. Fine, irregular branches extended into the alveolar wall from these main alveolar elastic fibers. These tiny fibers did not appear to have any intimate structural association with individual capillaries.

The pulmonary arteries possessed a rich supply of elastic fibers which, in the large elastic vessels, composed the internal elastic membrane, a large portion of the media and a small portion of the adventitia. In the muscular arteries and arterioles the elastic fibers were confined mostly to the internal elastic membrane and the adventitia. There was an exchange of these fibers with the elastic fibers of the associated bronchi, adjacent alveoli, interlobular septums and pleura. Thus an elaborate, continuous supporting framework of elastic fibers was formed which united the various pulmonary structures into an elastic unit.

Lungs of individuals in the older age groups frequently showed alterations in the elastic tissue which were considered to be associated with aging (Figs. 5 and 6). These alterations were occasionally seen in individuals over 50 years of age, but were more common in those over 80. The alterations in elastic fibers were confined to the small respiratory structures of the lung tissue, i.e., the alveolar ducts and alveoli. A generalized and uniform reduction in the number and thickness of the elastic fibers was observed. These changes were most apparent in the bundles of elastic fibers forming the alveolar ducts and the mouths of the alveoli.

The ducts and alveolar openings were slightly dilated apparently as a result of this atrophy and attenuation of elastic fibers.

Focal deposits of anthracotic material in the lung, with varying degrees of associated centrilobular emphysema, were a common finding in adult age groups (Figs. 7 and 8). The deposits of granular black pigment were most concentrated in the walls of the respiratory bronchioles, in the alveolar ducts and along the courses of vessels. Within and about the anthracotic sites the elastic tissue commonly exhibited degenerative alterations consisting of separation, fragmentation or complete absence of fibers. A slight degree of fibrosis was often associated with these degenerative changes, and frequently there was dilatation and distortion of the affected respiratory bronchioles and the adjoining proximal ends of the alveolar ducts.

Chronic Obstructive Emphysema

This disease did not affect the lung in a uniform manner; various regions of the lung were severely involved while other areas remained nearly normal even in the advanced stages of the disease. The areas of nearly normal lung exhibited only minor pathologic alterations of elastic fibers while the areas of advanced disease demonstrated striking degeneration of the elastic fibers (Figs. 9 to 12). In areas of slight to moderate morphologic emphysema, characterized by overdistended and distorted small air passages and alveoli, the elastic tissue showed focal defects varying from attenuation of the fibers to complete separation, with retraction of the unattached ends of the fibers. The heavy elastic bundles of the alveolar ducts were occasionally interrupted by separation and retraction of the free ends of the damaged fibers. Fenestration of alveolar walls, loss of capillaries and slight increases in fibrous tissue nearly always coexisted with the defective elastic tissue. The distortion and dissolution of tissue, i.e, partial to total absence of interalveolar walls, resulted in a loss of distinction between the various air passages and alveoli. In the advanced stages of the disorder, alveoli were replaced by large confluent air spaces which were separated and crossed only by strands and thin sheets of fibrous tissue possessing a few vessels, capillaries, numerous pigmented macrophages and multiple various-sized fenestrations. These connective tissue partitions and strands, remnants of the destroyed walls of alveoli, small air passages and vessels, frequently composed the walls of bullae and contained either no stainable elastic fibers or fragments of damaged ones. The damaged fibers were frayed, attenuated and often clumped into small, dense masses lying within the thickened fibrous tissue partitions. No evidence of regeneration of elastic tissue was observed. Minor degrees of focal emphysema

associated with deposits of granular, black, anthracotic pigment, occasionally noted in the normal lung, frequently coexisted with diffuse emphysema. Occasionally the two types of emphysema were so completely intermingled that they could not be separately distinguished; however, the diffuse type appeared to predominate in all cases. The elastic continuum which composed the structural framework of the lung unit always showed a degree of destruction consistent with the severity of the emphysema.

Discussion

The normal lung possesses an elaborate elastic supporting framework which appears to be responsible in part for the elastic behavior of the lung. The role of the surface tension [4] of the layer of fluid covering the surface of all air-containing structures of the lung could not be evaluated in this study. The elastic properties are essential to normal lung function since radial traction on the walls of the small airways and alveoli is necessary to maintain their patency during the inflation and deflation phases of ventilation. This can be accomplished only by an elastic type of tension which can provide continuous radial traction on the walls of these tiny air-conducting passages despite partial deflation of the lung during exhalation.

Chronic obstructive emphysema is characterized by a number of functional derangements which imply that alterations in the elastic properties of the lung have occurred. The most significant functional abnormalities are: (a) expiratory air flow obstruction; (b) increased residual volume; (c) reduced negative pressure in the intrapleural space; and (d) uneven distribution of inspired air. The expiratory obstruction is due to reduced elastic radial traction on the walls of the small bronchi and bronchioles [5–7] and to atrophy, weakening, and increased collapsibility of the medium and large bronchi in the advanced stages of the disease.[8] The reduced elastic tension in the emphysematous lung allows collapse of the small bronchi and bronchioles during the expiratory phase of ventilation, resulting in obstruction to air flow. This occurs because pressure relationships across the bronchial wall tend to cause their collapse when air is exhaled, particularly during a forced exhalation. Toward the end of the exhalation the partially deflated emphysematous lung fails to provide adequate radial traction on the walls of the small airways, and obstruction with "air trapping" occurs. The increased residual volume also results from a loss of pulmonary elasticity and a premature collapse of the airways during maximum exhalation. The reduced intrapleural negative pressure at maximum inspiration reflects a

reduction in the elastic recoil of the emphysematous lung.[9] The irregular distribution of the destructive changes in the emphysematous lung results in a non-uniform elastic behavior which probably is partly responsible for the uneven distribution of the inspired air. Obstructions to air flow in bronchi, due to collapse and accumulation of secretions, also contribute to this uneven distribution.

The thick (200 to 300 μ) lung sections stained with orcein and Gomori's trichrome stain offered a unique opportunity to observe the elastic fibers in the normal and emphysematous lung. The observations were in agreement with previous studies of the structure of normal pulmonary elastic tissue,[1,2,10–13] with the exception of Orsós' statement that fine elastic fibers in the alveolar wall form a supporting network about the capillary walls. Such an elastic fiber network was not observed in our material. The Weigert elastic stain used by Orsós is not specific for elastic fibers and probably stained the reticulum of the capillary network.

The alteration in elastic tissue commonly noted in the normal lungs of aged individuals was a diffuse uniform atrophy distinct from the non-uniform destructive changes observed in emphysema. Others describing the gross appearance of the aged lung have noted the uniformly dilated alveolar ducts.[14,15] Occasionally the two conditions coexisted in the lungs of aged individuals with emphysema.

The degree of elastic tissue destruction in the emphysematous lungs corresponded to the severity of the disorder as indicated by the macroscopic appearance. The disease process involved alveolar walls, capillaries and alveolar septal cells as well as elastic tissue. Slight degrees of fibrosis and chronic inflammatory cell infiltration were occasionally observed, but the process appeared to consist primarily of disintegration and dissolution of tissue rather than inflammation. The disease did not appear to destroy elastic tissue selectively but seemed to be a degenerative process affecting various tissue components of the lung, including capillaries, interalveolar septums and bronchi.

Deposits of anthracotic pigment were associated with small focal areas of emphysema in many of the normal and emphysematous lungs. This morphologic form of emphysema (centrilobular) has been observed to exist in advanced stages.[16–18] In this study it appeared only in minor degrees in otherwise normal lungs and as a coexisting process with the predominantly diffuse type of emphysema. There was a definite spatial relationship between the focal anthracotic deposits and elastic fiber destruction, which may indicate an etiologic relationship. Further clarification of this relationship was not possible in this study.

Emphysematous bullae appeared to result from severe localized destructive changes in the lung tissue. Their walls contained degenerating

fragments of elastic tissue and other remnants of structures replaced by the bullae. The destructive process did not appear to differ in any manner from that of the diffuse disorder.

Summary

Elastic tissue in thick sections of lung was examined microscopically in 3 dimensions. The structure of elastic tissue was observed in normal and emphysematous lung specimens. The normal lung revealed an abundance of prominent elastic fibers arranged in such a manner that the various components of the lung were united into an elastic continuum. Aged lungs showed some atrophy of the fibers. Some adult lungs revealed degenerative changes in the elastic fibers at the sites of accumulations of anthracotic material, and these changes were commonly associated with localized dilatation and distortion of the involved structures. Severe degenerative alterations in the elastic tissues were found in chronic obstructive emphysema. Destructive alterations also involved the alveolar walls, capillaries and alveolar septal cells. The disease process of chronic obstructive emphysema appeared to be one of degeneration and destruction affecting various tissue components of the lung, particularly the elastic fibers.

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[*Illustrations follow*]

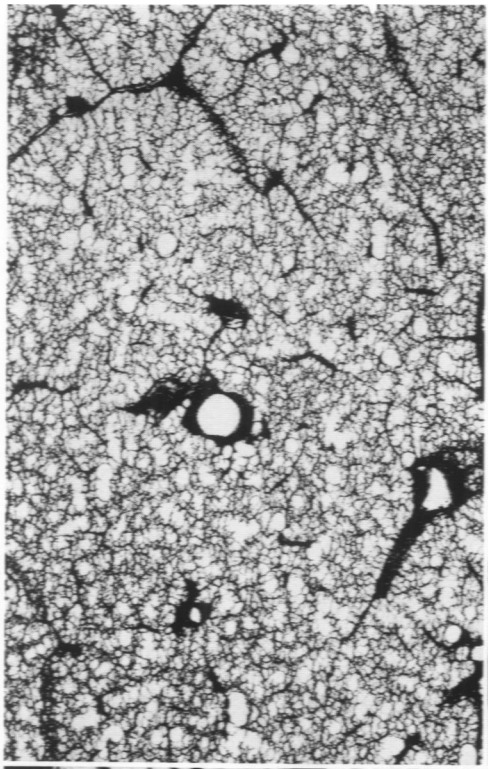
Legends for Figures

Fig. 1. Normal lung, 20-year-old man. Note the uniformity of size and shape of the alveoli and alveolar ducts. × 10.

Fig. 2. Normal lung, 37-year-old woman. A microscopic view of a tridimensional histologic preparation showing the elastic fibers forming a ring about an alveolar duct. Elastic fibers radiate peripherally into the walls of adjacent alveoli. The alveolar duct (A.D.) is at the left. Orcein elastic tissue stain. × 270.

Fig. 3. Normal lung, 53-year-old man. Note the sturdy, uninterrupted appearance of the elastic fibers of the alveolar wall. Combined orcein elastic tissue and Gomori trichrome stains. × 270.

Fig. 4. Normal lung, 67-year-old woman. The elastic fibers of an alveolar wall show fenestrations of the wall commonly referred to as "senile pores." Note the intact, thick, normal-appearing elastic fibers. Orcein elastic tissue stain. × 270.



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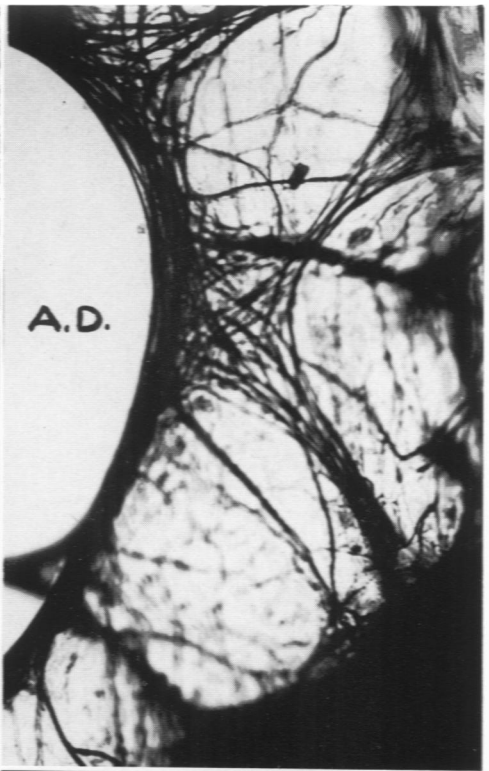

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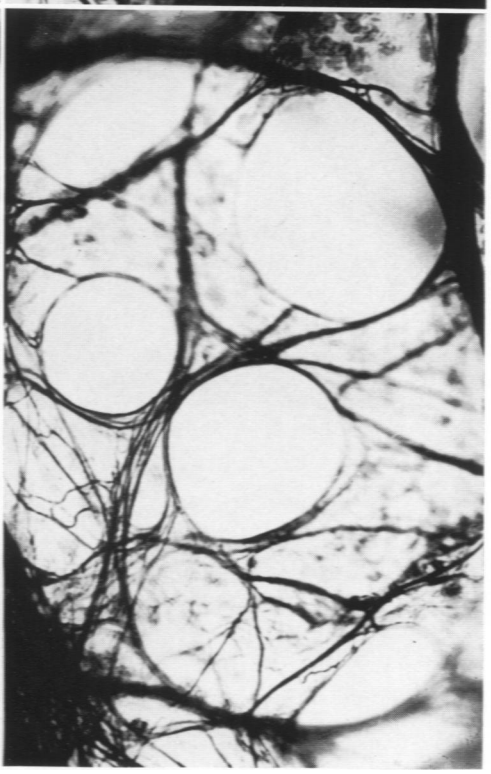

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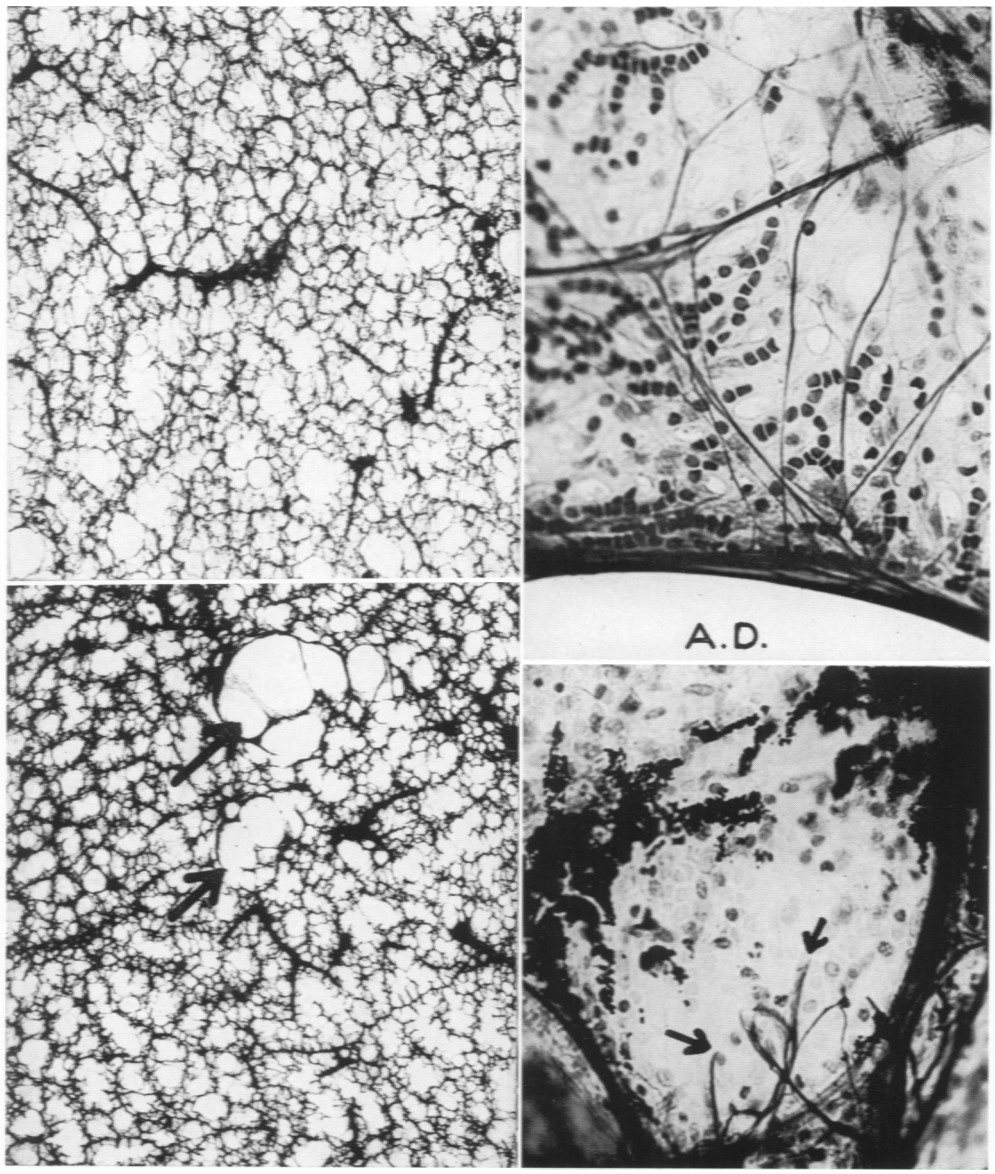
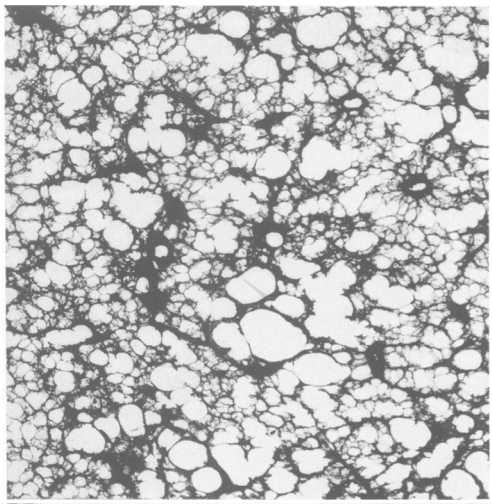


FIG. 5. Normal lung. 87-year-old man. Note the moderately uniform enlargement of the alveoli and alveolar ducts. × 10.

FIG. 6. Normal lung. 84-year-old woman. A tridimensional histologic preparation shows an attenuation and sparseness of elastic fibers in an alveolar duct (A.D.) ring and the adjacent alveolar wall. Combined orcein elastic tissue and Gomori trichrome stains. × 270.

FIG. 7. Normal lung, 63-year-old woman. Note the two focal areas of emphysematous degeneration (arrows) associated with anthracotic deposits. These changes are commonly seen in adults with otherwise normal lungs. × 10.

FIG. 8. Microscopic appearance of lung in Figure 7. There is interruption of elastic fibers in the region of anthracotic pigment deposit. Orcein elastic tissue stain. × 270.



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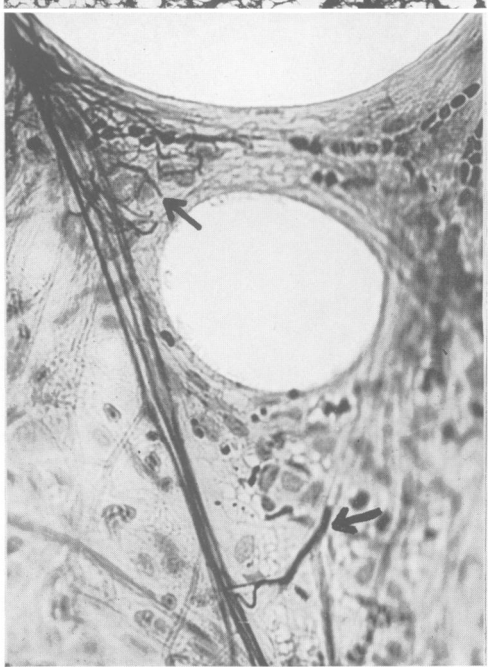

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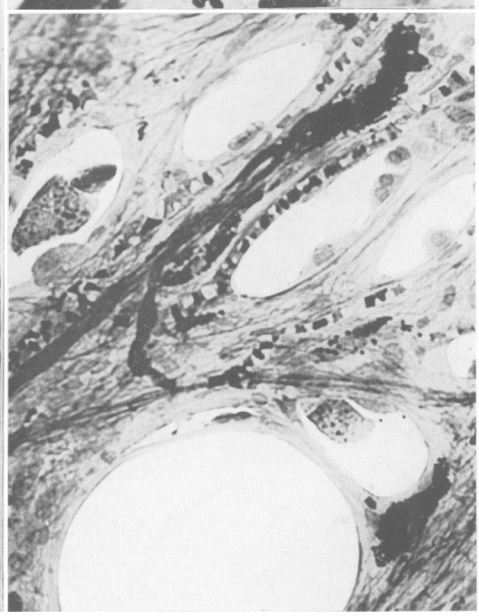

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FIG. 9. Chronic obstructive emphysema, 59-year-old man. Note the numerous enlarged air spaces formed by the loss of interalveolar septums and overdistention of alveolar ducts. × 10.

FIG. 10. Chronic obstructive emphysema, 64-year-old woman. Disrupted and disintegrated elastic fibers (arrow) are evident in an alveolar duct ring. Combined orcein elastic tissue and Gomori trichrome stains. × 270.

FIG. 11. Chronic obstructive emphysema, 67-year-old man. An alveolar wall shows a disintegration of the elastic fibers (arrows) and a large fenestration. Combined orcein elastic tissue and Gomori trichrome stains. × 270.

FIG. 12. Chronic obstructive emphysema, 57-year-old man. The wall of a bulla shows disintegration of elastic fibers, fenestrations, macrophages, and anthracotic pigment deposits. Combined orcein elastic tissue and Gomori trichrome stains. × 270.