Structural Basis for the Static Mechanical Properties of the Aortic Media

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The mechanical properties of the aortic wall have been investigated in several mammalian species. Measurements have been made on vessels in situ and on excised aortic segments and strips. In 1880, Roy, studying aortic segments from dog and rabbit, observed that the aortic wall does not obey Hooke's law; extensibility of the aorta is not proportional to stressing force. Subsequent studies revealed that the modulus of elasticity of the aortic wall is relatively small at distending pressures below normal mean aortic pressures but increases rapidly with increasing pressure. At and above physiological intraluminal pressures, the modulus is relatively high and remains almost constant as pressure rises. Aortic diameter changes little with intraluminal pressure variations between 100 and 200 mm Hg.

The aortic media contains elastin, collagen, smooth muscle cells, and a nonfibrous matrix. The dry weight is approximately 30% of the total weight; elastin and collagen account for 50% of the dry weight. Elimination of smooth muscle function by treatment of aortic segments with potassium thiocyanate does not alter the static mechanical properties of the media. These properties may therefore be attributed mainly to the elastin and collagen components.

The modulus of elasticity of collagen is approximately 400 times greater than that of elastin. It had been suggested that elastin is the main functional component at low and physiological pressures and that with increased dilatation adventitial collagen fibers are drawn taut preventing further distention and rupture. However, it was shown subsequently that the change in the modulus of elasticity of the aortic wall over a range of pressures from 0 to 200 mm Hg is much less than the difference in modulus between pure elastin and pure collagen; at a distending pressure of 100 mm Hg the elastic modulus of the thoracic aorta, which is relatively rich in elastin, is at least twice as large as that of elastin alone. It is therefore likely that both the elastin and collagen of the aortic wall are stressed over a wide range of distending pressures, particularly within the physiological range.

MacDonald and Bergel have speculated that with increasing intraluminal pressure and wall tension disarrayed medial collagen fibers become aligned and stressing forces are gradually transferred from elastin to collagen.

Light and electron microscopic studies of the aortic wall indicate that medial structural components are arranged in an orderly fashion; concentric fibrillar elastin lamellae are connected by an intricate network of elastin fibrils with interspersed collagen fibers and smooth muscle cells. Direct observation of the configuration and interrelation of these components at various distending pressures could provide anatomical data concerning the structural basis for the static mechanical properties of the aortic wall.

In the present investigation the architecture of the rabbit aortic media was studied by light and electron microscopy at various distending pressures. It will be shown that at physiological pressures the aortic media functions as a "two-phase" material; circumferentially aligned collagen fibers bear the tangential stressing
forces while the elastin net distributes the stressing forces uniformly throughout the wall.

**Methods**

New Zealand white rabbits three to six months of age and weighing 2700 to 3200 grams were used. The animals were kept one or two to a cage for approximately one month after arrival from the supplier,* fed standard rabbit food pellets,t and offered tap water ad libitum.

**PREPARATION OF AORTIC SEGMENTS**

Animals were anesthetized by intravenous injection of pentobarbital (Nembutal); in doses of 30 mg/kg of rabbit. A midline abdominal incision was made and the abdominal aorta exposed. The segment of the abdominal aorta from the origin of the renal arteries to the bifurcation was freed by gentle blunt dissection of surrounding areolar tissue. A stainless steel centimeter scale was placed beside the prepared aortic segment and a row of small dots made on the aorta at intervals of exactly 1.0 cm using a fine pointed pen and gentian violet solution. All aortic branches originating from the segment except the renal and the common iliac arteries were ligated 0.1 to 0.3 cm from their origin and cut. Two small hemostatic clamps were applied to the aorta just proximal to the bifurcation and two others just distal to the origin of the renal arteries. An aortic segment 5.0 to 6.0 cm in length was then excised by dividing the vessel between the proximal and the distal paired hemostats and transferred to physiological saline solution at 37°C.

**FIXATION OF DISTENDED AORTIC SEGMENTS**

A brass cannula was introduced into each end of the excised segment; the aorta was fastened securely by tying a ligature tightly over a circular groove near the end of each cannula. The segment was transferred to a special frame for fixation during distention. A diagram of the fixation apparatus is shown in figure 1. The distal cannula was adapted to a screw fitting at the bottom of the frame and the longer proximal cannula to

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† Ralston Purina Company: Rabbit Chow.
‡ Abbott Laboratories: Veterinary Nembutal, 60 mg/ml.

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a screw clamp at the top of the frame. The in vivo length of the aortic segment was restored by adjusting the proximal cannula so that the gentian violet markings matched 1.0 cm intervals of a scale etched on the frame. The markings were carefully aligned to avoid distortions of architecture due to twisting. The proximal cannula was then attached to a perfusion system consisting of a one-way rubber hand pressure bulb, an 18-liter air reservoir bottle, a manometer and a flask containing physiological saline solution or fixative (fig. 1). Flasks were changed with negligible loss of pressure because of the relatively large air reservoir; fine adjustments of pressure could be made with the hand bulb and its escape valve.

After flushing the aortic segment with physiological saline solution, the distal cannula was closed by means of a small screw clamp. The pressure in the system was adjusted to the desired level and a final check made of the length. The flask containing saline solution was then replaced by one containing 10% formalin and 1% CaCl₂ or 1% osmic acid buffered with collidine to pH 7.4. The screw clamp on the distal cannula was opened briefly to replace the saline solution in the segment with fixative and then closed; any necessary pressure adjustment was made immediately and the entire supporting frame immersed in a chamber containing fixative. No more than five minutes elapsed between removal of the segment from the rabbit and beginning of fixation.

Twenty-six aortic segments were fixed in formalin, 11 were fixed in osmic acid. All of the specimens were fixed for two hours. Intraluminal pressures were maintained at 5, 20, 40, 60, 80, 100, 120, 140, 160, 180, or 200 mm Hg during fixation with formalin and at 50, 100, and 150 mm Hg during fixation with osmic acid. Three segments were immersed in formalin without restoration of length or distention.

PREPARATION FOR MICROSCOPY

Fixed aortic segments were firm and did not retract upon removal from the frame. A razor blade was used to prepare transverse rings and longitudinal strips from portions of the wall which were free of branches.

Light Microscopy

Transverse rings, longitudinal strips, and small fragments oriented to permit transverse, longitudinal, and tangential sections were embedded in paraffin and sectioned at 6 microns. Sections were mounted carefully from a water bath maintained at 54°C to minimize wrinkles and folds. Adjacent sections were stained with hematoxylin and eosin, a modification of the Weigert and van Gieson methods for elastin and collagen and with iron-hematoxylin for smooth muscle cells.

Electron Microscopy

Osmium fixed material was embedded in epoxy or araldite and the blocks trimmed and reoriented so that transverse, longitudinal, and tangential sections could be cut on a Porter-Blum microtome (Servall). Sections were mounted on formvar coated copper grids. Uranyl acetate and phosphotungstic acid stains were used. Sections were studied and photographed in an RCA EMU-3d electron microscope.

MICROMETRIC DETERMINATIONS

Vessel diameters and wall thicknesses were measured on transverse sections of aortic rings using a micrometer eyepiece. Aortic diameter was taken as the mean of the diameters of the innermost and outermost elastin lamellae. Wall thick-
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Relation of rabbit aortic radius and wall thickness to distending pressure. The radii (curve a) and wall thicknesses (curve b) changed markedly as pressures increased from 5 to 80 mm Hg. Radius and wall thickness changed little above 80 mm Hg. Each point represents one aortic segment.

Results

RELATION OF AORTIC RADIUS AND WALL THICKNESS TO DISTENDING PRESSURE

Photomicrographs of representative cross sections of rabbit aortas fixed at various distending pressures are shown in figure 2. The differences in radius and wall thickness between vessels fixed with no intraluminal distending pressure and those fixed at 160 mm Hg were marked; the differences in radius and wall thickness between vessels fixed at 100 mm Hg and those fixed at 160 mm Hg were small. The wall was quite thin at and above intraluminal pressures of 100 mm Hg. Radius and wall thickness measurements were plotted against distending pressures; these graphs are shown in figure 3, curves a and b. Increase of radius and decrease of wall thickness were most marked as distending pressures increased from 5 to 80 mm Hg; from 80 to 200 mm Hg the curves were relatively flat. Tangential tension* at each distending pressure was plotted against the corresponding pressure; this graph is shown in figure 4. Tangential wall tensions increased at 60 mm Hg were marked; the differences in radius and wall thickness between vessels fixed at 100 mm Hg and those fixed at 160 mm Hg were small. The wall was quite thin at and above intraluminal pressures of 100 mm Hg. Radius and wall thickness measurements were plotted against distending pressures; these graphs are shown in figure 3, curves a and b. Increase of radius and decrease of wall thickness were most marked as distending pressures increased from 5 to 80 mm Hg; from 80 to 200 mm Hg the curves were relatively flat. Tangential tension* at each distending pressure was plotted against the corresponding pressure; this graph is shown in figure 4. Tangential wall tensions increased

* Joseph Mennen Company: Mile-O-Graph.

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*Tangential tension during distention-fixation was calculated using the expression for the law of Laplace as applied to cylindrical vessels. $T = \frac{P}{r}$, where $P$ is the intraluminal pressure in g/cm² or dynes/cm², $r$ is the radius of the vessel in cm and $T$ is the tangential tension in the wall g/cm or dynes/cm. It has been suggested that tension in vessel walls be expressed as force per unit wall thickness, $T = \frac{P}{d}$ where $d$ is the wall thickness in cm. $T$ is then the tension in g/cm² or dynes/cm².\(^\text{21}\)
with increasing intraluminal pressures while radius and wall thickness remained relatively constant above 80 mm Hg. These findings are in essential agreement with measurements made on individual canine and human vessels at various distending pressures by Bramwell et al., Remington, Burton, and Patel et al. The relation of tension to wall thickness is shown in figure 5A. Wall thickness decreased markedly at low tensions and remained relatively constant at high tensions; there was a prominent inflection corresponding to a tension between 10 and 20 g/cm (9,800 to 19,600 dynes/cm). The graph relating circumference to total tension was also sharply inflected (fig. 5B) at a tension of about 20 g/cm. This “tension-length” curve, reflecting the changing modulus of elasticity of the aortic wall, has been called an “elastic diagram”; the curve based on measurements of many rabbit aortas fixed at different pressures, is similar to that drawn by Roach and Burton from data on a single human external iliac artery segment measured over a range of pressures.

APPEARANCE OF MEDIAL ELASTIN AT VARIOUS DISTENDING PRESSURES

Aortas Fixed Without Extension to in vivo Length and Without Distention

Elastin appeared as a series of 11 to 15 approximately concentric, relatively thick fibrillar lamellae and abundant interlamellar fine fibrils. Lamellae were of approximately the same thickness throughout the wall; the density of fine fibrils was uniform throughout the wall. The thick lamellae were folded and waved on both longitudinal and transverse sections and resembled those seen in sections of aortas presented in standard textbooks of histology. Interruptions in lamellae were numerous; many ended abruptly and could not be traced as complete circles on transverse sections of complete aortic rings. Interlamellar fine elastin fibrils were most easily seen on tangential sections. These were attached to the thick lamellae and many could be traced from one thick lamella to an adjacent thick lamella. Although small groups of parallel interlamellar elastin fibrils were seen, no consistent overall pattern of orientation was evident.

Aortas Extended to in vivo Length Without Distention

With extension of the aortic segment to in vivo length elastin lamellae were almost completely straightened on longitudinal sections but remained folded and wavy on transverse sections. Interlamellar distances markedly decreased throughout the wall so that the wall thickness diminished to approxi-
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The rate of straightening at low pressures and the abruptness of the transition to complete straightening was well shown when the "waviness index" of thick lamellae was plotted against distending pressure (fig. 8). At distending pressure of 40 mm Hg waviness of lamellae was considerable; at and above 80 mm Hg all elastin lamellae were straight. (At 60 mm Hg all but the innermost lamella were straight. Although the internal elastic lamina straightened progressively with increasing intraluminal pressure along with the other elastin lamellae, it was not yet completely straight at 60 mm Hg.)

The marked thinning of the wall with increasing pressure up to 80 mm Hg corresponded to lamellar straightening, decreased interlamellar distances and decreased lamellar thicknesses; however, interlamellar distances decreased more than lamellar thicknesses (fig. 9). Between 100 and 200 mm Hg there was little change in either interlamellar distances or lamellar thicknesses. The average interlamellar distance over the range of distending pressures from 5 and 80 mm Hg was $2.95 \times 10^{-3}$ cm, the average lamellar thickness was $1.13 \times 10^{-3}$ cm. Between 100 and 200 mm Hg distending pressure average interlamellar distance was $0.88 \times 10^{-3}$ cm and average lamellar thickness was $0.83 \times 10^{-3}$ cm. Thus, the ratio of average interlamellar distance to average lamellar thickness was approximately 3:1 for pressures below 80 mm Hg and 1:1 for pressures above 80 mm Hg. Average interlamellar distance was 70% less at high pressures than at low pressures; average lamellar thickness was 25% less at high than at low pressures.

Interlamellar Elastin Fibrillar Net

Interlamellar fine fibrils showed no consistent pattern of orientation at distending pressures of 5 mm Hg. Groups of fibrils passed obliquely or perpendicularly between folded and wavy thick lamellae. With lamellar straightening at increased pressures fibrils became oriented. A definite pattern of alignment could be discerned when near maximum distention was reached at 80 mm Hg without any further change in alignment at or above 100 mm Hg. Fibrils were arranged in the...
narrowed interlamellar spaces in nearly circumferential interlacing strands connecting adjacent thick lamellae. On some nearly tangential sections elastin was seen to be distinctly fibrillar within the thick lamellae and in the interlamellar space and gave the appearance of a continuous fenestrated sheet of fibrils much denser in thick lamellae than in interlamellar spaces. In figure 10 nearly tangential oblique sections of the wall are shown at distending pressures of 40, 60, and 100 mm Hg.

**APPEARANCE OF MEDIAL COLLAGEN AT VARIOUS DISTENDING PRESSURES**

Light microscopic study of van Gieson stains of longitudinal, transverse, and tangential sections revealed abundant small bands and wisps of collagen in the interlamellar spaces throughout the media. At pressures below 80 mm Hg fiber bundles were not arranged in a consistent pattern of orientation and were not obviously related to the elastin fibrils. At pressures above 80 mm Hg collagen bundles were less distinct; bands and wisps seemed less numerous.

Individual collagen fibers could be seen with the resolution afforded by electron microscopy. At distending pressure of 50 mm Hg collagen fibers showed no definite overall arrangement. Fibers occurred separately or in small bundles. Although fibers within bundles tended to be parallel to one another, bundles were oriented in many planes (fig. 11A). At 100 and 150 mm Hg collagen...
fibers were arranged circumferentially. On transverse sections of the wall most collagen fibers were seen as individual bands; relatively few were cut obliquely or in cross section. On longitudinal sections most collagen fibers were seen in cross section as round or oval spots (fig. 11B). It is also noteworthy that at the high pressures almost no bundles of fibers were seen; fibers were separated and dispersed uniformly.

RELATION OF MEDIAL COLLAGEN TO ELASTIN AT VARIOUS DISTENDING PRESSURES

At low pressure, disarray of the collagen fibers and folding of elastin lamellae often gave the impression that collagen and elastin components were connected. No connections between elastin and collagen fibers were seen at or above physiological distending pressures.

Though collagen fibers were generally arranged circumferentially, examination of many sections in different planes of section suggested that there was a small longitudinal displacement. Collagen fibers could be considered to be distributed in the wall along a uniform helix of small pitch. Among the collagen fibers, the interlamellar elastin strands were less numerous but larger than individual collagen fibers. Many interlamellar fibrils appeared to consist of aggregations of smaller fibrils. Branching and connections among elastin fibrils were numerous so that the circumferential arrangement was much less uniform than that of collagen fibers.

A semidiagrammatic representation of the interrelation of the structural elements of the interlamellar space is shown in figure 12. Interlamellar elastin fibers were arranged as though they formed a series of nets each stretched...
obliquely between adjacent thick lamellae with the circumferential stretching component greater than the longitudinal. Collagen fibers were uniformly arrayed among the elastin fibrils, passing through the oblique holes of the elastin nets, thereby producing a closely interwoven and aligned complex of collagen and elastin. It should be emphasized that the normally narrow interlamellar space maintained the structural elements in very close proximity. This compression could not be appreciated on sections of aortas fixed without extension or adequate distention.

**ADVENTITIAL COLLAGEN AND ELASTIN**

Collagen fibers were abundant in the adventitia and were arranged in bundles; no definite consistent alignment of bundles or individual fibers was observed at any of the pressures used. The relatively few adventitial elastin fibrils and short thick elastin lamellae were not as wavy as those of the media at low pressures and were not as straightened as those of the media at high pressures.

**MEDIAL SMOOTH MUSCLE**

Detailed data on the appearance of smooth muscle cells in the wall of the distended aorta will be presented in another communication. In general, orientation of medial smooth muscle followed that of interlamellar elastin. Cells were arranged obliquely or perpendicular to adjacent thick elastin lamellae at distending pressures below 80 mm Hg. With increased distention the smooth muscle cells elongated and the ends became almost pointed. At and above distending pressures of 80 mm Hg the cells were oriented in a helix between adjacent thick lamellae with a pitch approximating that of the interlamellar fibrillar elastin net. Elastin fibrils often seemed to frame smooth muscle cells on both transverse and longitudinal section but did not form a complete sheath around individual cells. Attachment of smooth muscle cells to elastin lamellae and fibrils was observed but no obvious attachment of muscle cells to collagen fibers was seen.

**Discussion**

In the present investigation many rabbit abdominal aortic segments were fixed while extended to in vivo length and distended at...
fixed intraluminal pressures from 0 to 200 mm Hg. The relation of aortic radius to distending pressure was essentially that found by investigators who have made determinations on single arterial segments at various distending pressures.\(^2\)\(^{-6}\), \(^12\), \(^13\) Observations of the orientation and interrelation of aortic elastin and collagen fibers at various distending pressures could be used to develop a concept of the structural basis for some of the static mechanical properties of the aortic media.

The marked thinning of the wall which occurred as distention increased at pressures below diastolic values for the rabbit\(^29\) was due primarily to the marked narrowing of the spaces between adjacent elastin lamellae accompanying the progressive straightening of the lamellae. At and above diastolic pressures lamellae were straight; the relatively constant wall thickness corresponded to relatively fixed interlamellar distances and lamellar widths. At physiological pressures the extensive interlamellar net of elastin fibrils joining the thick elastin lamellae took up a nearly circumferential orientation. Below diastolic pressure, with elastin lamellae still wavy, the abundant interlamellar collagen fibers were disposed in groups and bundles; fibers oriented in many planes were observed on any given section. At and above physiological pressures collagen fibers were uniformly dispersed and aligned circumferen-
tially in a helix of small pitch passing among the elastin fibrils. Thus, the fibrillar components of the interlamellar space are normally aligned and much more intimately associated than is apparent in material fixed without distention.

The taut, relatively inextensible, circumferentially arranged medial collagen fibers accounted for the relatively constant aortic diameter at and above physiological intraluminal pressures. This finding provides a structural basis for the proposals of Roach and Burton,12 MacDonald,6 and Bergel7 that medial collagen is the effective structural component of the aorta at and above physiological mural tension. The adventitial collagen may prevent rupture at extremely high pressures as initially suggested by Remington3 and Burton20 or exert a tethering effect as suggested by MacDonald,6 but morphologic evidence of a static mechanical role in rabbit aortas was absent at distending pressures up to 200 mm Hg.

The relatively great extensibility of the aorta at unphysiological pressures below 80 mm Hg was associated with the straightening and uncrumpling of elastin lamellae and fibrils, the alignment of collagen fibers and the restoration of the interlamellar spaces to physiological dimensions. The disordered appearance of vessel wall components at distending pressures below diastolic pressure resulted from the recoil of elastin and collagen from a normal aligned state. The mechanical properties of the aortic wall in this low pressure range are, therefore, only indirectly related to mechanical properties in the physiological pressure range and their significance should not be exaggerated.

The structural components of the aorta are probably elaborated within a wall in which tensions maintain straight elastin lamellae and circumferentially aligned collagen fibers. Weiss21 has shown that growing fibroblasts and newly formed collagen fibers follow lines of mechanical stress. Dempsey and Lansing22 examined elastin fibers with the polarizing microscope and found that fibers became birefringent when stretched; this effect was attributed to the alignment of the strands of the elastin “fishnet” under tension. In the normally distended rabbit aorta collagen and elastin fibers followed lines of tangential tensions; it is reasonable to presume that the fibers were deposited along these lines of tension.

The modulus of elasticity of the aorta at physiological pressures is less than that of collagen alone but much greater than that of elastin alone.6,7,12 Collagen has a relatively high tensile strength and a modulus of elasticity of about $1 \times 10^9$ dynes/cm$^2$; elastin has a relatively low tensile strength and a modulus of elasticity of about $3 \times 10^8$ dynes/cm$^2$. Materials consisting of two closely associated components of different tensile strength and elastic modulus have been called “two-phase” materials; the aortic wall may well function as such a system at and above physiological pressures.
Some of the advantageous properties of these systems have been described. In a "two-phase" material, the elastic modulus is less than that of the highly elastic component but greater than that of the less elastic component. The resultant modulus is related to the relative cross-sectional area occupied by each component. Substances of high tensile strength may yield at much less than the intermolecular binding forces because of structural defects; however, a "two-phase" material may have an actual tensile strength greater than that of the stronger component alone. This occurs because the more extensible (less elastic) component distributes the stressing forces uniformly. Stresses about flaws are transferred to other parts of the system, preventing the extension of structural defects and permitting the tensile strength of the stronger component to approach the theoretical value. Glass fibers embedded in plastic ("fiberglas"), felted fur, and silica in metals are examples of industrial "two-phase" materials. Some of the special properties of bamboo and other woods are attributable to the presence of aligned cellulose fibers dispersed in lignin. Currey has described bone as a "two-phase" material in which the high tensile strength of collagen and the relatively high elasticity of apatite crystals combine to form a substance of great strength and resilience.

Though the relative quantities of medial elastin and collagen fibers may vary with species and age and in different segments of the aorta and the major "elastic" arteries, these materials are aligned and in intimate association at physiological distending pressures. The high tensile strength of collagen permits great increases in tangential tension. The aorta rarely breaks despite numerous irregularities and flaws of composition and architecture which increase with age and despite rapid fluctuation in wall tension at relatively constant diameter. Thus, under usual conditions of distention at physiological pressures, the elastic modulus of the aortic wall is relatively high because the circumferentially oriented collagen fibers bear most of the tangential stressing forces while the interconnected net of elastin fibrils distributes the stressing forces uniformly.

The tension gradient related to radius within the rabbit aortic wall is normally relatively small. At physiological pressures the wall was very thin and the diameter quite large; the difference between the luminal and adventitial radii was of the order of 2% of the mean radius. Furthermore, the progressive straightening of elastin lamellae and fibrils was uniform throughout the wall; all lamellae straightened simultaneously. The configuration of the collagen and elastin components of subintimal and deep interlamellar spaces was the same at each of the observed distending pressures due to the uniform distribution of stressing forces throughout the wall by the extensible "phase" (elastin). It is therefore probable that intramural tension drops quite precipitously near the outermost aortic layers from nearly intraluminal values to those prevailing in the surrounding tissues. In chick embryo aortas Karrer has shown that successive collagen-elastin layers form on the adventitial side of the media. This may be the zone of maximum tension change. Attempts to assess the role of pressure or tension gradients within the aortic media in the pathogenesis of aortic lesions must take into account the special mechanical features of this "two-phase" material. Focal medial defects and medial pressure and tension gradients may be relatively insignificant factors in the development of aortic disease.

Summary

The arrangement and interrelation of the structural components of the rabbit aorta were studied by light and electron microscopy. Segments of abdominal aorta were restored to in vivo length and fixed in formalin or osmic acid while intraluminal pressures ranging from 0 to 200 mm Hg were maintained by a constant pressure perfusion apparatus. Transverse, longitudinal, and tangential sections of vessels fixed at various distending pressures were examined. Micrometric measurements in-
cluded vessel diameters and wall thickness, thickness and waviness of elastin lamellae and interlamellar distances.

With increasing pressures below the diastolic value, aortic radius increased and wall thickness decreased rapidly. Waviness of the tubular elastin lamellae decreased uniformly throughout the wall. Interlamellar distances decreased uniformly and markedly. Lamellar thicknesses decreased uniformly but much less than interlamellar distances. A fine fibrillar elastin network connected the thick lamellae. Collagen fibers showed no definite pattern of orientation.

At and above diastolic pressure radius and wall thickness changed little with increasing pressures. Elastin lamellae were straight and interlamellar distances were uniform; the fibrils of the interlamellar elastin net were arranged obliquely. Collagen fibers were arranged nearly circumferentially. Collagen and elastin fibers were closely intermingled in the narrow interlamellar space but no collagen-elastin connections were observed.

The mechanical properties and organization of the collagen and elastin components of the aortic media indicate that the wall normally functions as a "two-phase" material. At and above physiological pressures, circumferentially aligned collagen fibers of high tensile strength and relatively high modulus of elasticity bear most of the stressing force. Elastin lamellae and fibrils of relatively low modulus of elasticity distribute stressing forces uniformly.

Attempts to assess the role of medial pressure and tension gradients in the pathogenesis of aortic disease must take into account the special mechanical properties of this "two-phase" material.

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