CARDIOVASCULAR BIOMECHANICS

Hypertension

Problem Magnitude

- Hypertension(HTN) is the **most common** primary diagnosis in America.
- Primary risk factor of other fatal disease such as Atherosclerosis & Stroke
- 50 million or more Americans have high BP.
- Worldwide prevalence estimates for HTN may be as much as 1 billion.
- 7.1 million deaths per year may be attributable to hypertension.

Hypertension

- Systemic Hypertension is defined as a persistent elevation of blood pressure
  - A systolic blood pressure (SBP) >139 mmHg and/or
  - A diastolic (DBP) >89 mmHg.
- pulmonary hypertension
  - systolic pressures > 30mmHg
  - diastolic pressures > 12mmHg
- Alterations associated with hypertension include a thickening of the arterial wall and an altered stiffness and contractile response

Classification of blood pressure in humans

	Diastolic (mm Hg)	Systolic (mm Hg)
Normotensive	<85	<130
High blood pressure	85–89	130–139
Hypertensive		
Stage 1	90–99	140–159
Stage 2	100–109	160–179
Stage 3	110–119	180–209
Stage 4	>120	>210

From Pickering (1995).

Hypertension

- Mean Arterial Pressure:

$$P_m = P_{dias} + \frac{1}{3}(P_{sys} - P_{dias})$$

- primary determinants of the mean arterial pressure
  - total volume of blood in the arterial system
  - capacitance (or elasticity) of the vasculature

- retention of water(increased retention of water vs. hemorrhage)
- Vascular tone(heightened tone in the vasculature vs relaxation of the vasculature)
- Transient variations in systemic blood volume are controlled by cardiac output (from the left ventricle) and the total peripheral resistance **(TPR)** to arterial flow.

Hypertension

- Although the etiology of hypertension is not understood completely, causes include **genetics, improper diet, and abnormal functioning of the kidneys, heart, vasculature, or nervous system**
- Increased secretion of renin by the kidneys
- Unusually high cardiac output
- abnormal downregulation of vasodilators
- increased expression of growth factors by the vasculature
- Increased global or local activity within the sympathetic nervous system.

(**Sympathetic nervous system:** A part of the nervous system that serves to accelerate the heart rate, constrict blood vessels, and raise blood pressure. The sympathetic nervous system and the parasympathetic nervous system constitute the autonomic nervous system)
(**Autonomic nervous system:** A part of the nervous system that regulates key involuntary functions of the body, including the activity of the heart muscle; the smooth muscles, including the muscles of the intestinal tract)

Hypertension

- Secondary vs. Primary Hypertension

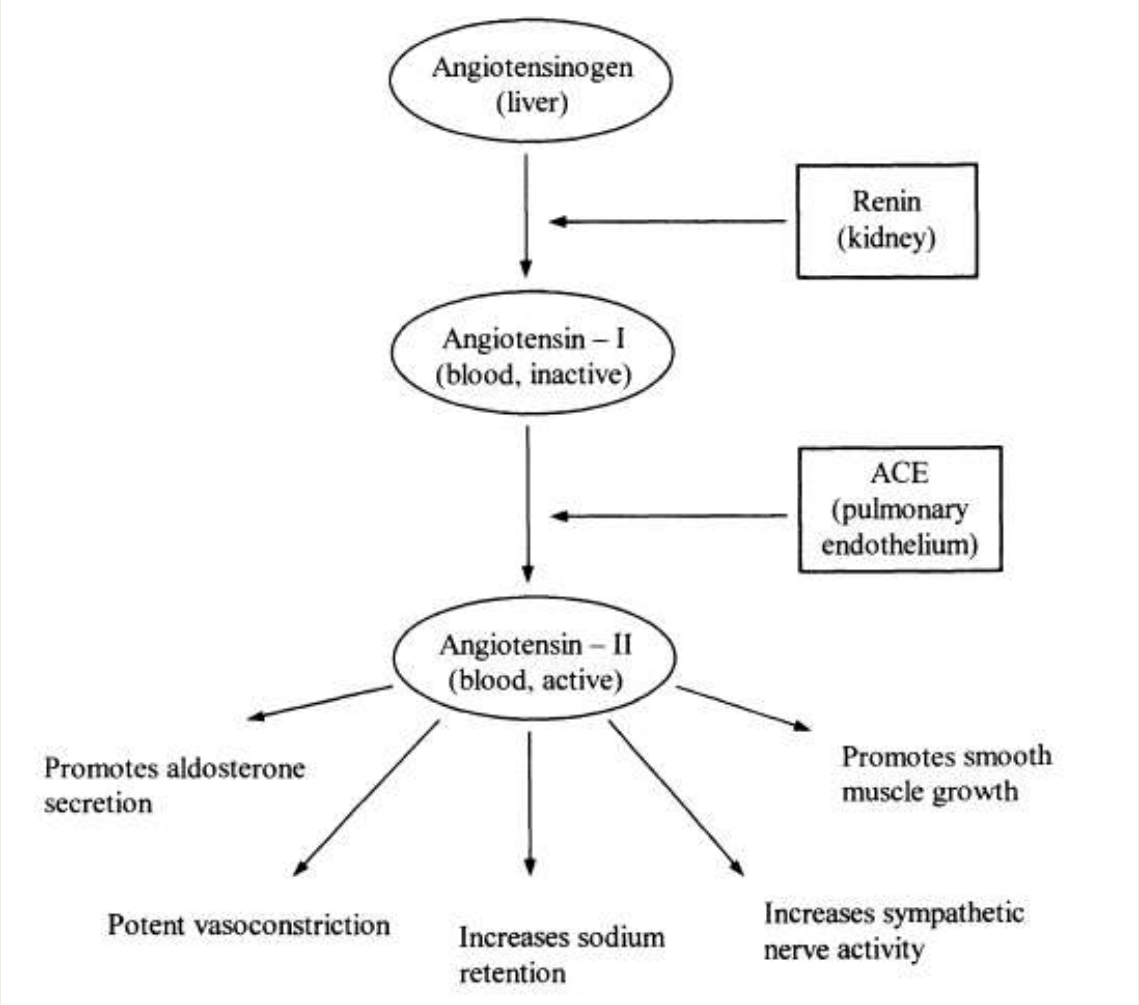
- When hypertension clearly results from another disorder, such as kidney disease
- when the specific cause is unknown

- Regardless of type, hypertension is a risk factor for many other cardiovascular disorders, including **atherosclerosis, stroke, intracranial hemorrhage, dissecting aortic aneurysms, and heart failure**

Aspects of Renin-Angiotensin system

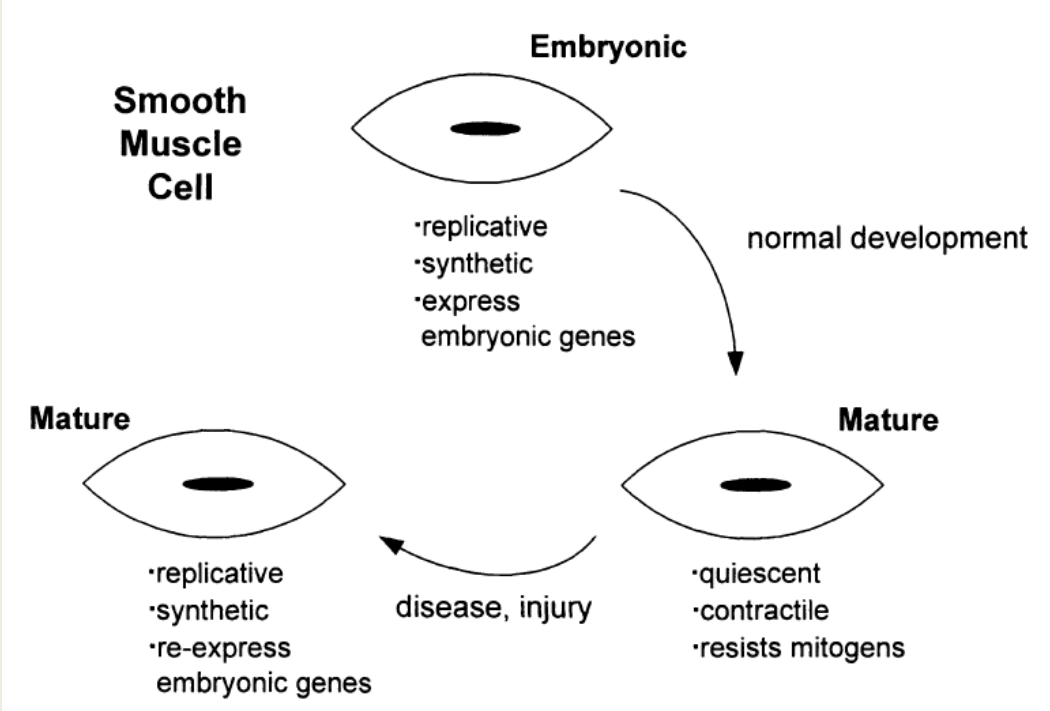
- Renin: a hormone in kidney that is released to compensate reduced blood volume
- ACE: angiotensin-converting enzyme
- ANG-II
  - Extracellular matrix growth
  - Inhibiting arterial baroreceptors
  - Degrading Vasodilator agents

– Animal Models



SMC alteration in Injury

- hypertension results in structural changes in the arterial wall: thickened media.
- hypertensive changes involve both the extracellular matrix and smooth muscle (hyperplasia, hypertrophy)
- smooth muscle cell phenotype



Matsumoto and Hayashi (1994, 1996):

- Locations of thoracic aorta used for experiments

- Hypertension-induction
- inflation-extension experiments
- Histology sections

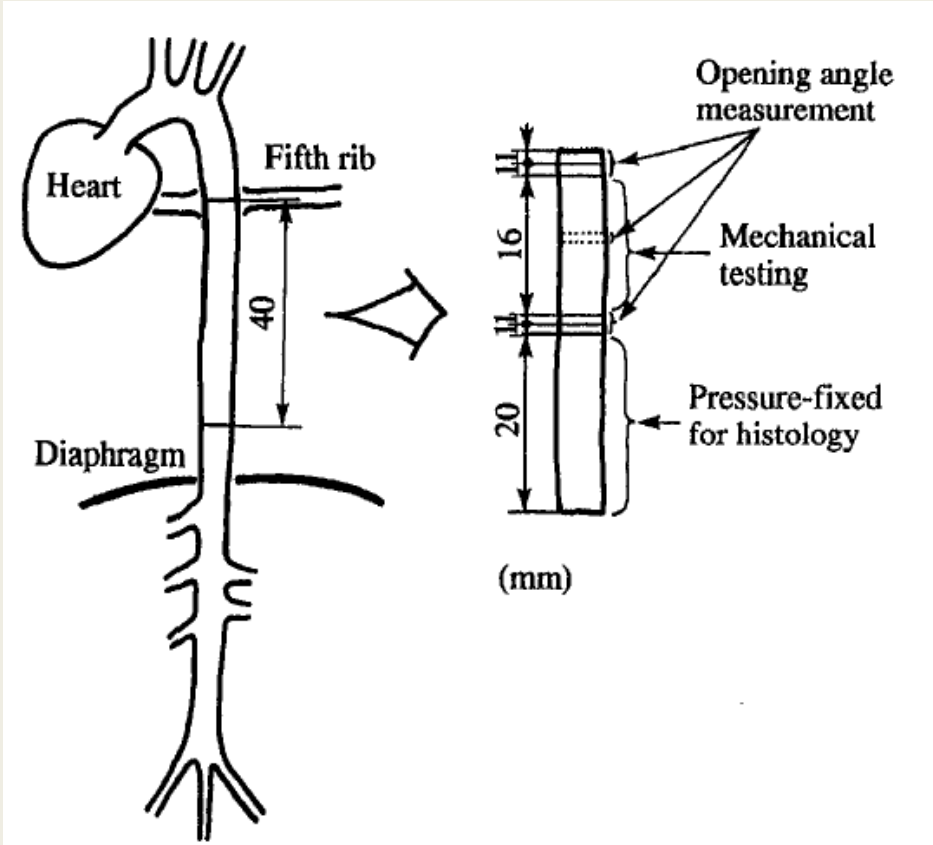
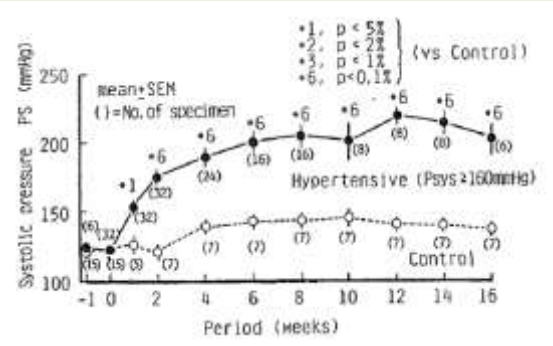
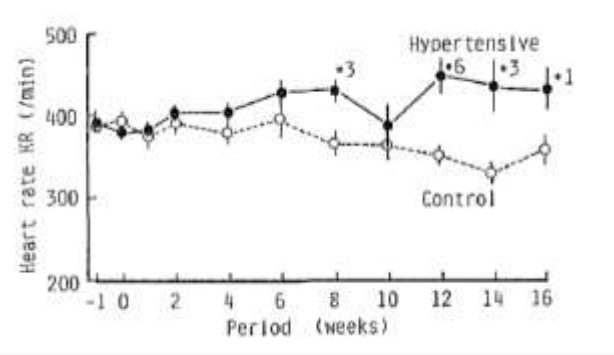


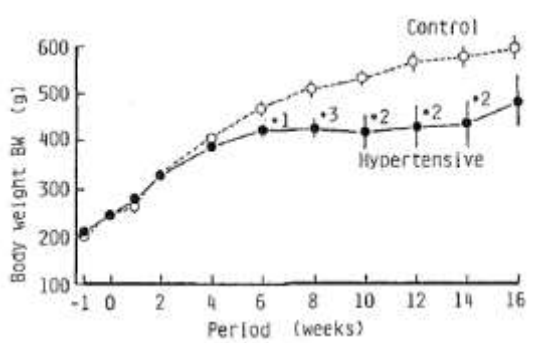
Fig. 1 Locations of thoracic aorta used for each experiment

Matsumoto and Hayashi (1994, 1996):

- Induction of Hypertension:
  - Goldblatt hypertension by constricting their renal arteries
    - decrease of the blood pressure in the renal artery due to the constriction stimulates the release of renin

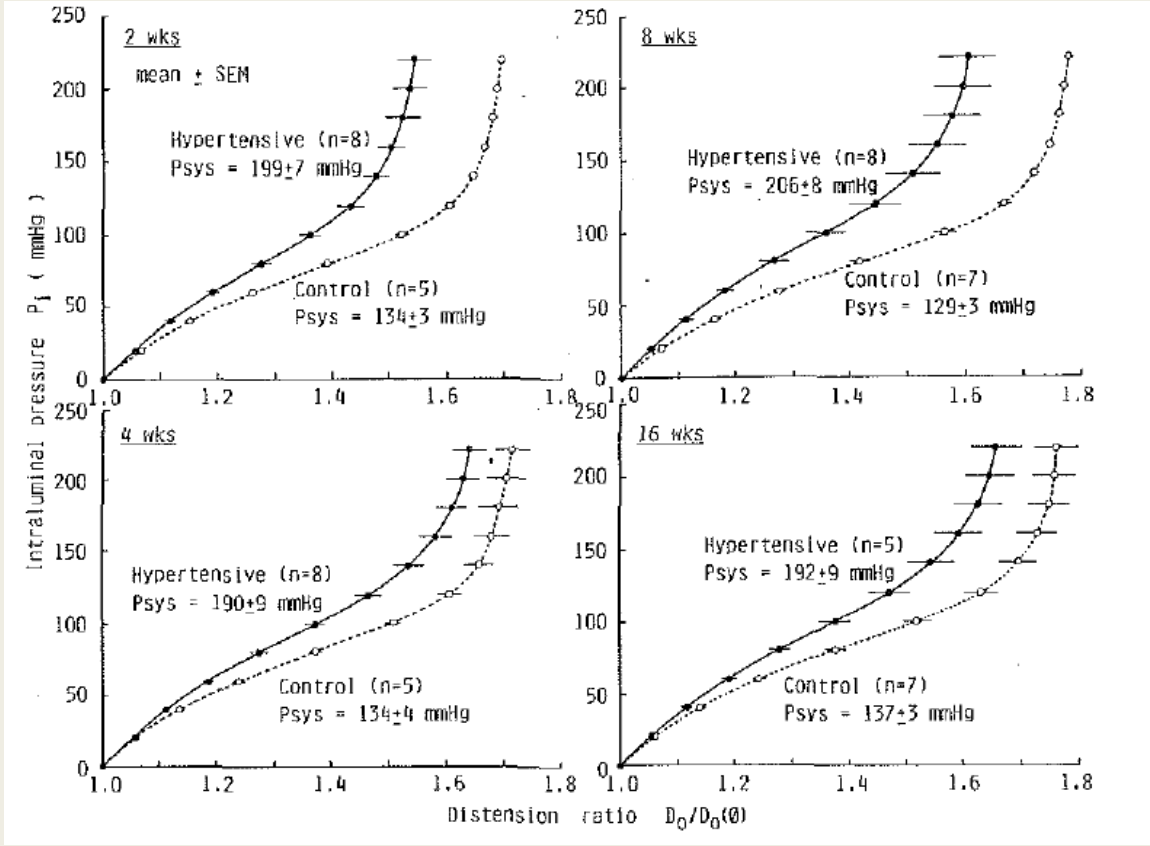






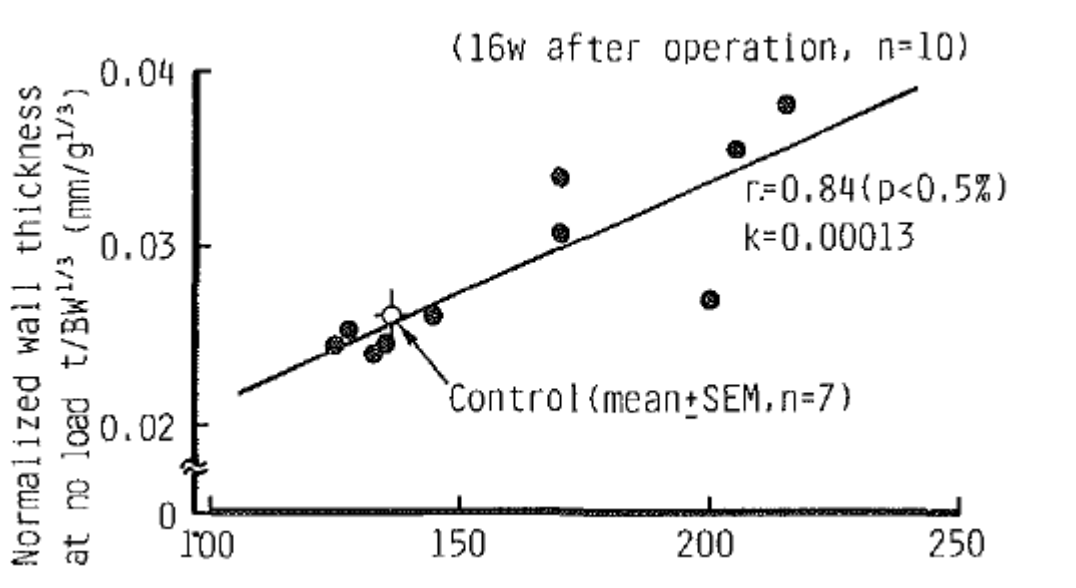
Pressure-diameter curves of the aorta in the hypertensive and control rats.

- Psys, systolic blood pressure before sacrifice;D_0, outer diameter; $D_0(0)$, outer diameter at zero pressure.

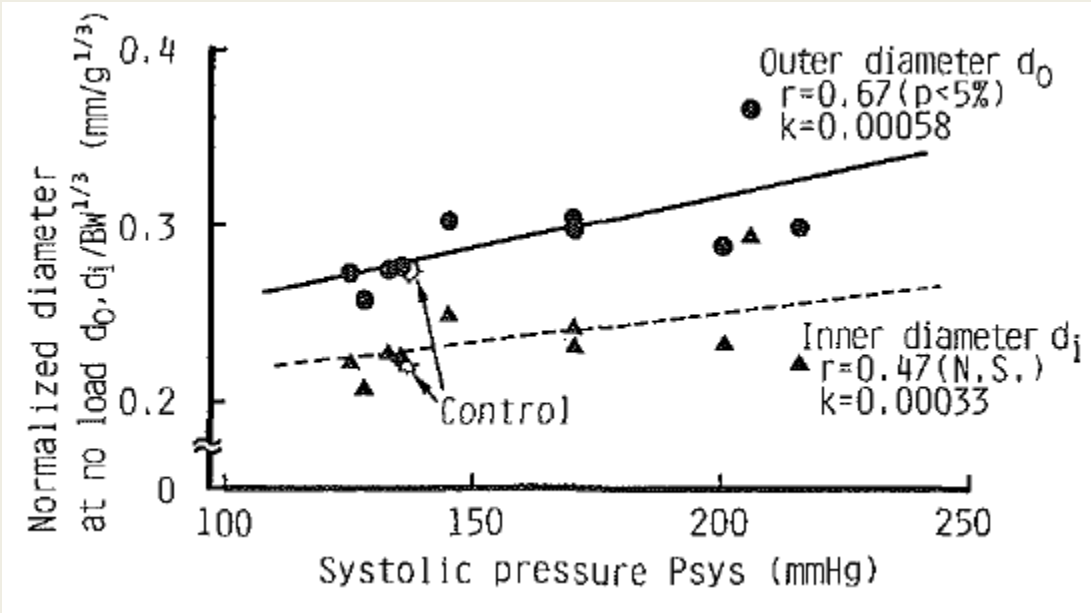


Thickness and Diameter changes

Thickness

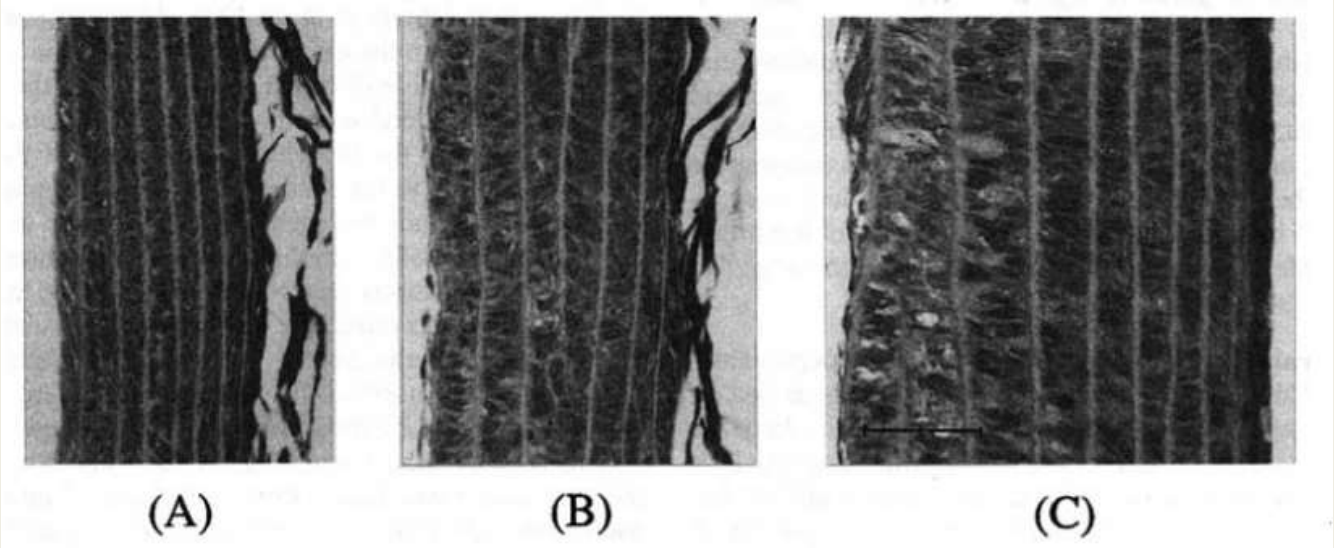


Diameter



Normalization by BW

Structural Alterations



(A) Normotensive (B) hypertensive and (C) Severely hypertensive rat aorta

- wall thickness increased significantly

Discuss Changes

- hypertrophy was mainly due to thickening of the lamellar units in the media, but not due to increase in the number of the lamellar units. Similar findings have been reported by Wolinsky.
- The lamellar units near the inner wall thickened more than those near the outer wall.
- the inner radius increased only slightly

(Wolinsky 1970 & 1971)

Structural Alterations

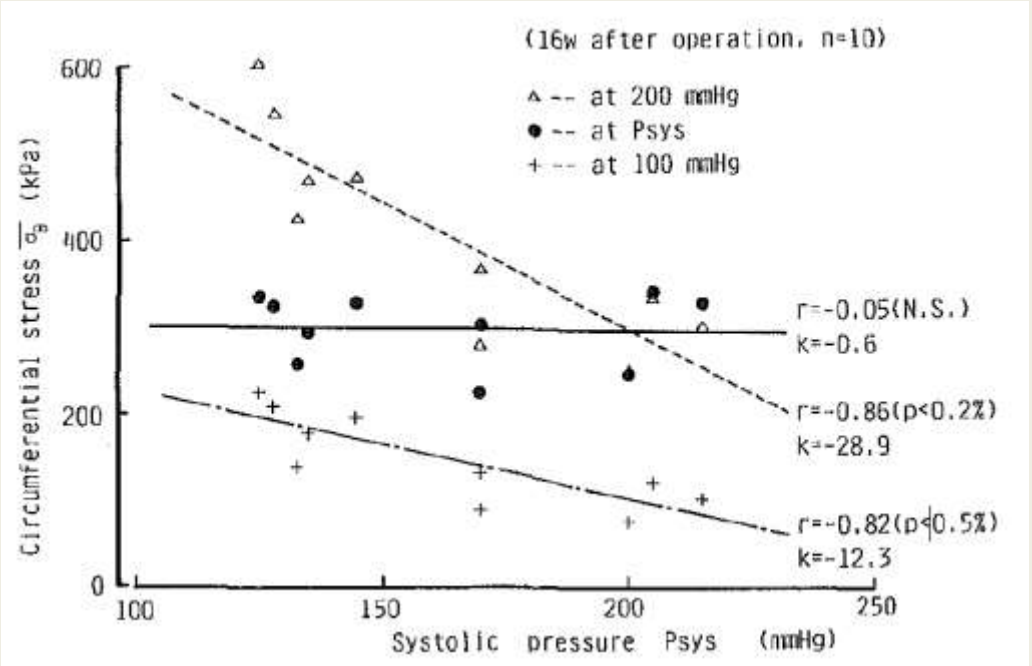
- significant increases in intramural collagen (136%) and modest increases in elastin (30%), despite the number of elastic lamellae remaining the same.
- luminal diameter increased little (8%), the primary geometrical effect was a decrease in the lumen/medial thickness ratio.

- Despite an increase in total collagen, its mass fraction actually decreases because of the greater increase in smooth muscle.
- Dimensional changes served to maintain the mean circumferential stress near the homeostatic level of 320 kPa.

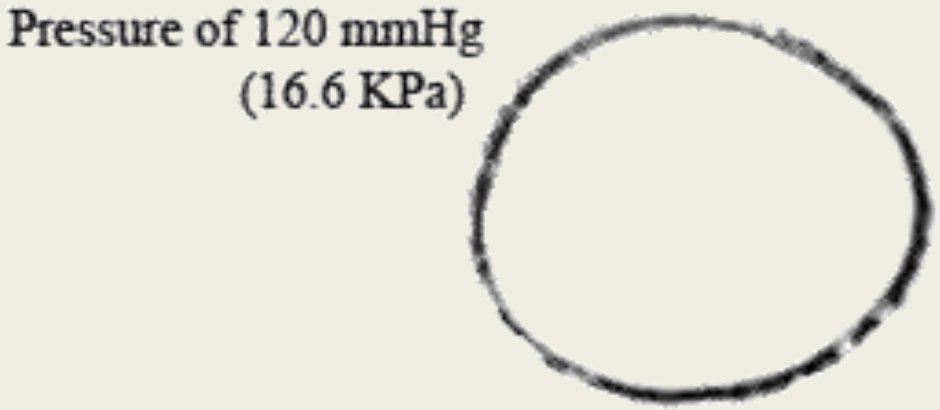
Mean Circumferential Stress

- the circumferential stress calculated for the systolic blood pressure was almost independent of this pressure at 16 weeks after the operation.
- the aorta wall thickens with the progress of hypertension so as to maintain the circumferential stress developed by the in-situ blood pressure at a constant level.
- Thin-walled cylinder approximation
- Is the arterial wall a thin-walled cylinder? (what is the border between thin & thick-walled cylinders)

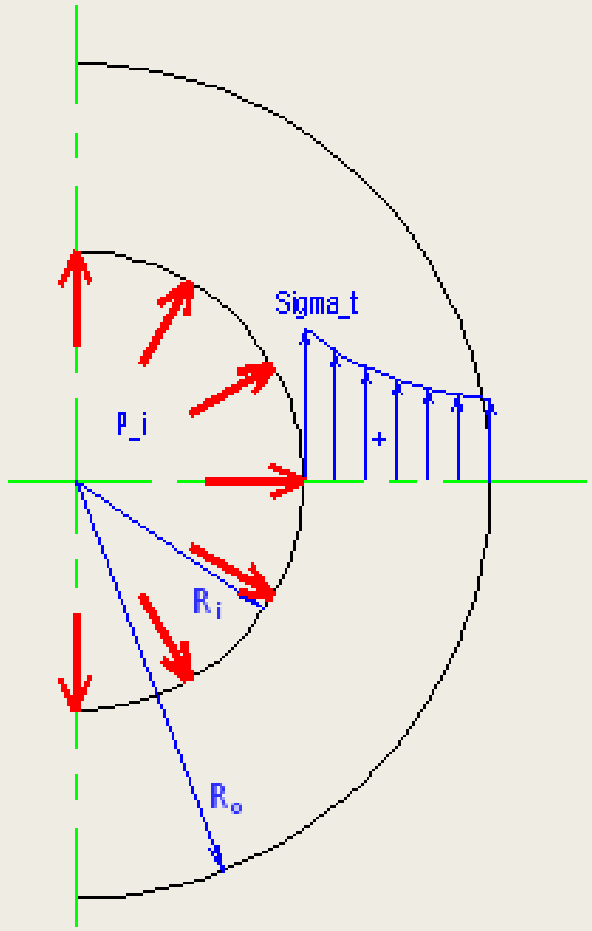
$$\sigma \equiv \langle t_{\theta\theta} \rangle = \frac{Pr_i}{h}$$



Aortic wall thickness in Different Pressures



Transmural stress Profile



Residual Stresses

- Circumferential residual stress: Opening Angle

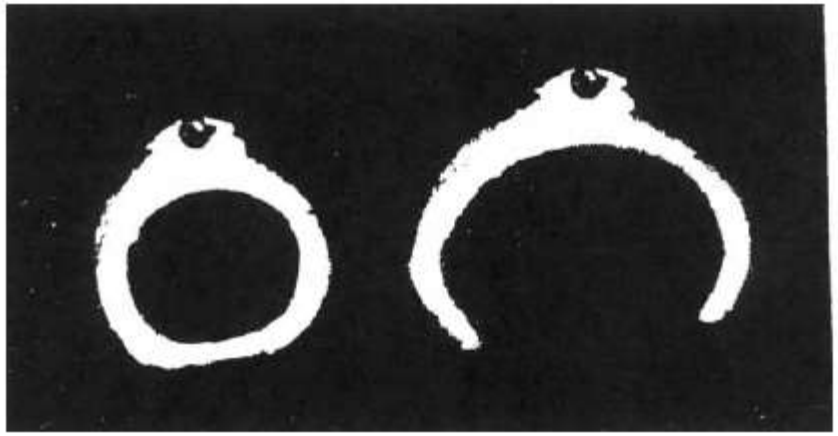
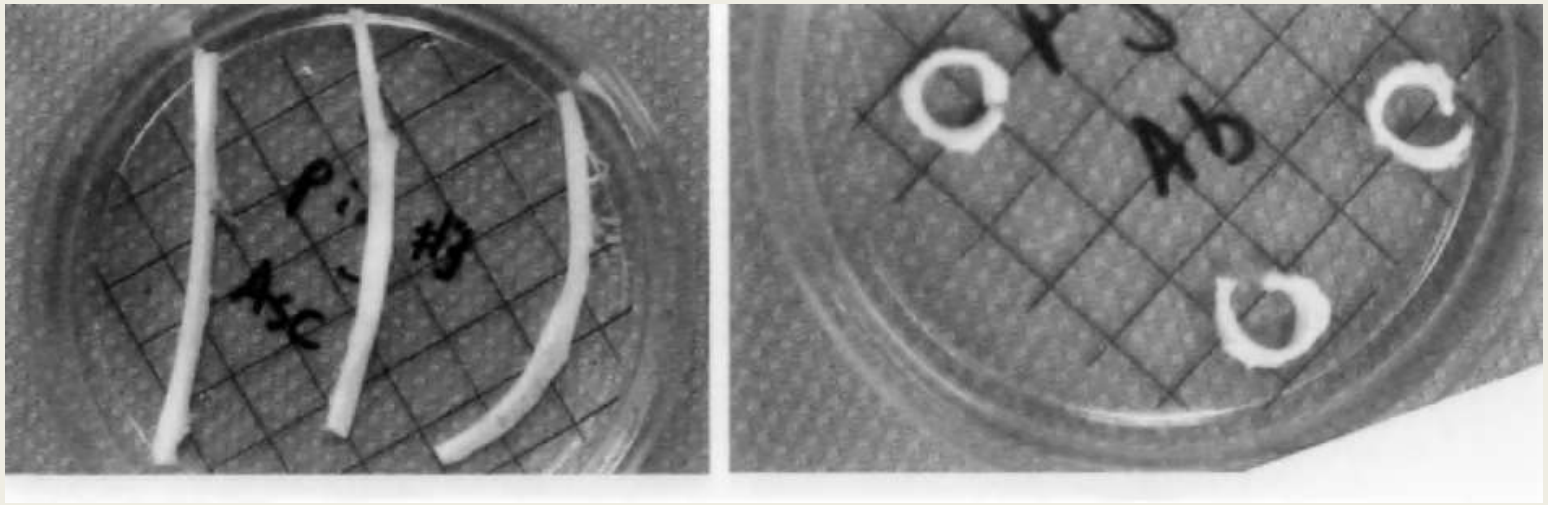


FIGURE 7.9. The "opening up" (right) of an originally unloaded intact arterial ring (left) following the introduction of a radial cut. (From Fung, 1984, with permission.)

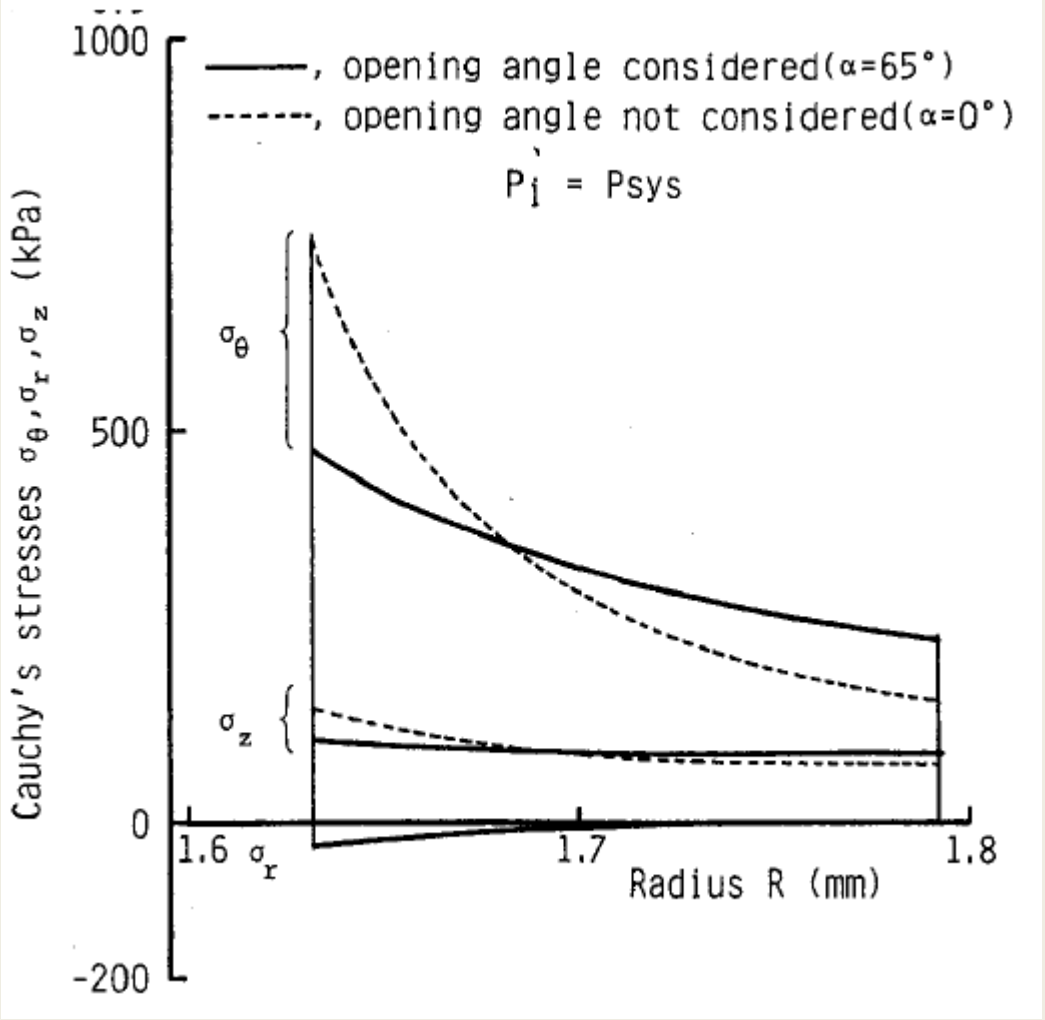
- Longitudinal pre-stretch
  How to measure this deformations??

Residual Stresses



Effect of residual stress consideration

- residual stress cancels the high stress concentration near the intimal surface and elevating the stress on its outer side



Residual and axial pre-stretch in Hypertension

- opening angle increased with hypertension, and in fact tended to correlate linearly with P_{sys}
- in situ axial stretches were 1.17 in the hypertensive aorta and 1.37 in the controls, which corresponded to calculated mean axial stresses of (t_{zz}) = 99kPa and 159kPa, respectively.
- it is not yet clear what causes this change in axial properties and structure

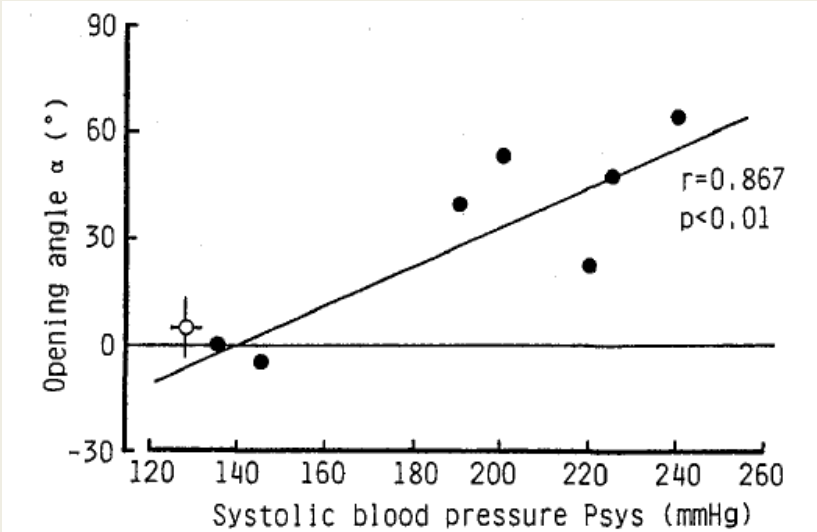
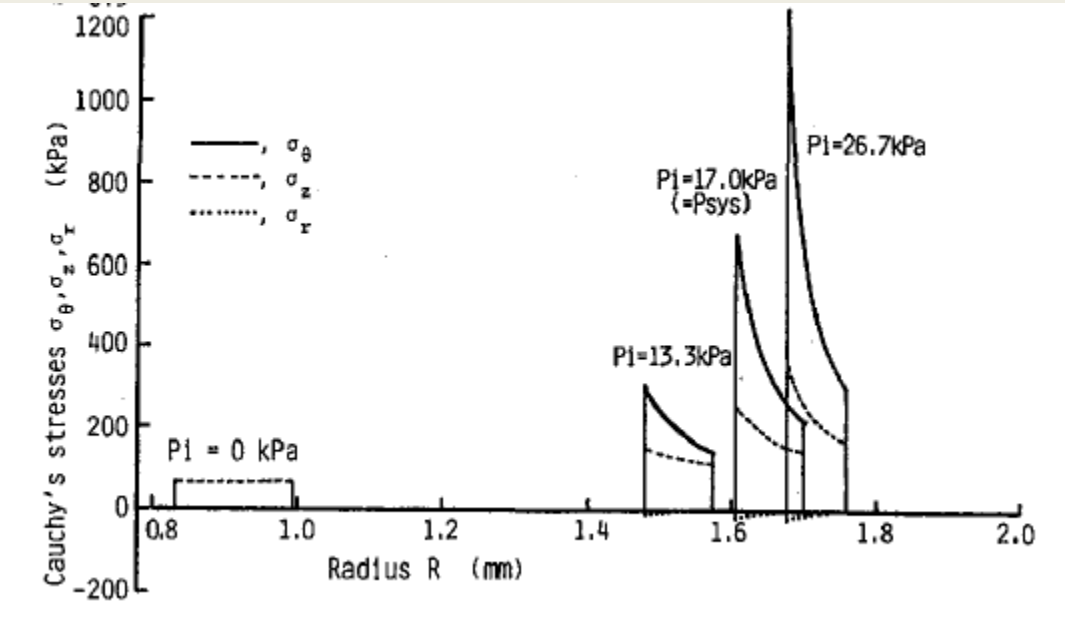


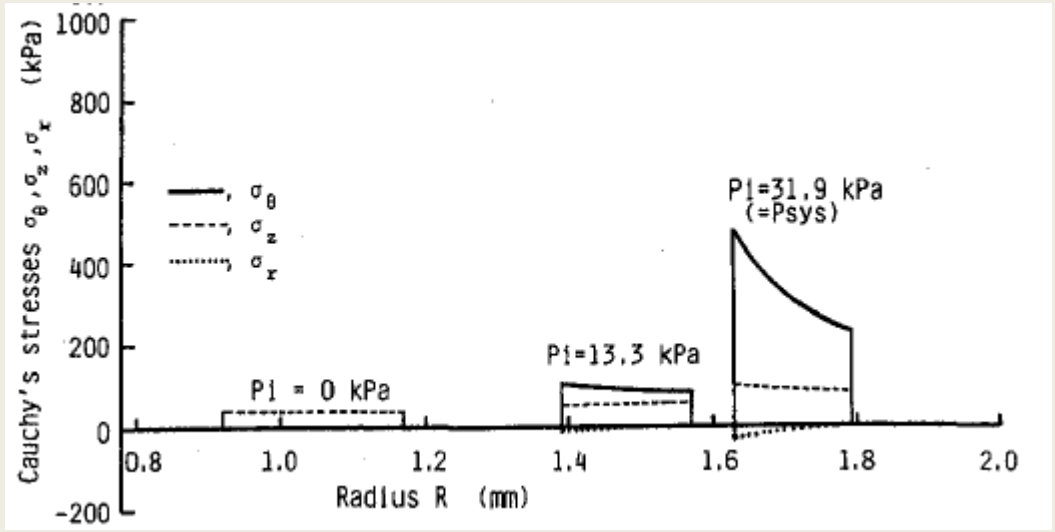
Fig. 3 Correlation between systolic blood pressure and opening angle. The closed circles show data obtained from the operated rats. The open circle shows the mean value of the control data with the standard errors. Correlation coefficient, *r*, and its significant level, *p*, were calculated including the data shown by the open circle.

Control vs. Hypertensive Stress profiles

Control

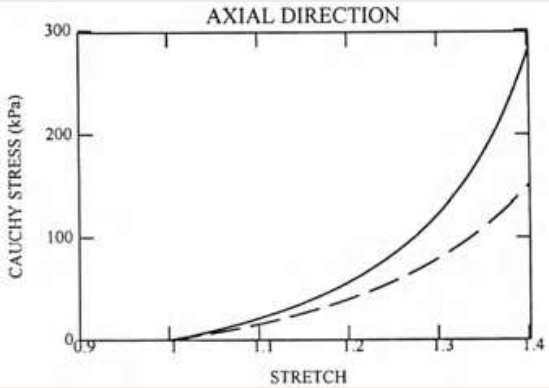


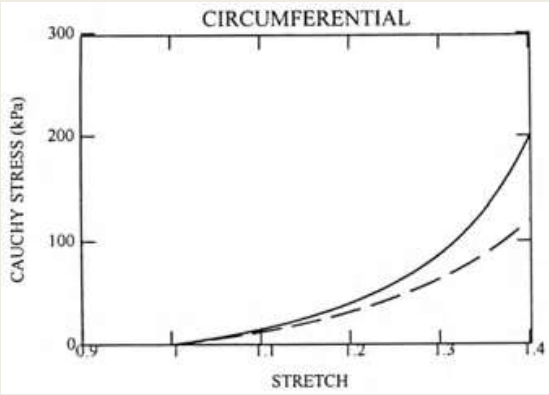
Hypertensive



Mechanical Properties

- Comparison of stresses for normotensive (dashed) and hypertensive (solid) aortas





- Further Readings on Hypertension:

See Wolinsky (1971), and more recent reports such as Anastos et al (1991), Cacciabaudo and August (1995), Cohen et al (1995), Hayes and Taler (1998), and O'Donnell et al (1998).