as great in an 8-cm diameter aneurysm as it is in a 2-cm diameter normal aorta. Therefore ecstasies and aneurysms are subject to both increased pressure force (\( -FP \)) and decreased retractive force (\( \overline{FR} \)). This combination of changes causes ecstasia and aneurysm arteries to lengthen. It is very important for the longitudinal retractive force (FR) that the elastin of the vessel wall is intact. While changes in the geometry, pressure and failure of elastin are involved in the development of tortuosity (Table 1).

### Table 1 - Mechanisms of tortuosity.

<table>
<thead>
<tr>
<th>Clinical condition</th>
<th>Altered forces</th>
<th>Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age and hypertension</td>
<td>FP, FR</td>
<td>Hypertension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased elasticity</td>
</tr>
<tr>
<td>Congenital kinking</td>
<td>FP</td>
<td>Failure of elastin</td>
</tr>
<tr>
<td>Ectasias, Aneurysms</td>
<td>FP</td>
<td>Increased diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Failure of elastin</td>
</tr>
</tbody>
</table>


2- MECHANICAL PROPERTIES OF ANEURYSMS

In order to maintain a stable diameter, the vessel wall must exert a circumferential force that opposes the distending effects of pressure (10). This relation is often described with Laplace’s Law: \( T = P \times r \), where \( T \) is circumferential wall tension, \( P \) is transmural pressure, and \( r \) is mean vessel radius. In order to maintain a stable diameter, the vessel wall must exert a circumferential force that opposes the distending effects of pressure. The product of pressure and radius gives the distending force, while the retractive force offered by the wall is the tension (11).

Accounting for the fact that the wall is not extremely thin may refine Laplace’s Law. In this case, when the wall thickness is relevant enough the wall stress is used: 
\[ s = \frac{P \times r_i}{th} \]
where \( s \) is the stress (force per unit area) developed by the stretched vessel wall, \( P \) is transmural pressure, \( r_i \) is the internal radius, and \( th \) is wall thickness. It is evident that both tension (\( T \)) and stress (\( s \)) required to maintain equilibrium rise with increasing vessel radius. In addition, the stress rises with decreasing wall thickness (\( th \)).

One may inquire how a vessel that could not provide enough tension or stress to maintain equilibrium at a normal diameter and normal wall thickness can do so when it becomes a large-diameter, thin walled aneurysm; under these conditions, the dilated vessel requires even more tension or stress to maintain equilibrium. Why does not the unstable wall proceed immediately from normal dimensions to rupture?

Aneurysms often dilate gradually, sometimes taking several years to achieve large dimensions. There are several answers to this question. First, as aneurysms dilate, they recruit collagen fibers that previously had not been loaded and the walls of human aneurysms are stiffer than normal vessels. Only about 1 percent of the collagen in the normal vessel wall is load-bearing, so that there is a large amount available for recruitment. Sumner and coworkers (12) also found that the walls of human aneurysms are stiffer than normal vessels.

There is a second reason for aneurysms to dilate gradually and it is related to changes in their geometry with a more spherical shape (Fig. 4). The development of a second radius provides additional retractive force. This reduces the stress necessary in any one direction to maintain equilibrium. As a result of this change from cylinder to sphere, only about 50 per cent of the usual tension or stress is required in each direction to balance the increased distending force.

The thrombus in the lumen of aneurysmal vessels does not decrease the value of the radius in Laplace’s...
femoral region, developing a higher systolic and larger pulse pressure in the abdominal aorta and femoral arteries. This results from at least three factors: 1) the aorta tapers, decreasing in cross-sectional area as it passes from the aortic valve to the bifurcation; 2) the aorta becomes stiffer as it progresses distally, especially after it enters the abdomen (13) (abdominal vessel possesses more collagen and less elastin than does the thoracic aorta); 3) The pressure waves reflect from the peripheral vessels add to the incoming pressure waves in the abdominal aorta.

3- ANIMAL MODELS OF ANEURYSMS

Several animal models in-vivo have been developed, including:

- a) atherosclerosis;
- b) genetic abnormalities;
- c) experimental alterations of metabolism;
- d) mechanical and chemical injury;
- e) hemodynamic factors;
- f) allografts and xenographs;
- g) inflammation;
- h) elastase infusion model. Particular emphasis is given to the elastase infusion model (14).

a) ATHEROSCLEROSIS AND ATHEROSCLEROSIS REGRESSION.

Zarins and Glagov (15) argue that aneurysms may be caused by the degeneration of the vessel wall as a result of atherosclerosis. The atherosclerotic lesion may cause thinning of the media, provoking the formation of an aneurysm. Experimental studies (16), were performed in cynomolgus and rhesus monkeys on atherogenic diet and after 6 to 12 months the diet was discontinued and the animals were placed on an atherogenesis-regression diet. With regression of atherosclerosis, 13% of cynomolgus monkeys and 1% of rhesus monkeys developed aneurysms and in other monkeys that did not develop aneurysms a twofold increase in diameter of the abdominal aorta without modification in the diameter of the thoracic aorta was found. These findings in animals may reflect what occurs in humans. However, Tilson and Stansil (1) in a study over 100 consecutive patients who underwent grafting of the abdominal aorta found that patients with aneurysmal and occlusive disease were of different ages and gender, and had different long-term prognoses. The authors suggested that aneurysms may result from a process that is separate from atherosclerosis.

b) GENETIC ABNORMALITIES OF METABOLISM.

The blotchy mouse develops aneurysms genetically from abnormalities on the X chromosome and causes defects in the connective tissue, skin color, and neurologic function. The underlying defect seems to be an abnormality of the copper metabolism (17). Copper is essential for lysyl oxidase activity, an enzyme that facilitates the cross-linking of elastin and of collagen (18). Treating the blotchy mouse with propranolol delays the appearance of aneurysms (19) and there is evidence that propranolol actually increases the cross-linking of elastin and collagen (20). Copper alterations seemed to be a promising area for research of aneurysms in humans, but this has not proven to be a consistent feature of human aneurysms (21).

c) EXPERIMENTAL ALTERATIONS OF METABOLISM: BAPN, THEOPHYLLINE, AND HORMONAL MANIPULATIONS.

The lathyris is one example of deliberate disruption of the normal synthesis of connective tissues in the artery wall. This disease can be produced by feeding animals with sweet pea meal and the active agent in the meal is beta-aminopropionitrile (BAPN). Feeding to animals on this agent also causes the development of aneurysms and spontaneous aortic rupture (22-23). A mortality rate of 24% observed after treatment with BAPN rose to 91%.