Rheological, mechanical and failure properties of biological soft tissues at high strains and rates of deformation

Society of Rheology Conference
Salt Lake City, Utah
October 10, 2007

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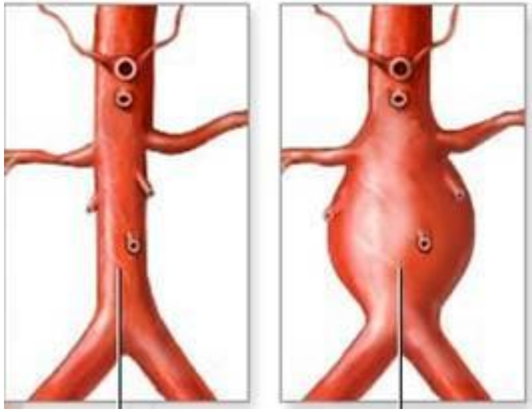
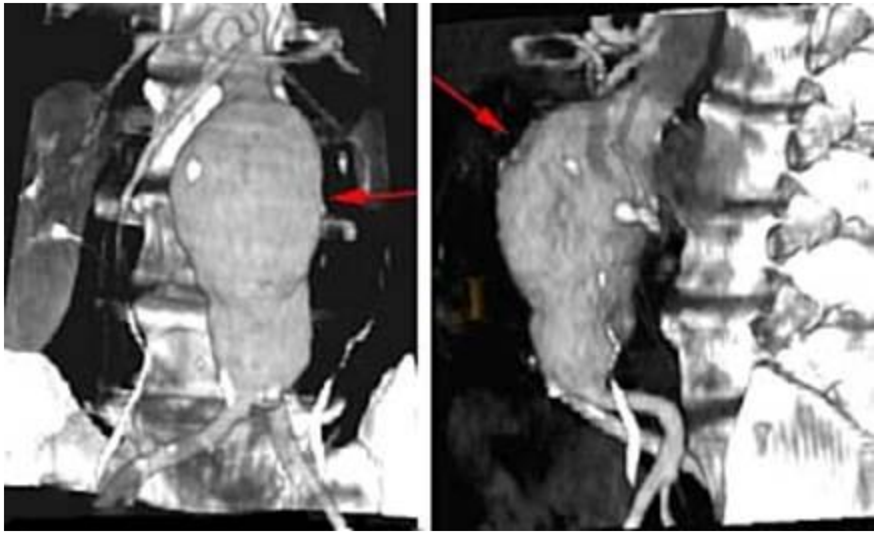
Blood Vessel Aneurysms

- An aneurysm is a localized, blood-filled dilation (bulge) of a blood vessel caused by disease or weakening of the blood vessel wall.
- The bulge in a blood vessel can burst and lead to death at any time, much like a bulge in an over-inflated inner tube - the larger an aneurysm, the more likely it is to burst.

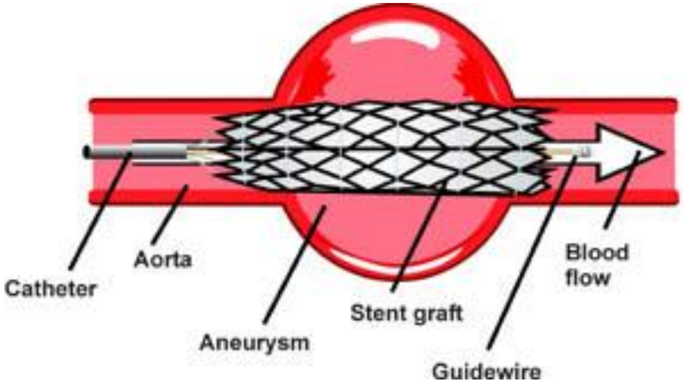


Normal Aneurysm



Blood Vessel Aneurysms

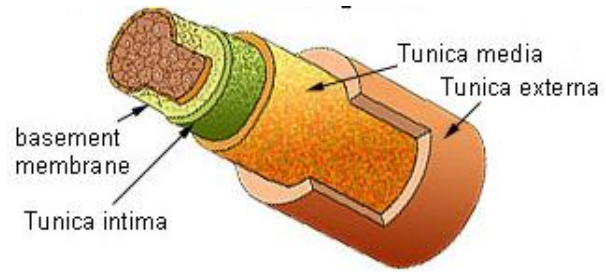
- A saccular aneurysm develops when fibers in the outer blood vessel layer separate allowing the pressure of the blood to force the two inner layers to balloon through.
- It is not clear exactly what causes aneurysms. Defects in some of the parts of the artery wall may be responsible. In certain cases, high blood pressure is thought to be a contributing factor. Some aneurysms are congenital (present at birth).

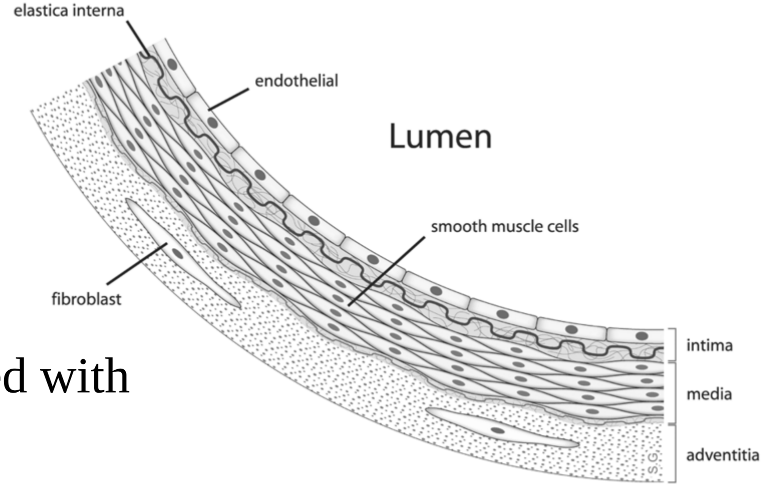


Treatments typically include catheterization and stent graft insertion

Anatomy of a Blood Vessel

- Tunica interna (Aka, tunica intima) – the innermost layer
  - Contains endothelium (simple squamous epithelium)
  - Underlying layer of elastic connective tissue
  - Provides a friction-free surface for blood flow
- Tunica media – the middle layer
  - Contains concentric layers of smooth muscle cells
  - Underlying band of elastic fibers
  - Layer responsible for vasoconstriction and vasodilation
  - This affects blood pressure and blood flow
- Tunica externa (Aka, tunica adventitia) – the outermost layer
  - Composed mainly of collagen fibers interspersed with elastin fibers
  - Innervated, vascularized (vasa vasorum), and infiltrated lymphatic vessels
  - Protects and reinforces the vessel





Types of Arteries

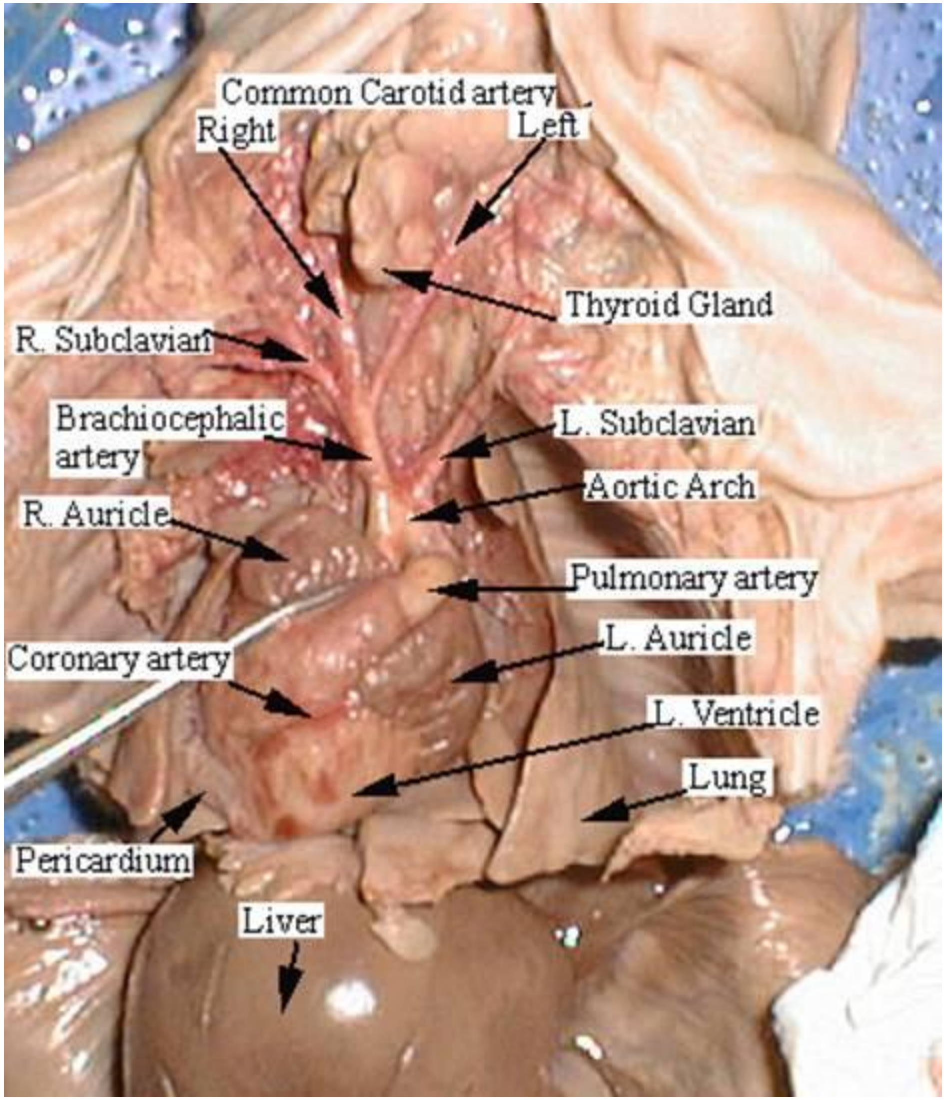
- Elastic (conducting) arteries
  - Arteries near the heart; largest in diameter
  - Large lumens, therefore low-resistance
  - Contain more elastic fibers than any other vessel type, esp. in the tunica media
    - Enables the arteries to withstand and smooth out large pressure fluctuations
  - Expand and recoil passively to accommodate changes in blood volume – continuous flow of blood
- Muscular (distributing) arteries
  - Deliver blood to specific body organs
  - Have the thickest tunica media of all vessels – more smooth muscle, less elastic fibers
  - More active in vasoconstriction
  - Ex. Include: the external carotid arteries of the neck, brachial arteries of the arms, and femoral arteries of the thighs
- Arterioles
  - The smallest of the arteries
  - Contain all three tunics, but they have a poorly defined tunica externa and the tunica media is composed of a single sheet of smooth muscle cells
  - Blood flow into the capillary beds is determined by arteriole diameter

Mechanical Study of Biological Soft Tissues

- For reasons of practicality, it is not always feasible to characterize the mechanical properties of human soft tissues.
- Consequently, other mammalian biological soft tissues are studied as a human equivalency.
- Pigs possess many of the same anatomical features to that of humans, hence porcine soft tissues are often studied as a human equivalency.

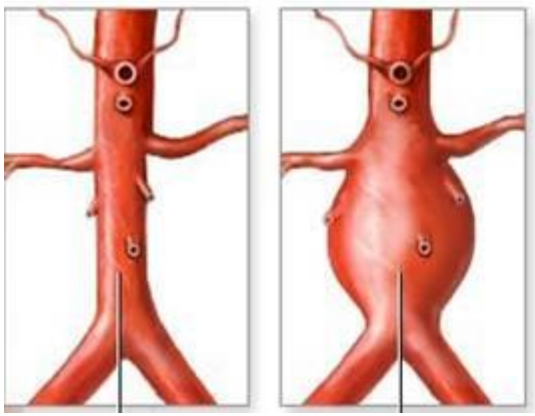
Porcine vs. Human Circulatory System

- In pigs, the brachiocephalic artery splits into the right subclavian artery and the bicarotid trunk. The bicarotid trunk then splits into the right and left common carotid arteries.
- Humans do not have a bicarotid trunk; instead, the left common carotid artery branches from directly from the aorta, while only the right common carotid artery originates from the brachiocephalic artery.



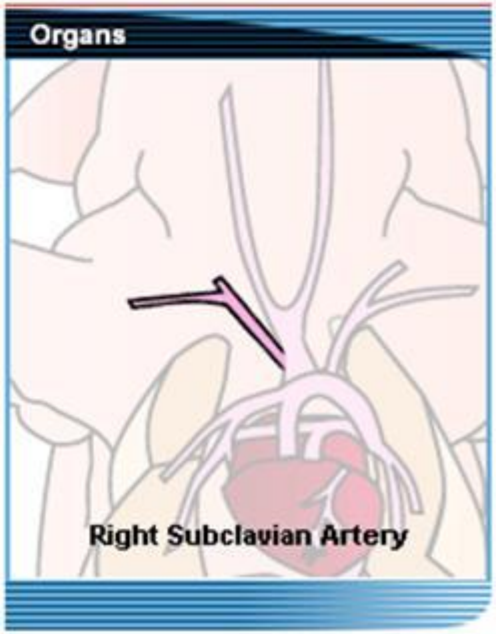
Objective

- Study the mechanical failure properties of a porcine artery specimen for insight into the mechanisms of aneurysm propagation and vessel rupture in human blood vessels.



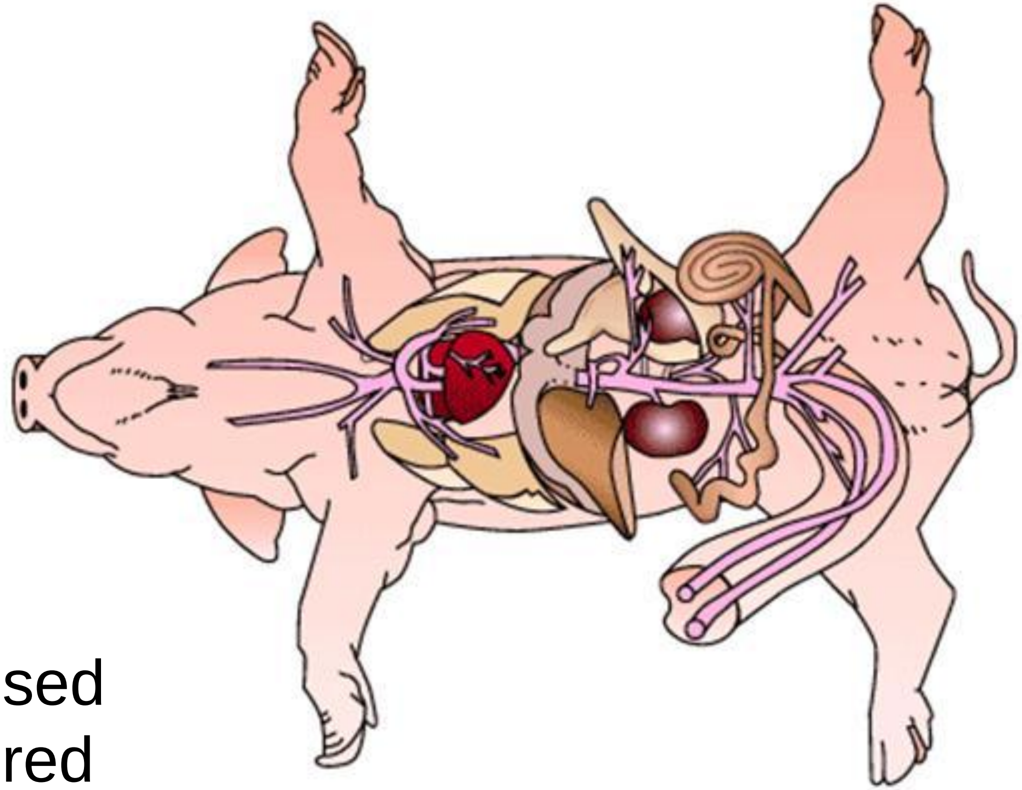
Normal Aneurysm

Experimental: Material



Definition of Organ Function

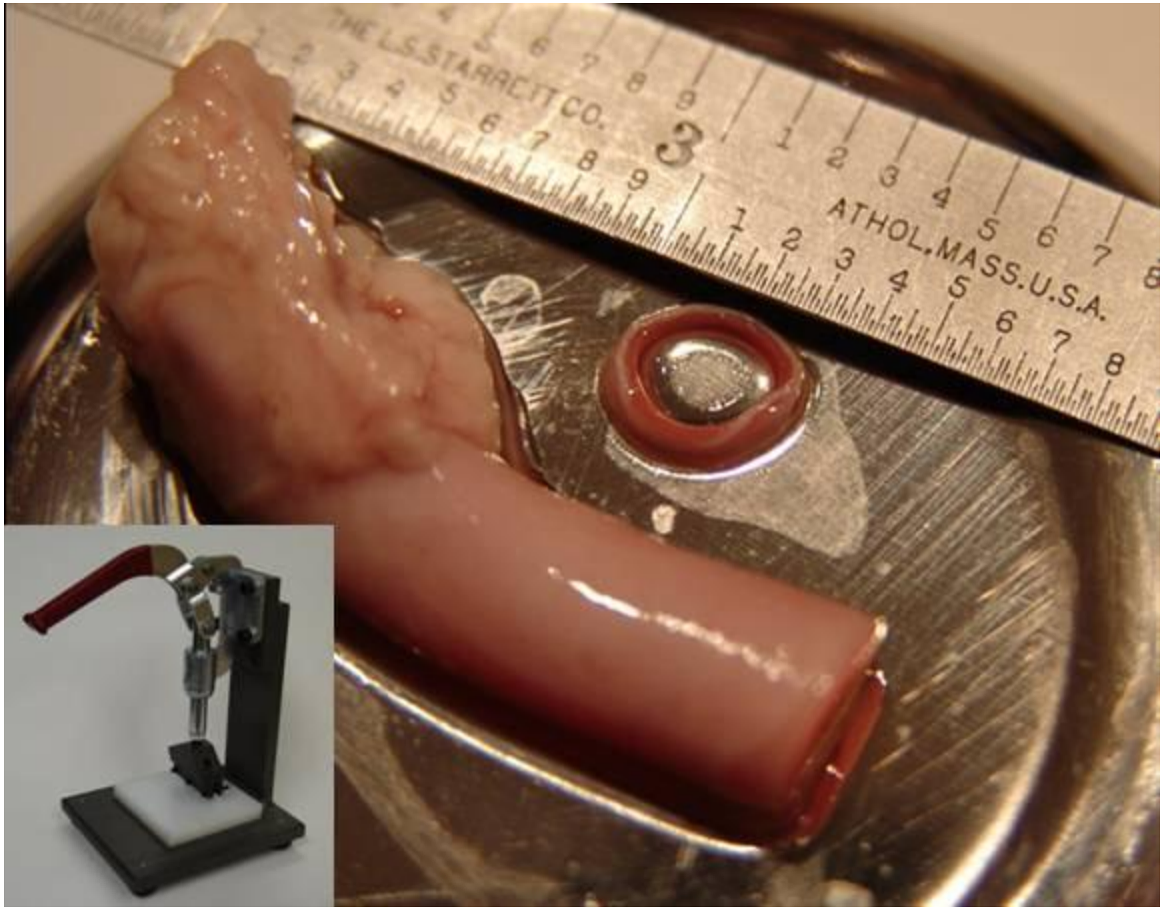
Right Subclavian Artery: supplies blood to the right forelimb and to the right ventral chest wall



A right subclavian artery specimen approximately 60mm in length was excised from the freshly slaughtered carcass of an adult male pig.

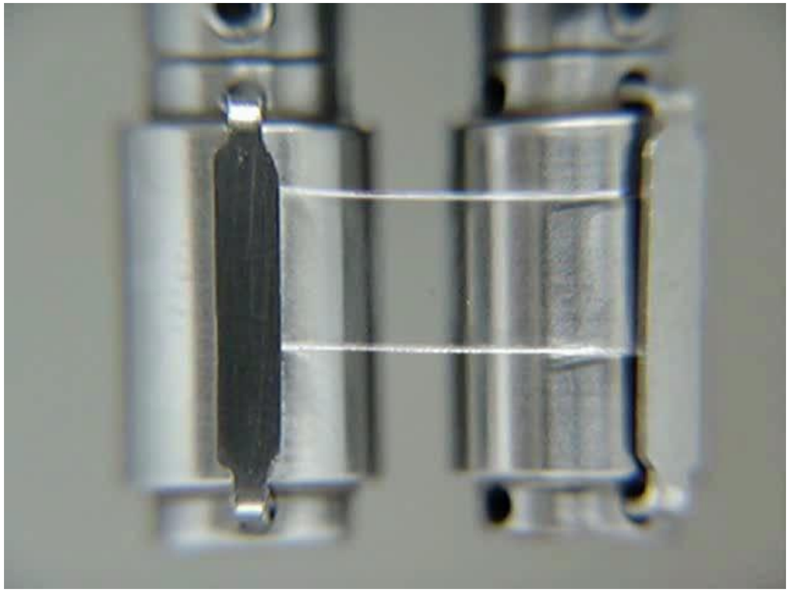
Experimental: Material

- Multiple thin cross-sectional hoop segments approximately 1.2mm in depth were sliced from a section of the right subclavian artery specimen using a multi-blade cutter assembly.



Experimental: Equipment – SER2

- Uniaxial extension experiments were performed on the arterial ring sections using a *new* SER2 Universal Testing Platform model SER2-P hosted on an Anton Paar MCR 501 host station.
- SER2's drums are detachable and can be configured with specific surface textures.
- The model SER2-P is capable of fluid immersion testing.



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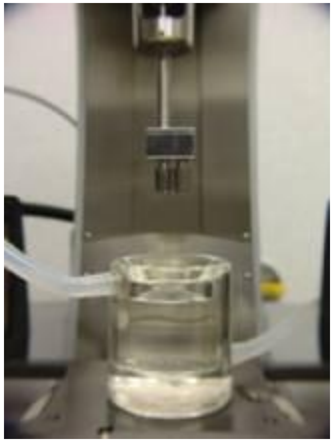
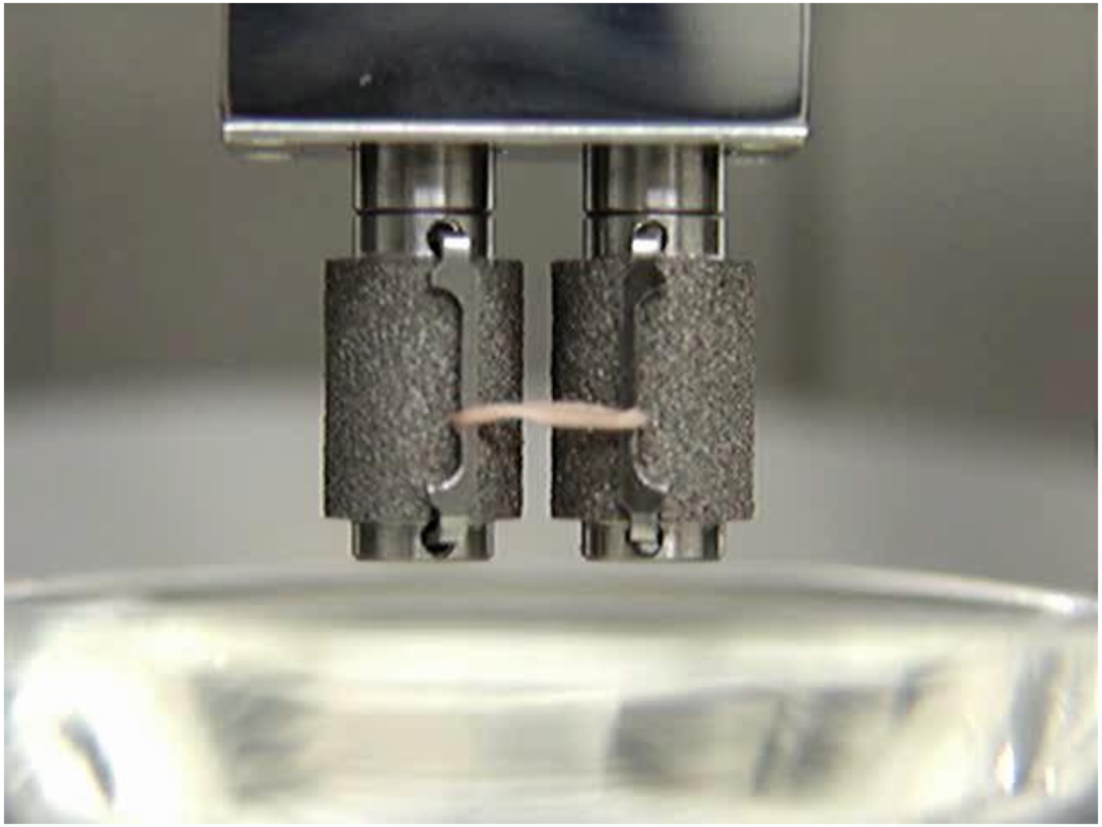
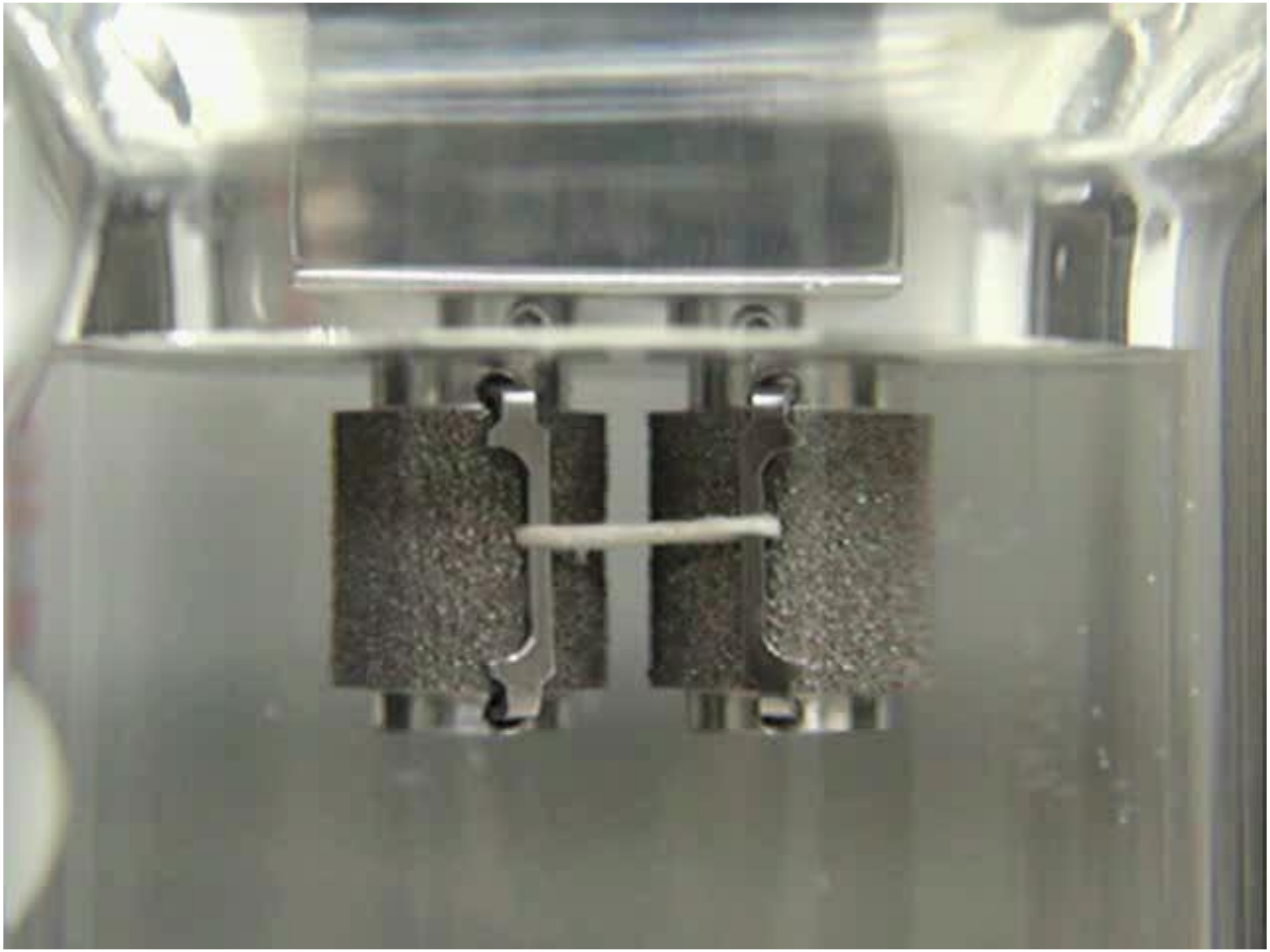


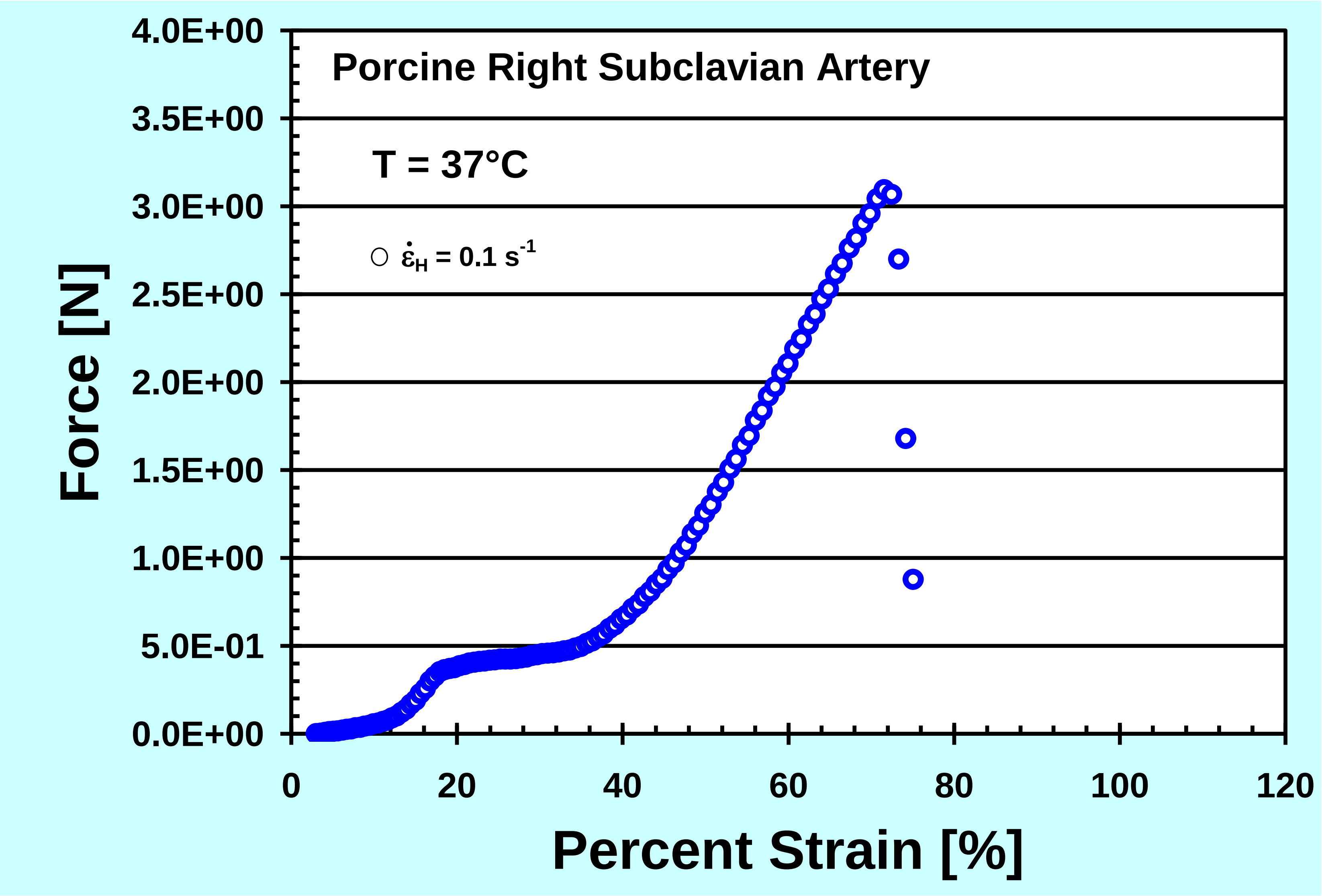


- Measurements were performed in a saline solution environment using a jacketed beaker and recirculation bath set to a temperature of 37°C.
- 420SS drums with a 180-grit surface texture were utilized on the SER2-P.

Subclavian Artery Section – 0.1s-1



Uniaxial Extension of Subclavian Artery Section



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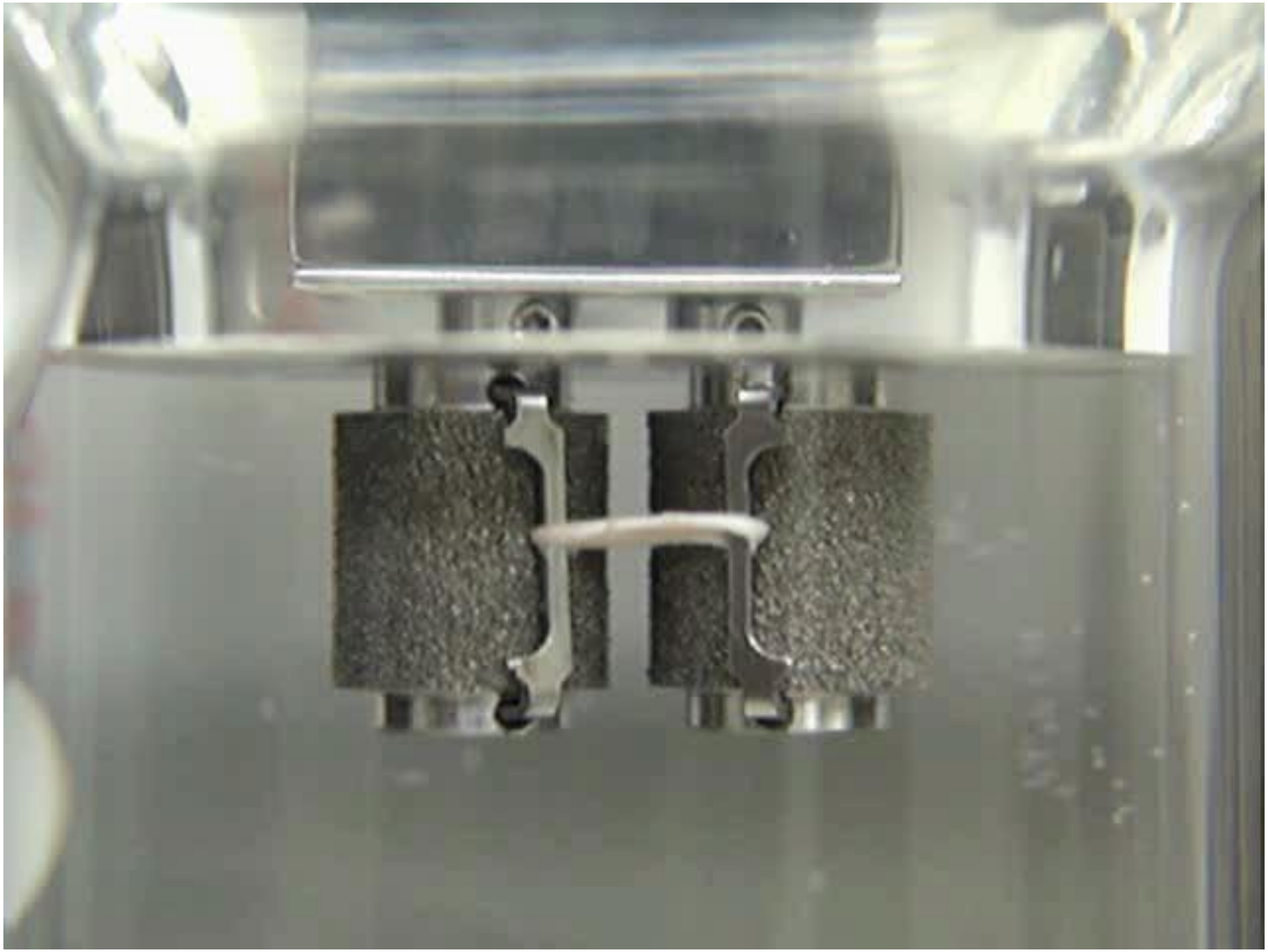

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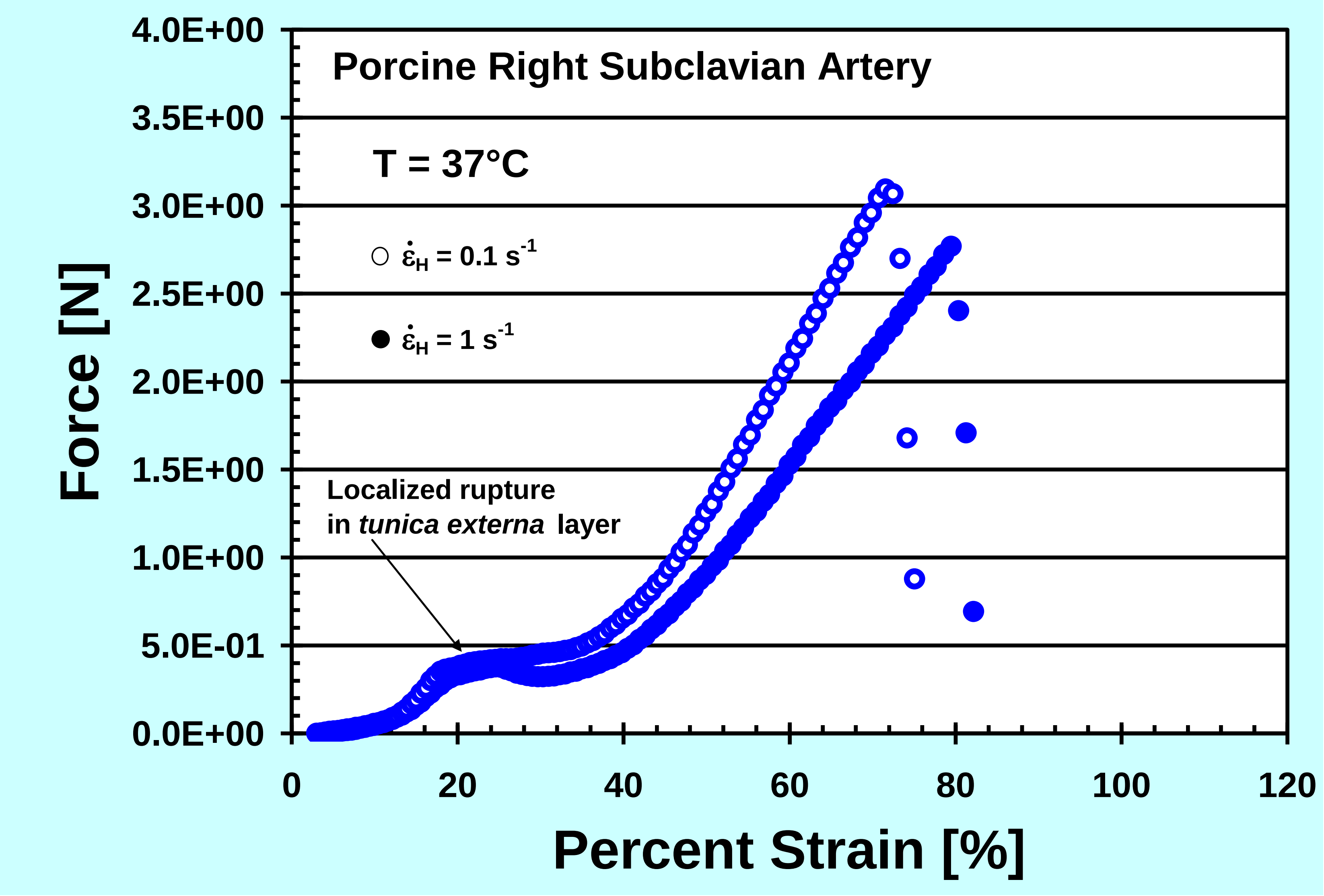
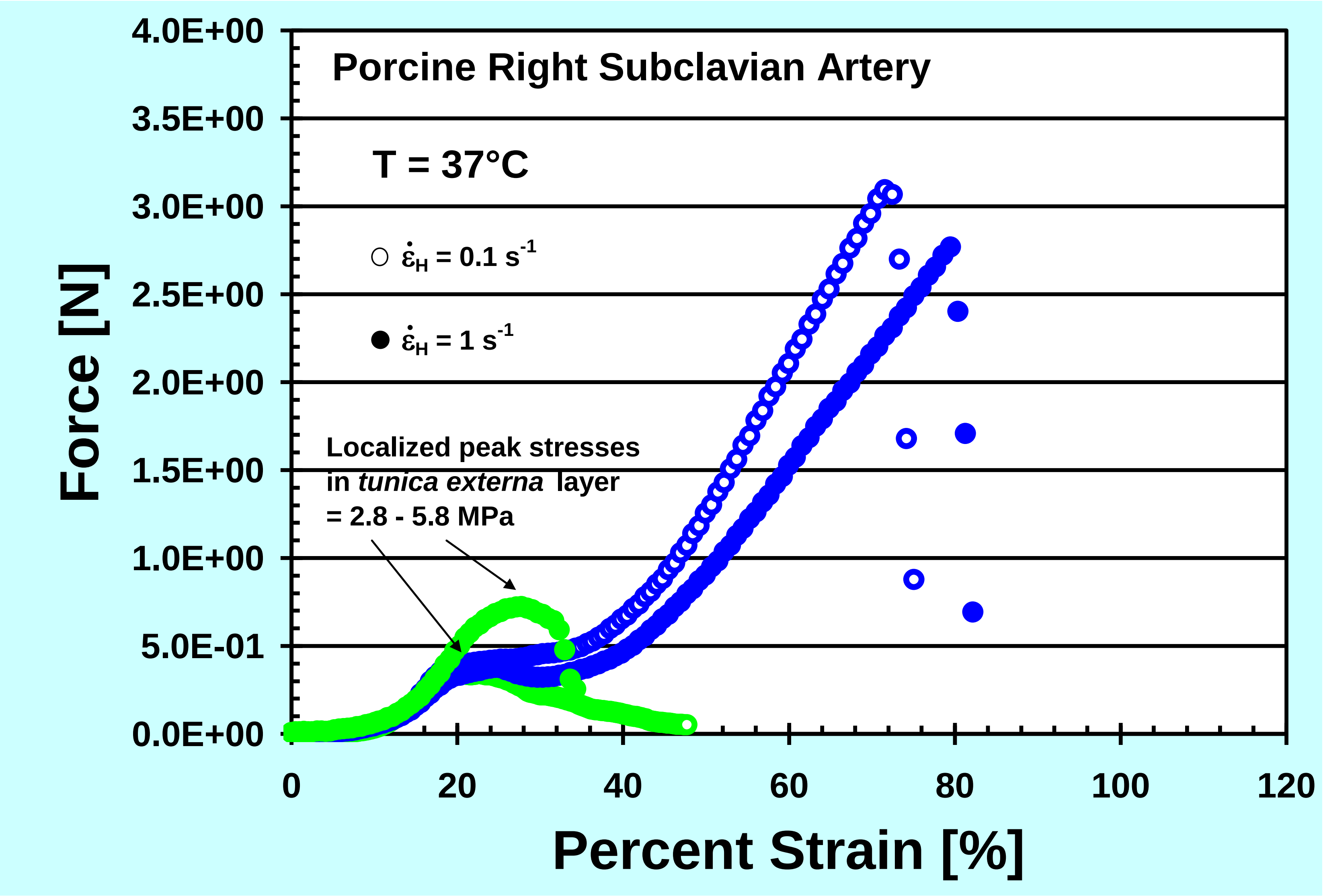
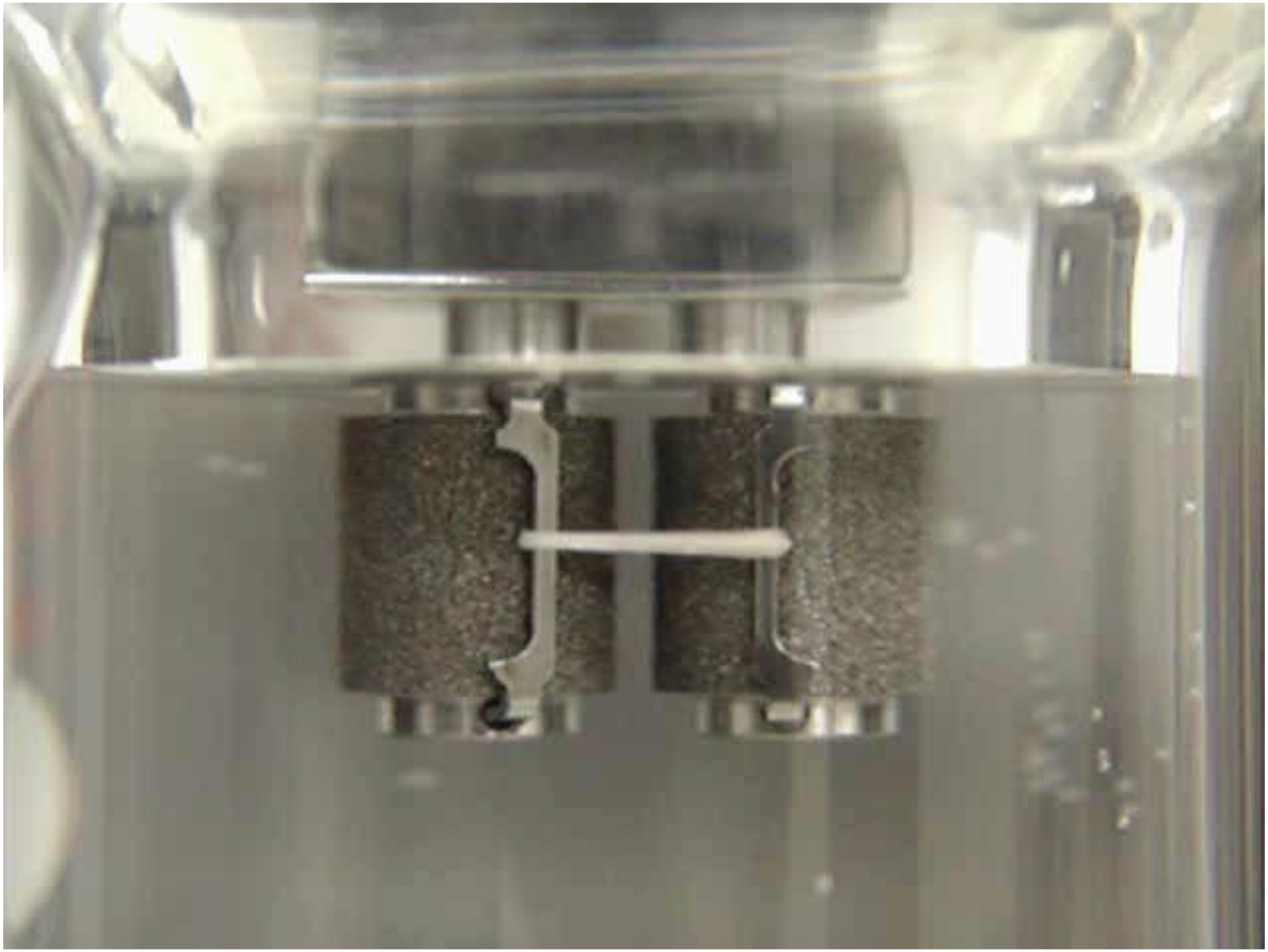


Subclavian Artery *tunica externa* layer – $0.1s^{-1}$

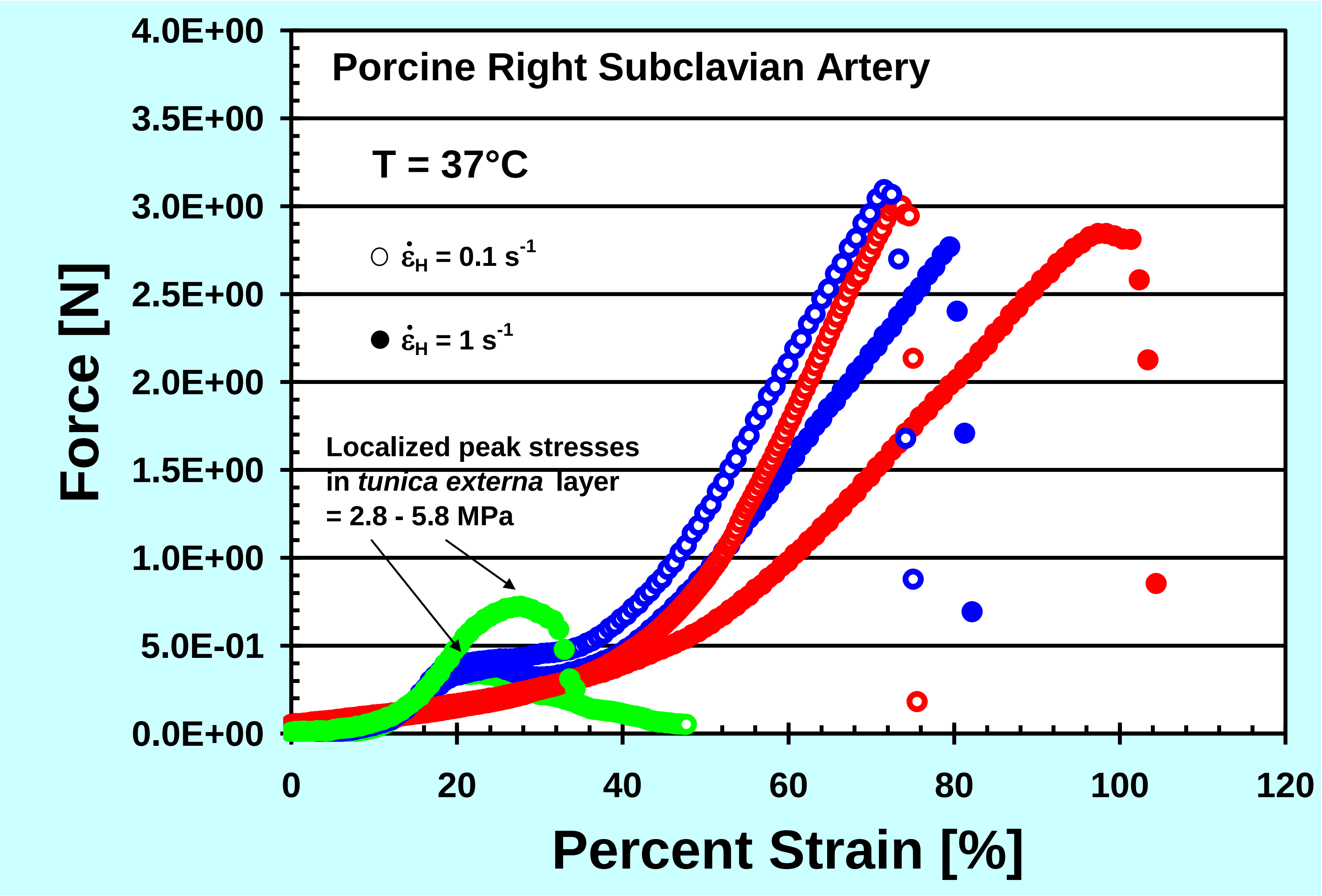
Uniaxial Extension of Subclavian Artery Section



Subclavian Artery *tunica media+intima* layers – $0.1s^{-1}$



Uniaxial Extension of Subclavian Artery Section



Vessel Extension/Dilation Summary

- Critical circumferential strain at rupture for:
  - Vessel composite (*tunica externa* + *media* + *intima*): 74-76%
  - *Tunica externa*: 20-28%
  - *Tunica media*: 74-94%

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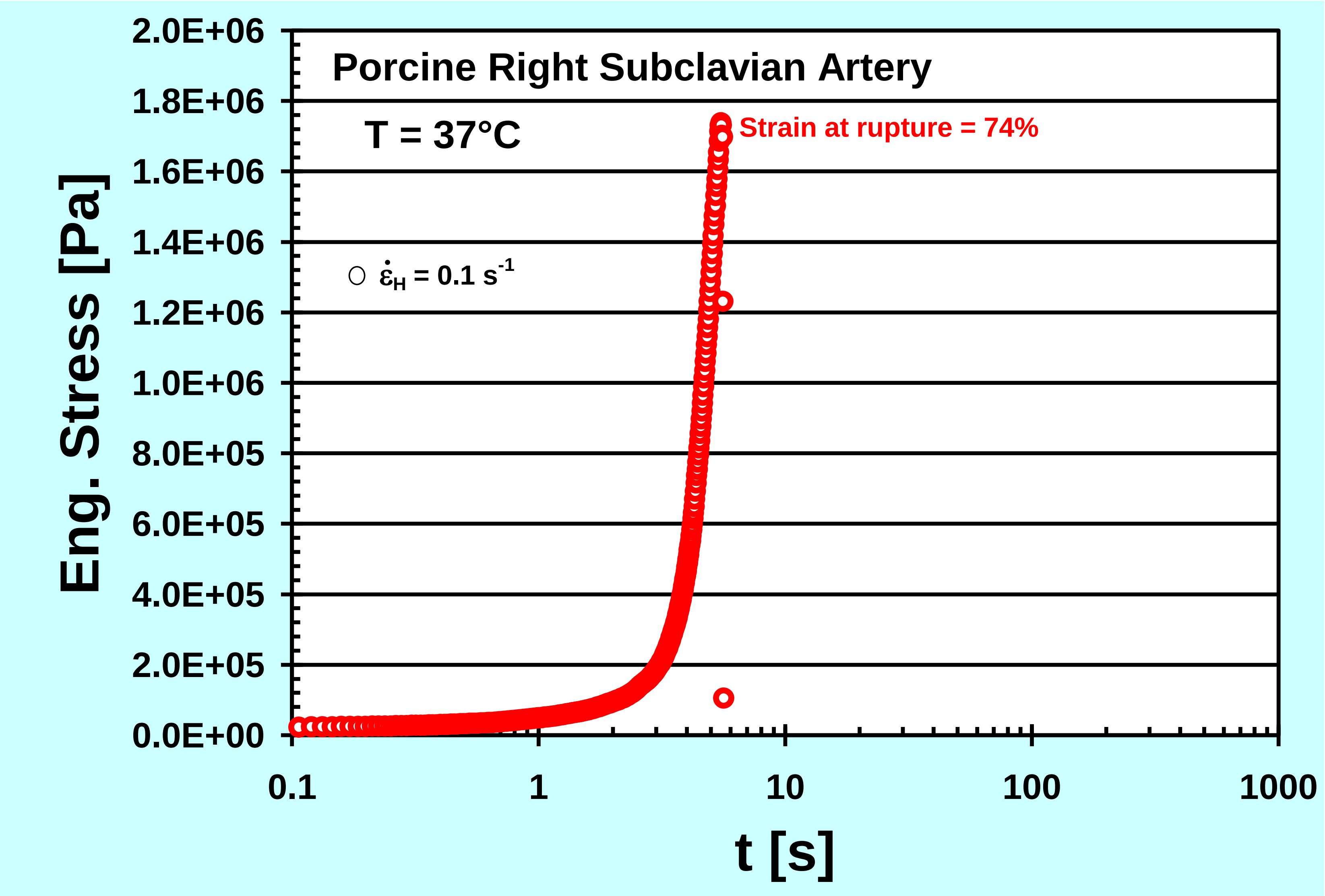
- van Andel, et. al, “Mechanical properties of porcine and human arteries: implications for coronary anastomotic connectors”, *The Annals of Thoracic Surgery* (2003) 76:58-64:
  - “…the porcine arteries could be safely stretched by 60% to 70% compared with about 20% for the human arteries before reaching their maximum circumferential strain.”

Stress Relaxation in Uniaxial Extension



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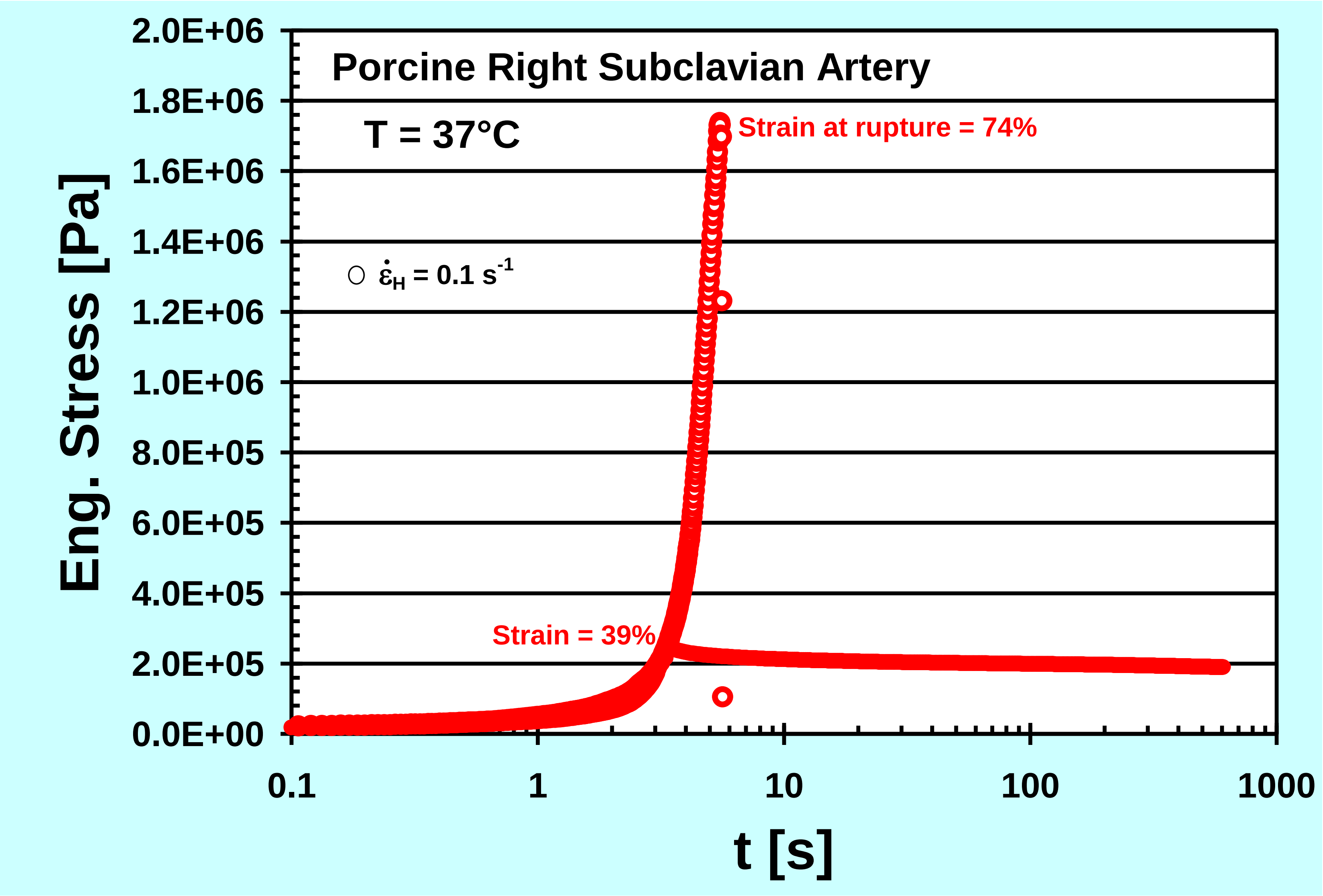

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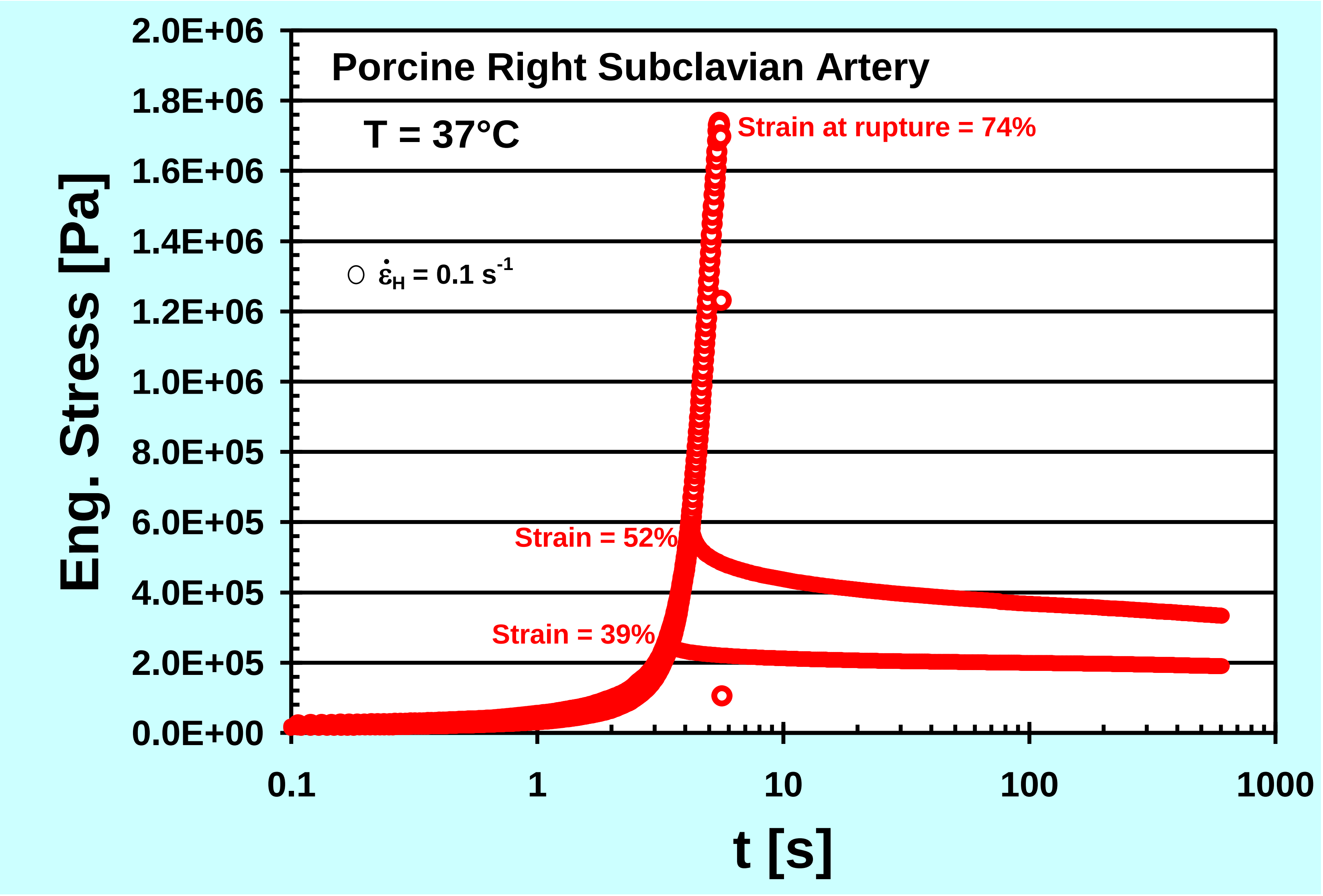

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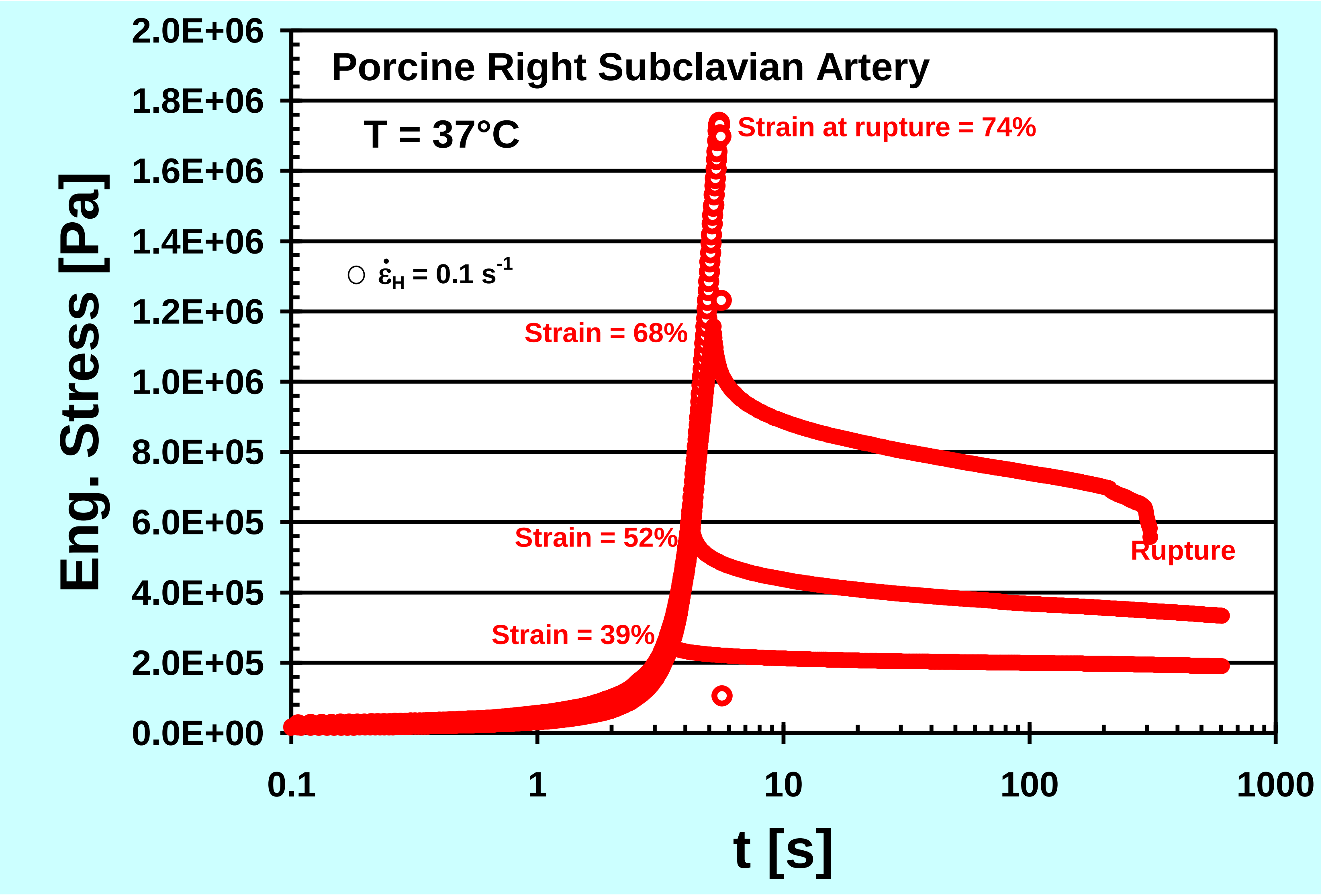

Summary

- The mechanical behavior of a porcine subclavian artery sections were characterized in uniaxial extension in a saline solution environment at 37°C with the use of the new SER2 Universal Testing Platform
- Results revealed that during blood vessel wall extension, the blood vessel behaves like a composite solid-like assembly
  - the thinner *tunica externa* layer ruptured at 20-28% elongation
  - the thicker *tunica media* layer ruptured at 74-94% elongation
- Failure of the *tunica externa* shell layer during vessel dilation appears to result in the propagation of a blood vessel aneurysm
- Stress relaxation experiments revealed that the tunica media layer can exhibit premature rupture under an extended period of vessel dilation