Aneurysm Rupture is Not Simply a Mechanical Event: How So and What Are The Implications ?

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Why mechanical properties?

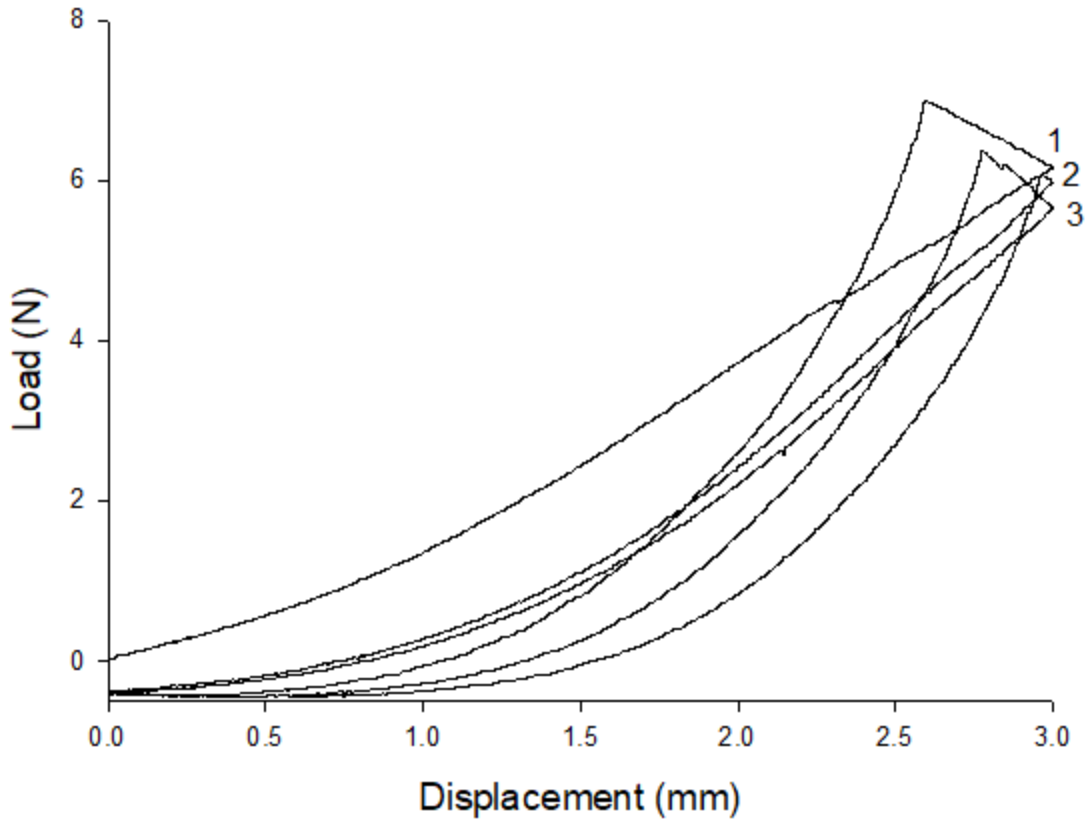
- Basic concept of aneurysm rupture
- Computational models

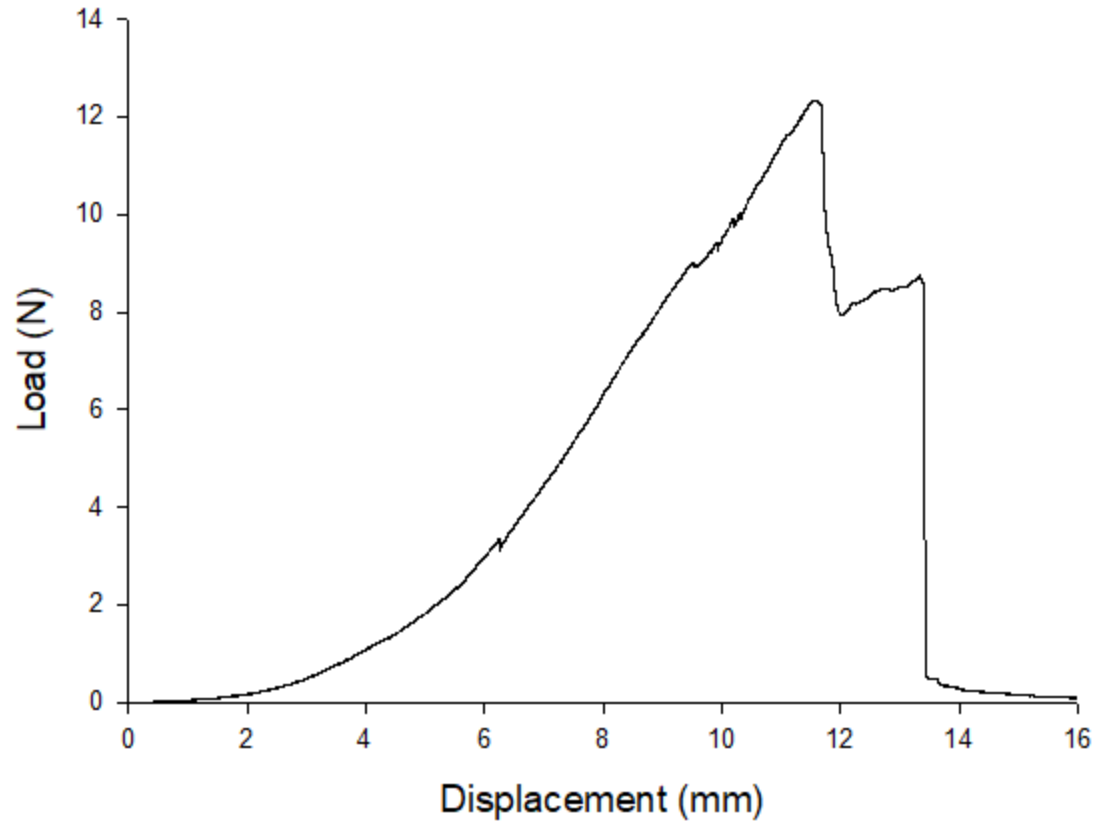
Mechanical Properties of Aorta

- Aneurysm wall specimens
- Standard strips for mechanical testing
- Control from beating heart organ donors

Mechanical testing

- Aneurysm wall taken during open repair
- Standard width strip cut using a custom made die-cutter
- Nene® tensile testing machine
- Three cycles followed by to failure

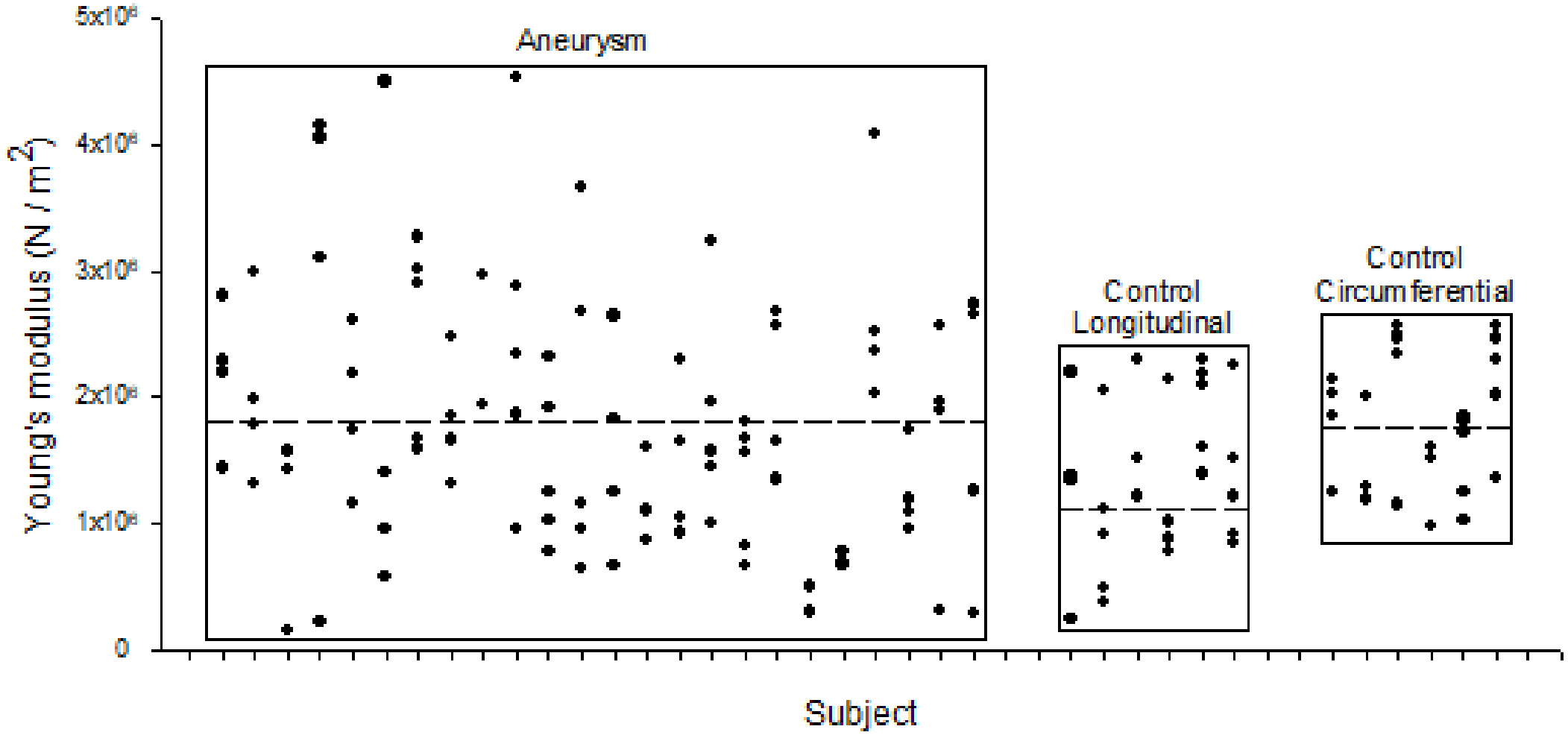

Load (N)
Displacement (mm)
1
2
3
0
2
4
6
8
0.0
0.5
1.0
1.5
2.0
2.5
3.0


Load (N)
Displacement (mm)
0
2
4
6
8
10
12
14
16

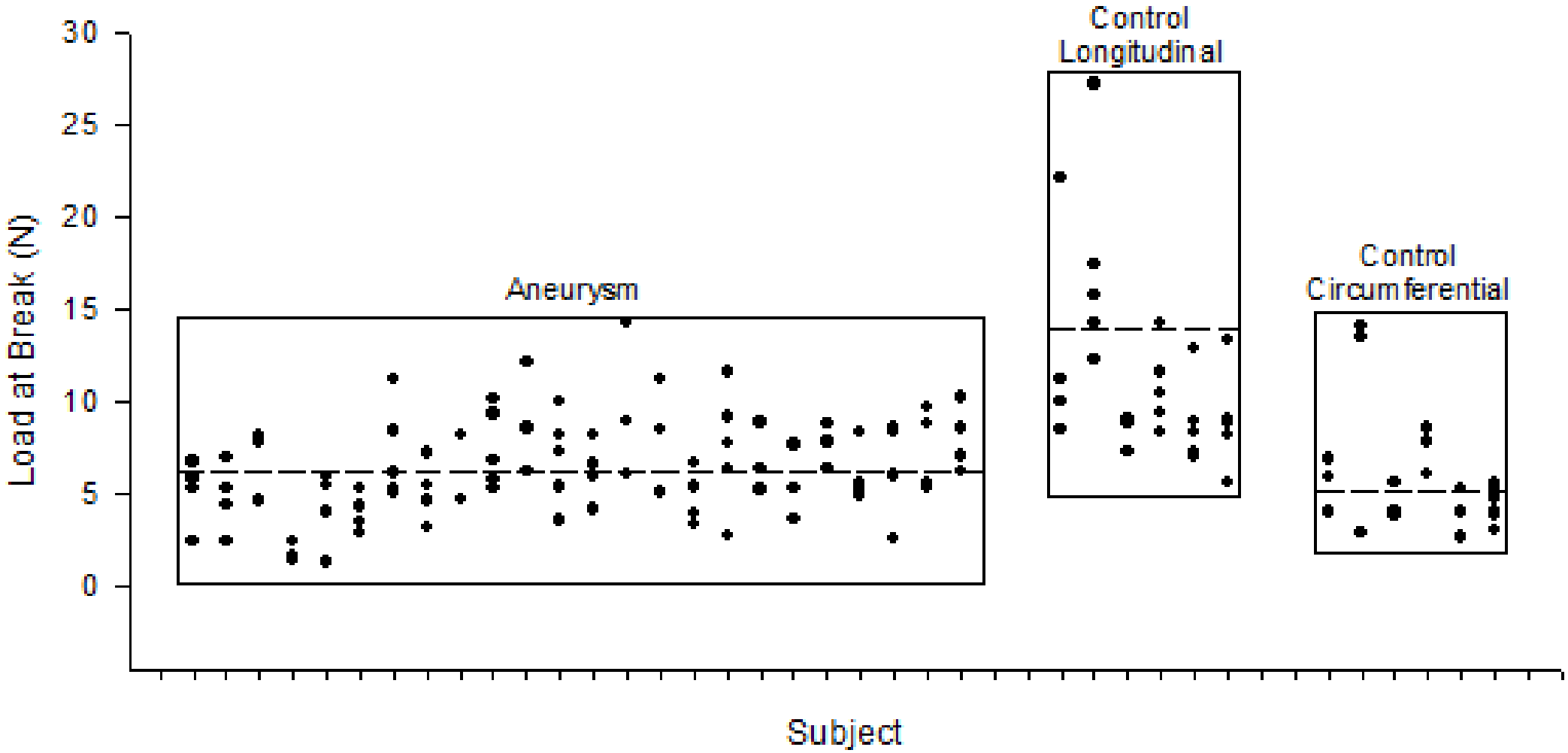
Results

Parameter	Mean	CV%	SE	F (p)
Aneurysm specimens (circumferential)				
Young's Modulus ($\times 10^6$ N/m^2)	1.80	7-96	0.10	1.57 (0.075)
Load at Break (N)	6.36	22-50	0.26	2.49 (0.002)
Strain at Break	0.30	14-56	0.02	5.94 (<0.0001)
Ultimate Strength ($\times 10^6$ N/m^2)	0.53	16-50	0.023	2.61 (0.001)
Non-aneurysmal aorta (circumferential)				
Young's Modulus ($\times 10^6$ N/m^2)	1.82	0.51	0.10	2.63 (0.55)
Load at Break (N)	5.43	2.93	0.57	4.51 (0.007)
Strain at Break	0.29	0.19	0.04	2.93 (0.38)
Ultimate Strength ($\times 10^6$ N/m^2)	0.61	0.35	0.07	4.75 (0.005)
Non-aneurysmal aorta (longitudinal)				
Young's Modulus ($\times 10^6$ N/m^2)	1.38	20-67	0.12	1.56 (0.216)
Load at Break (N)	11.38	11-48	0.93	3.56 (0.017)
Strain at Break	0.33	13-71	0.04	4.3 (0.008)
Ultimate Strength ($\times 10^6$ N/m^2)	1.30	12-48	0.11	4.24 (0.008)

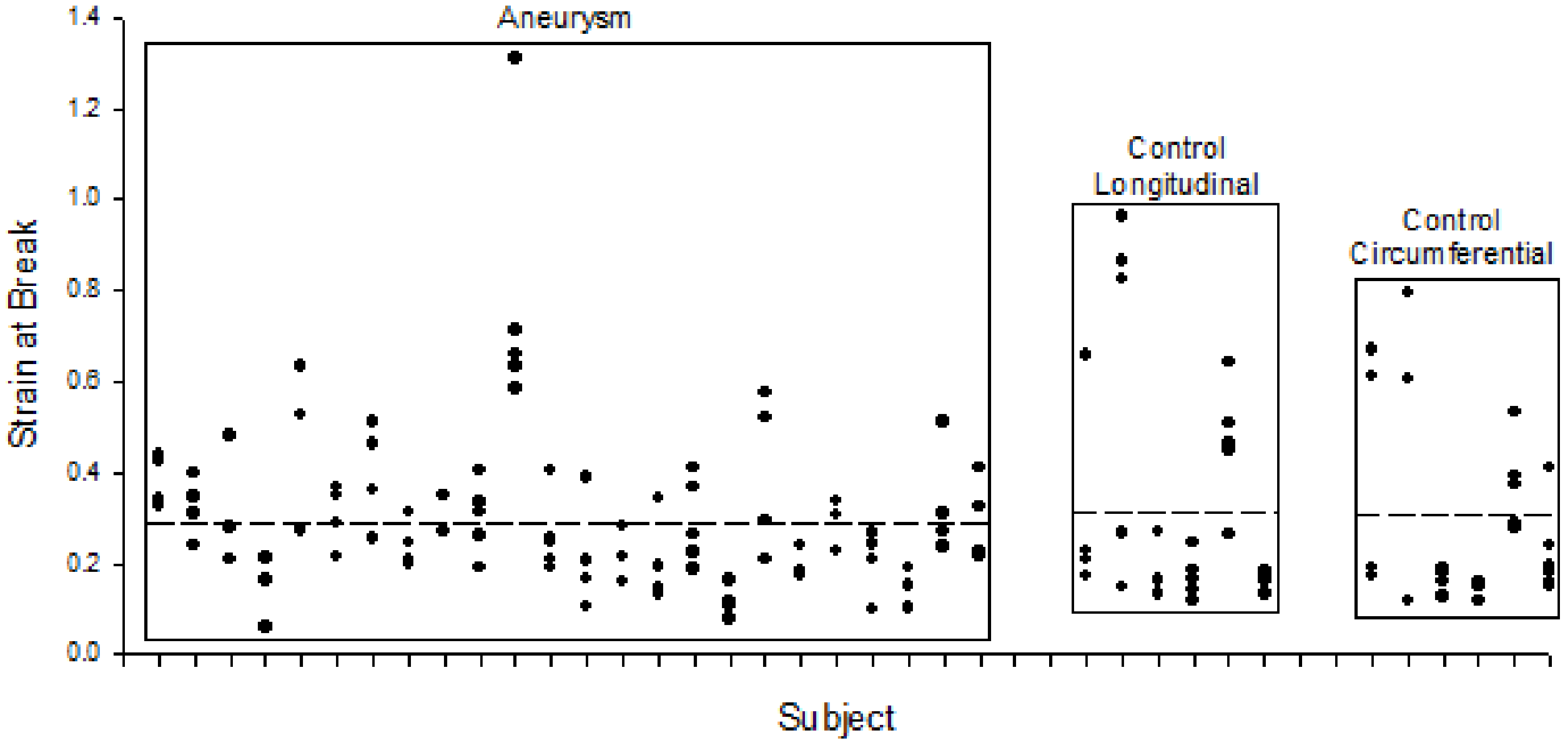
Young’s modulus



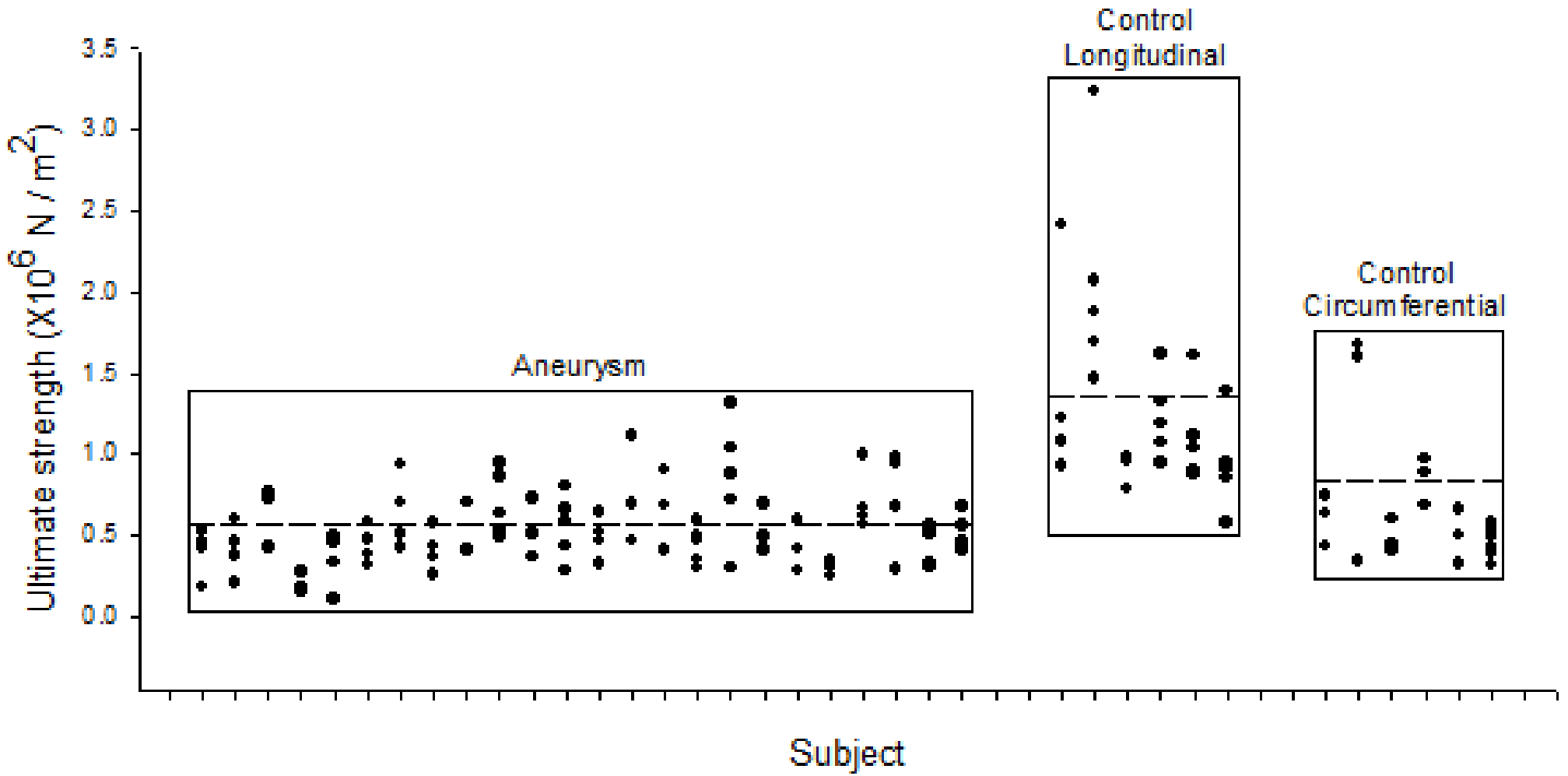
Load at break



Strain at Break



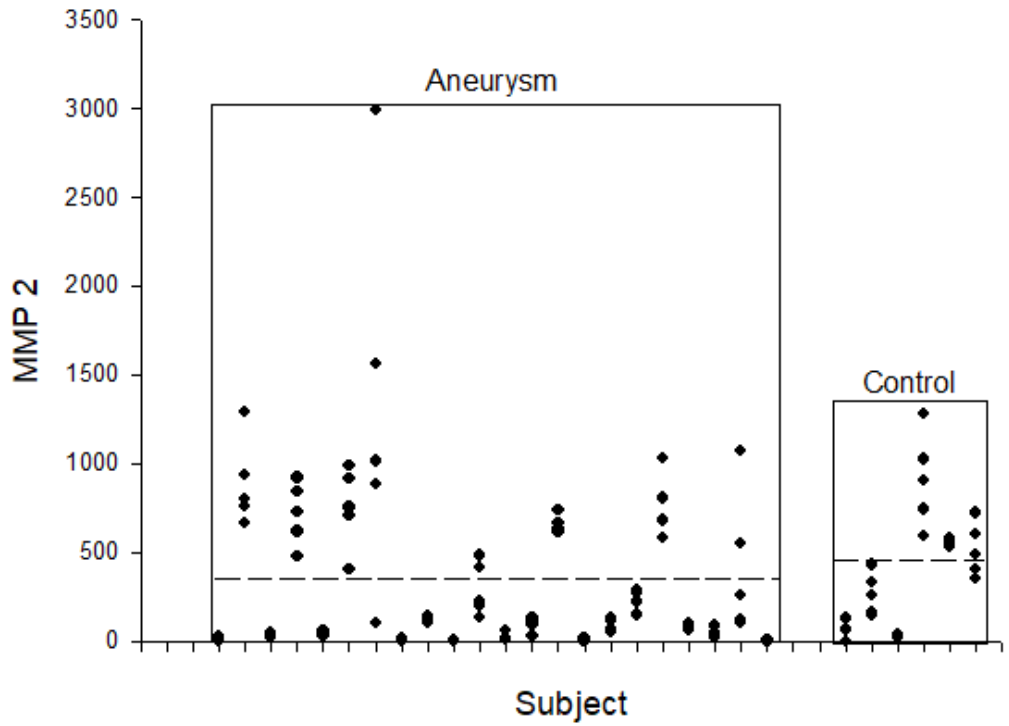
Ultimate Strength



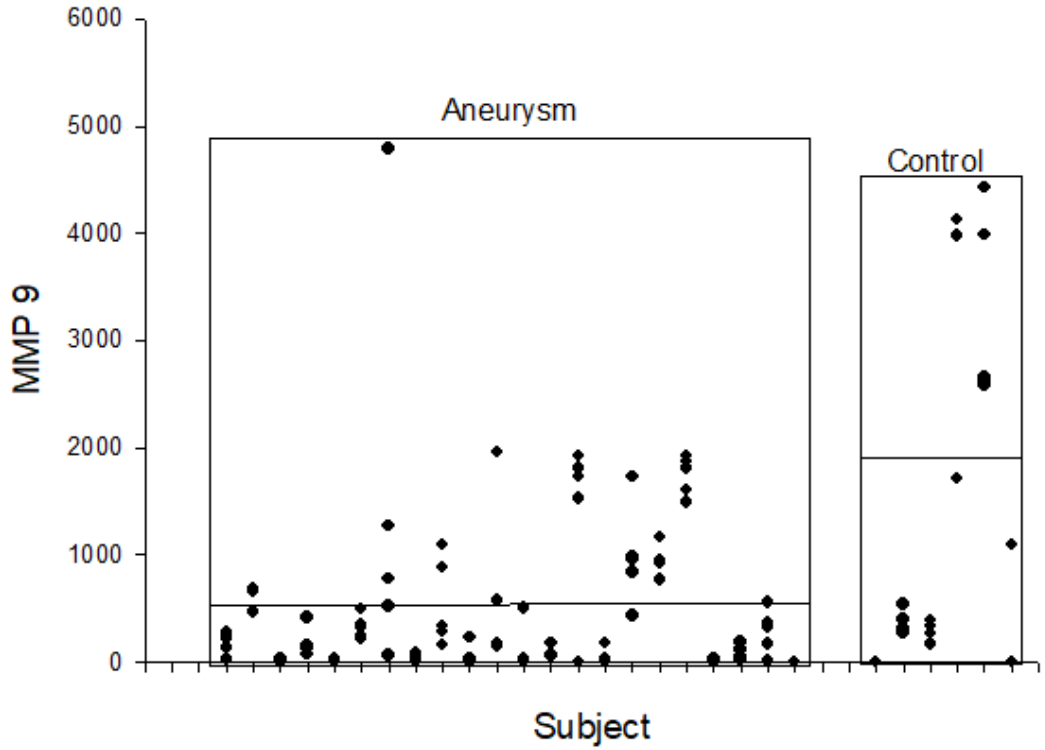
Burst pressure of aneurysms

- 142 – 948 mm Hg

MMP 2


3500
3000
2500
2000
1500
1000
500
0
MMP 2
Aneurysm
Control
Subject

MMP 9


6000
5000
4000
3000
2000
1000
0
MMP 9
Aneurysm
Control
Subject

Observations

- Mechanical properties of aorta are anisotropic
- Not homogenous
- High variance
- Strength is sufficiently high that mechanical failure is unlikely to be sole mechanism of rupture