Finite Element Modeling and Experimental Validation of a z-Type Self-Expanding Endovascular Stent

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Abstract

Stent migration due to haemodynamic drag remains the primary cause of type I endoleak, potentially leading to aneurysm rupture. The prevalence of migration and endoleak can be partially attributed to deficiencies in stent-graft radial spring design and a lack in understanding of the mechanical properties of endovascular stents. A converged finite element model of a custom radial extensometer was developed, fit, and validated using experimental results for bare stent wire (”uncovered”) with outer diameter of 12 mm stent. During stent constriction to 50 % of the original cross- sectional area, a comparison of experimental and modeled results produced an r2 value of 0.946, a standard error of 0.099 N, and a mean percent error of 1.69 %. This validated finite element model can be used to analyze the mechanisms responsible for radial force generation in 316L stainless steel self-expanding endovascular stents, as well as to evaluate new stent designs.

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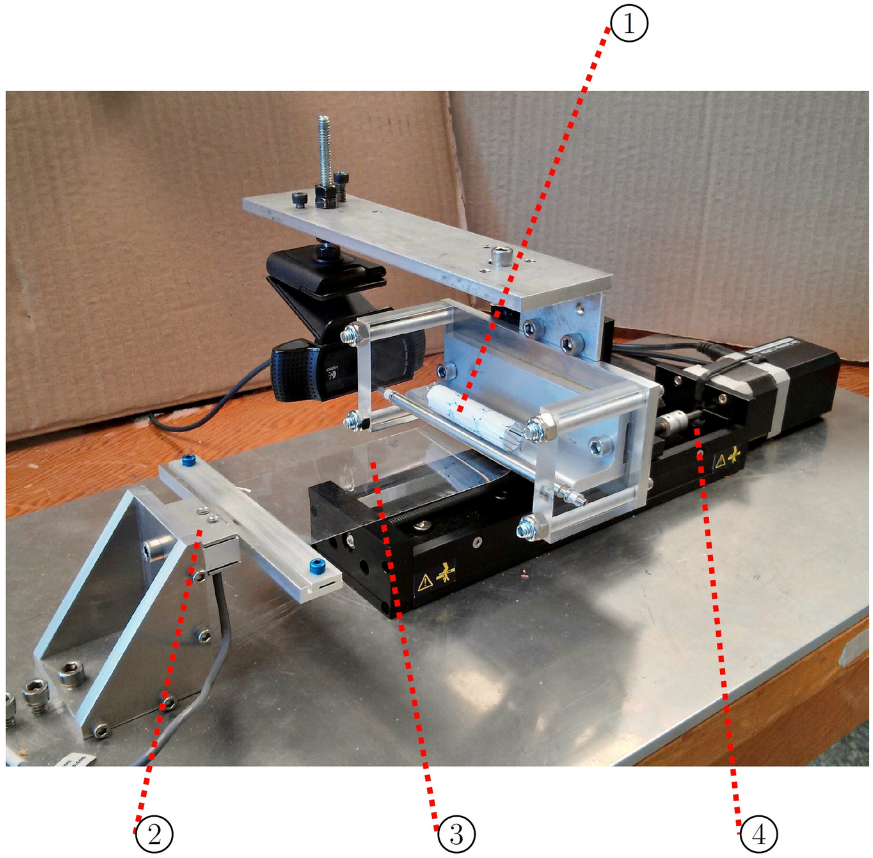
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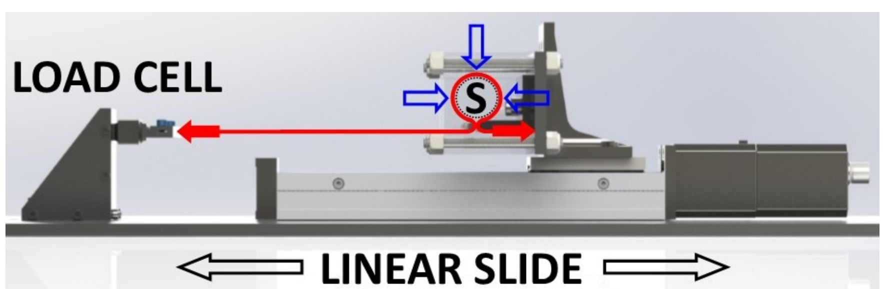
3
4


LOAD CELL
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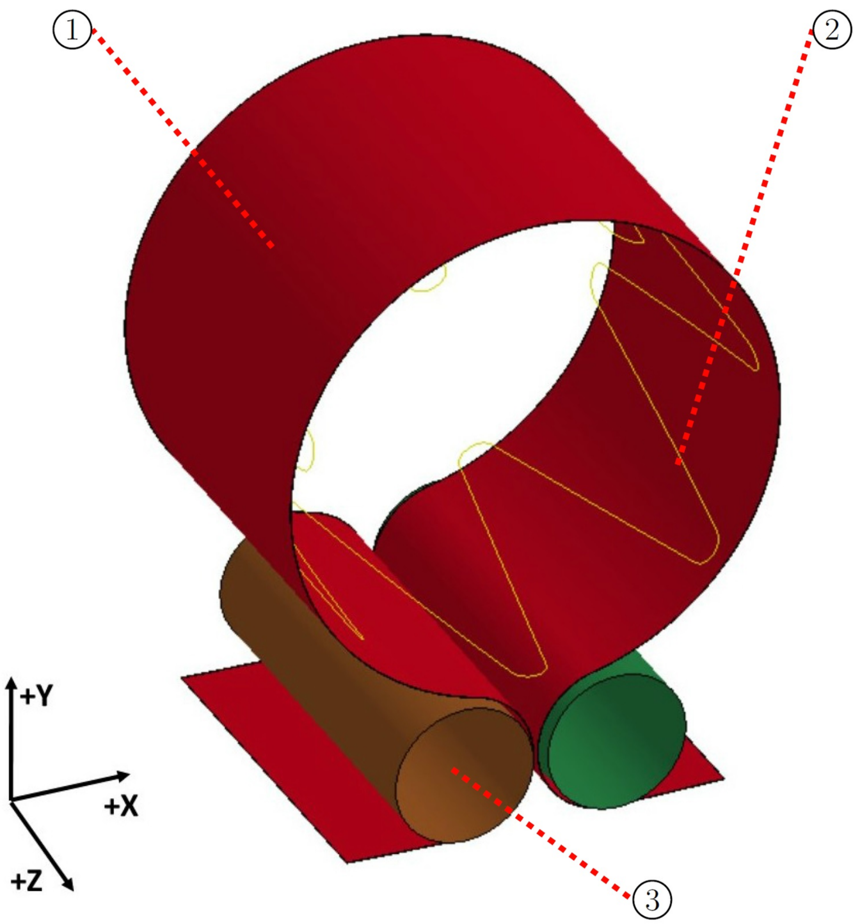
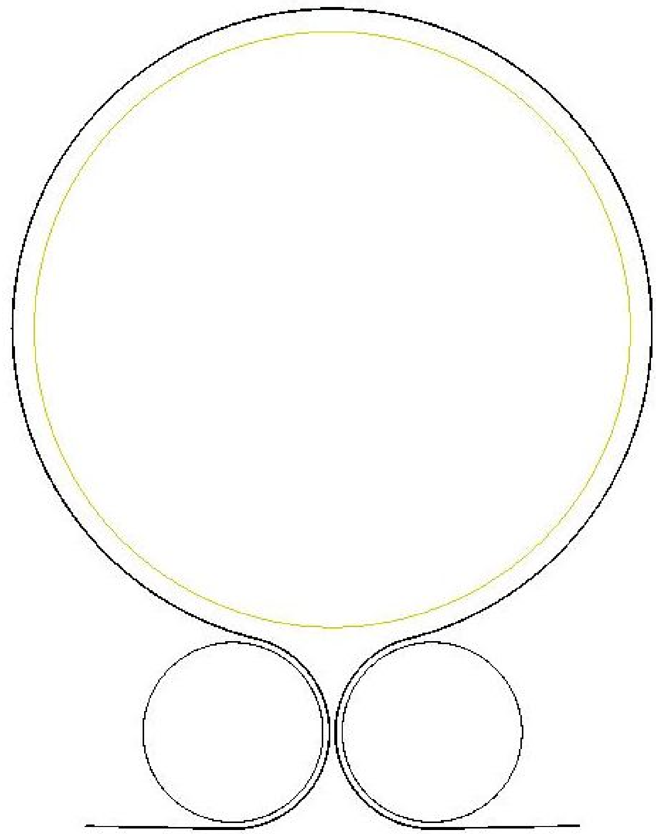
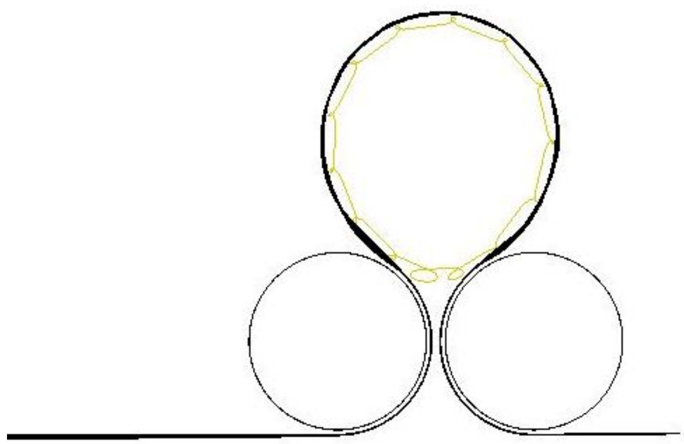
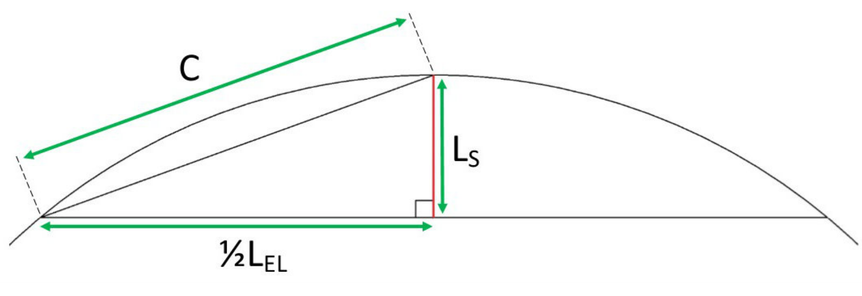
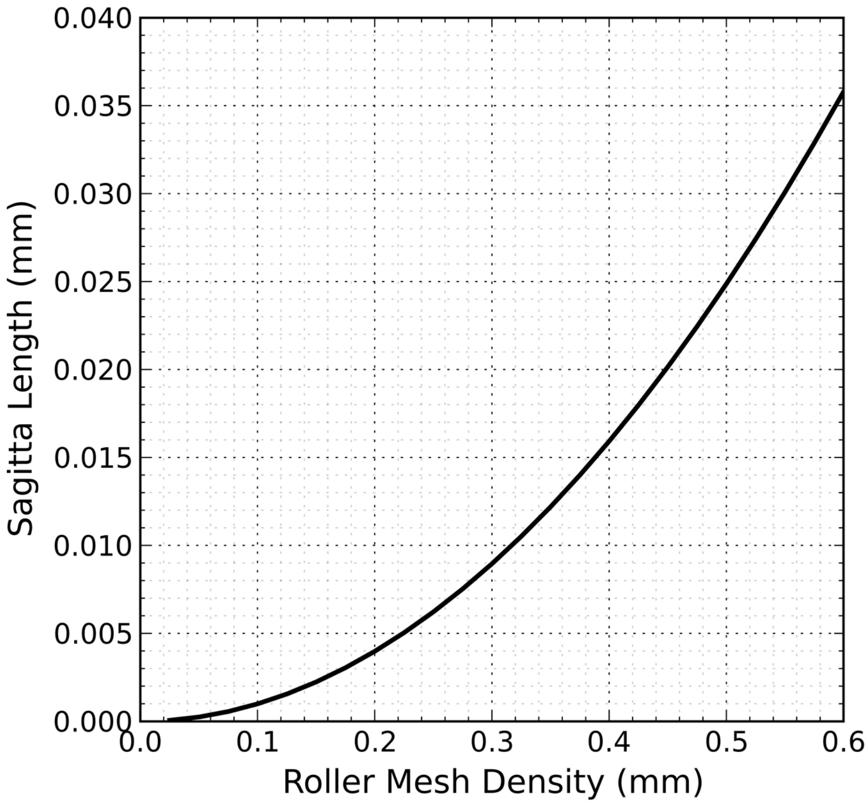
LINEAR SLIDE

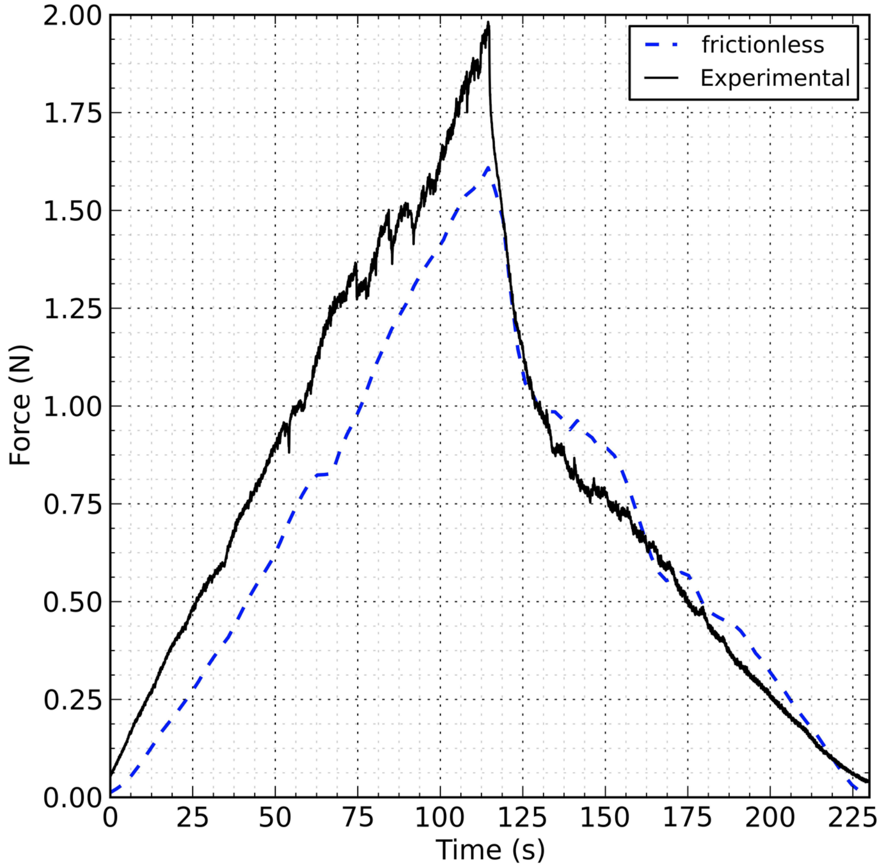

1
2
3
+Y
+X
+Z

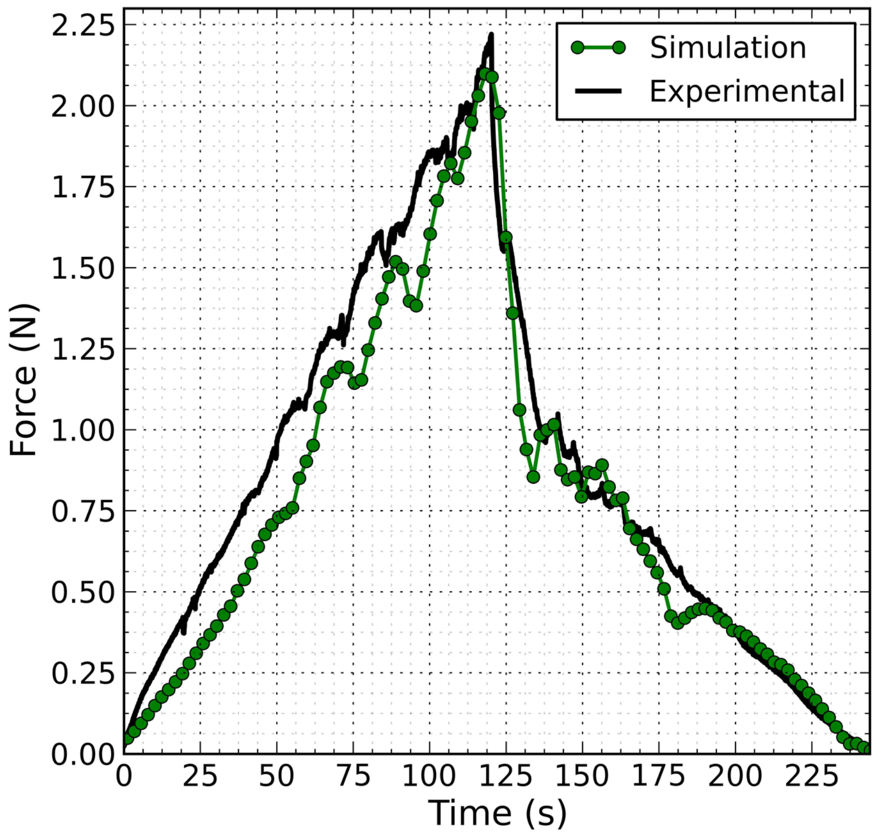


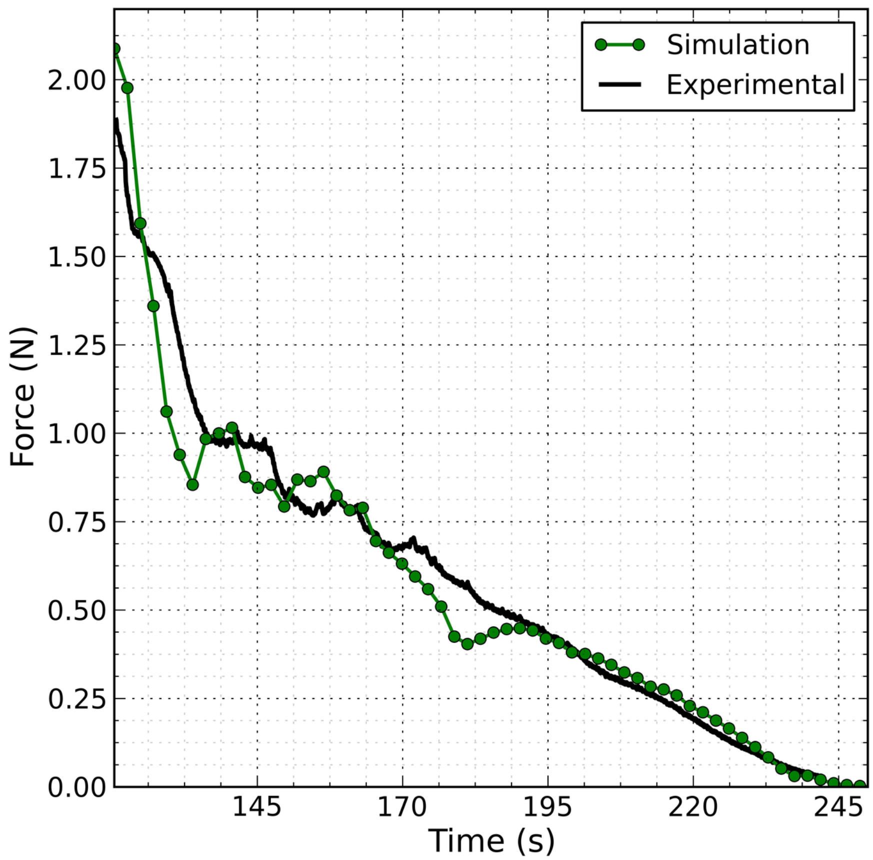


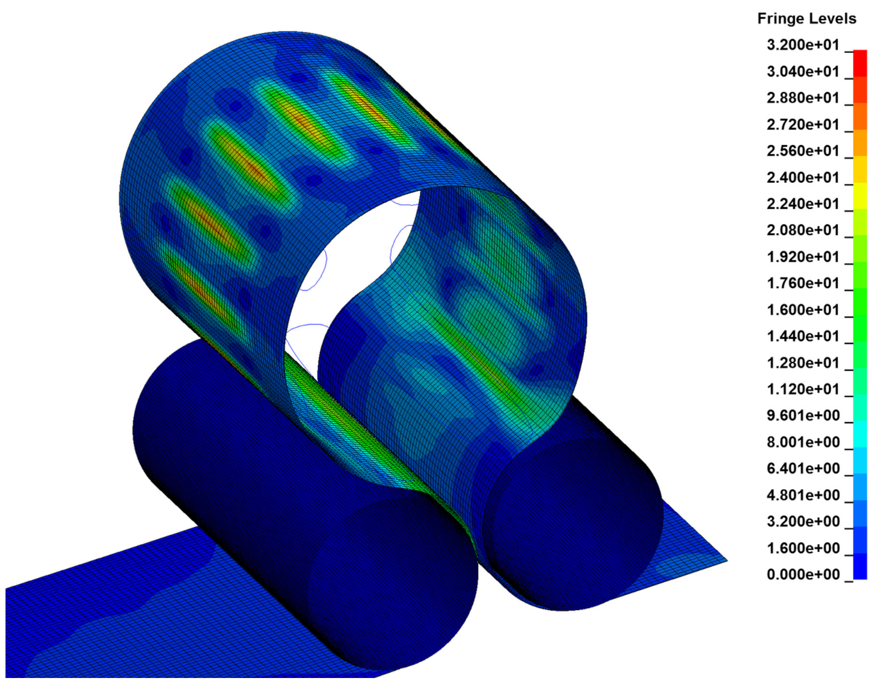

C
L_S
½L_EL


0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Sagitta Length (mm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Roller Mesh Density (mm)


frictionless
Experimental
Force (N)
Time (s)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
25
50
75
100
125
150
175
200
225


Simulation
Experimental
Force (N)
Time (s)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
0
25
50
75
100
125
150
175
200
225


Simulation
Experimental
Force (N)
Time (s)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
145
170
195
220
245


Fringe Levels
3.200e+01
3.040e+01
2.880e+01
2.720e+01
2.560e+01
2.400e+01
2.240e+01
2.080e+01
1.920e+01
1.760e+01
1.600e+01
1.440e+01
1.280e+01
1.120e+01
9.601e+00
8.001e+00
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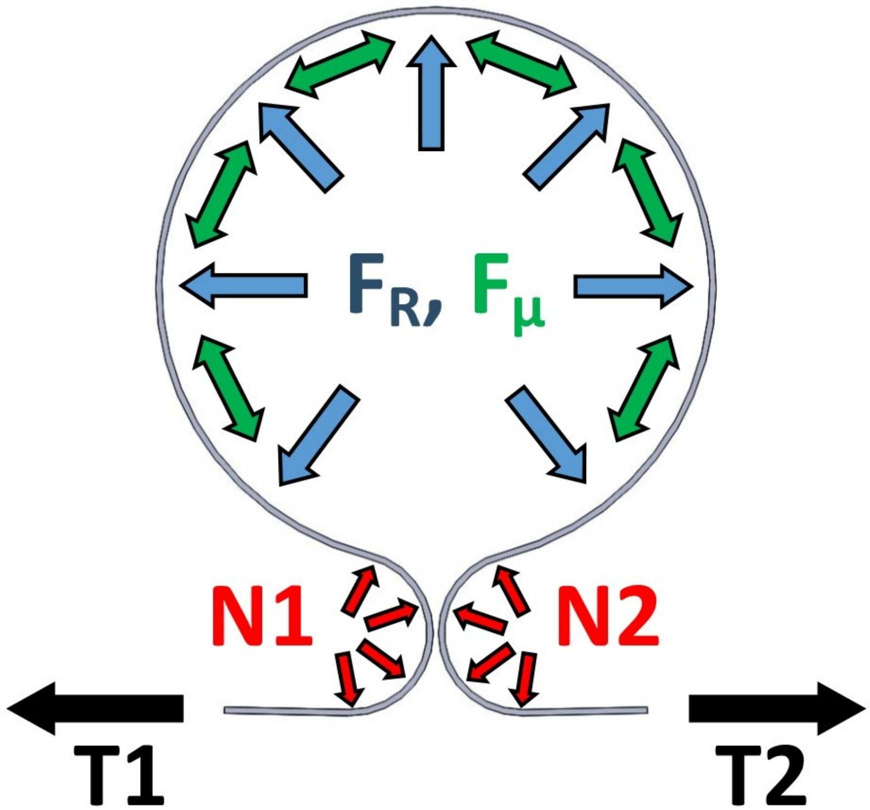
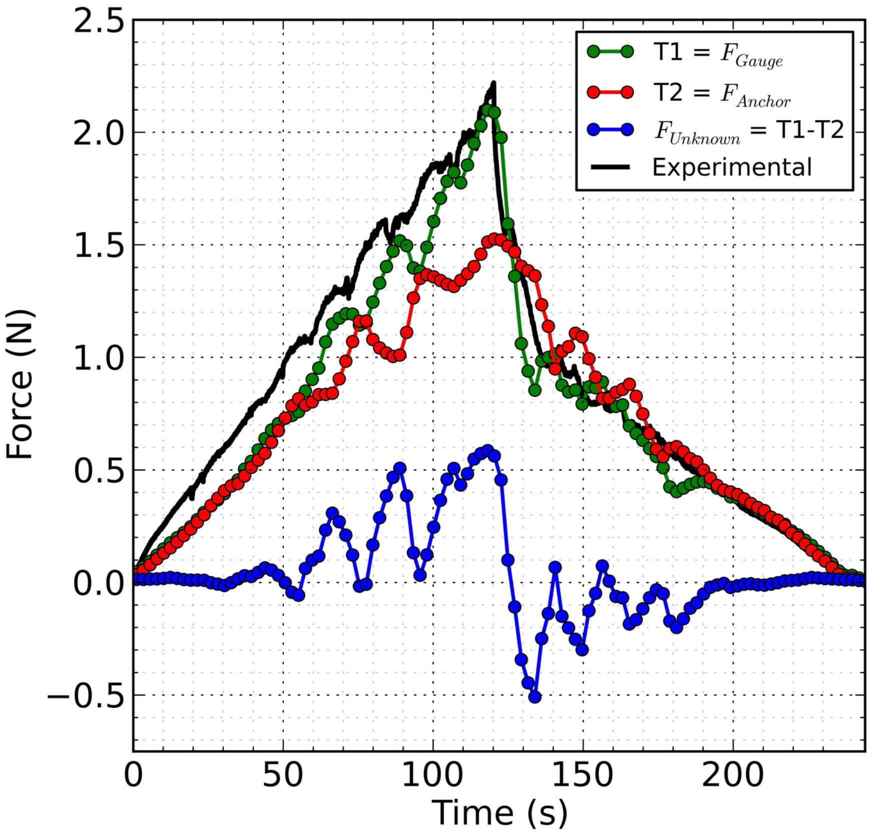
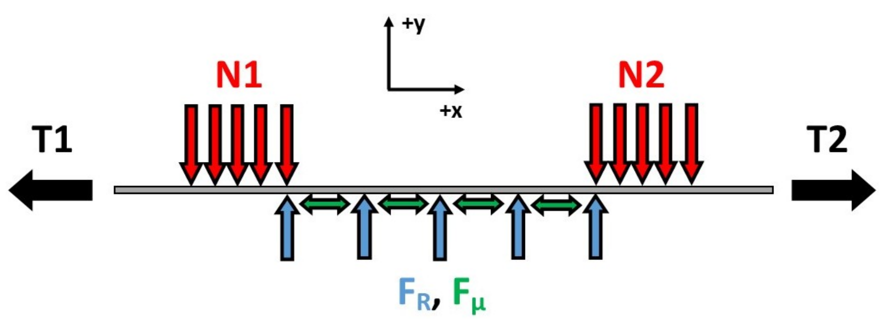
4.801e+00
3.200e+00
1.600e+00
0.000e+00


F_R, F_μ
N1
N2
T1
T2

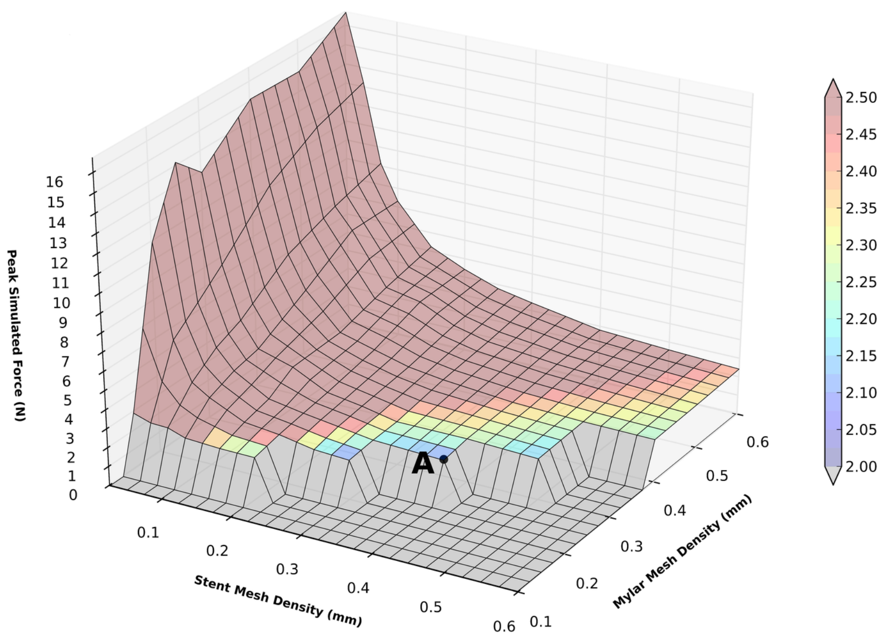


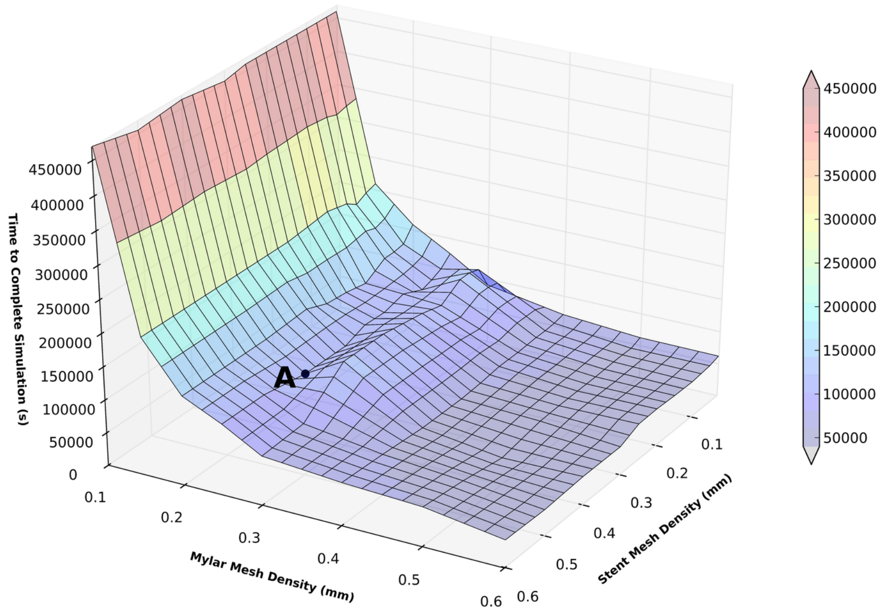


Property	Typical Value	Unit
Tensile strength, ultimate	585	MPa
Tensile strength, yield	380	MPa
Young's modulus	193	GPa
Density	0.008	g/mm^3
Poisson's ratio	0.3	

Property	Direction	Typical Value	Unit
Tensile strength, ultimate	MD	196	MPa
	TD	235	MPa
Young's modulus (tension)	MD	4805	MPa
	TD	5001	MPa
Young's modulus (compression)		2726 – 2834	MPa
Density		0.00139	g/mm^3
Poisson's ratio		0.38	

Coulomb	CPU Time (s)	F_{Peak} (N)	r^2	SE (N)	MAPE (%)	MPE (%)
0.0	98638	1.61	0.967	0.072	15.20	-8.29
0.00001	92002	1.97	0.852	0.150	20.44	12.38
0.0001	91927	2.14	0.842	0.155	20.51	11.10
0.0005	93533	2.04	0.860	0.146	19.70	11.61
0.001	96466	2.10	0.914	0.114	16.01	3.76
0.0025	**98638**	**2.04**	**0.946**	**0.099**	**11.69**	**1.69**
0.005	93534	2.12	0.843	0.154	20.24	11.21
0.0075	95597	2.04	0.865	0.143	19.64	11.73
0.01	93155	2.15	0.811	0.169	20.48	11.28
0.02	97391	2.13	0.934	0.100	13.56	4.55
0.05	99542	2.11	0.919	0.111	15.92	11.52
0.075	81722	2.40	0.776	0.184	19.20	11.53
0.1	81794	2.47	0.750	0.195	20.74	13.42
0.2	81794	2.62	0.502	0.275	33.96	26.70




Time to Complete Simulation (s)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0.1
0.2
0.3
0.4
0.5
0.6
Mylar Mesh Density (mm)
0.1
0.2
0.3
0.4
0.5
0.6
Stent Mesh Density (mm)
A
450000
400000
350000
300000
250000
200000
150000
100000
50000