Modern trends in personalized hemodynamics

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Mathematical models in biomedicine-2022, Moscow

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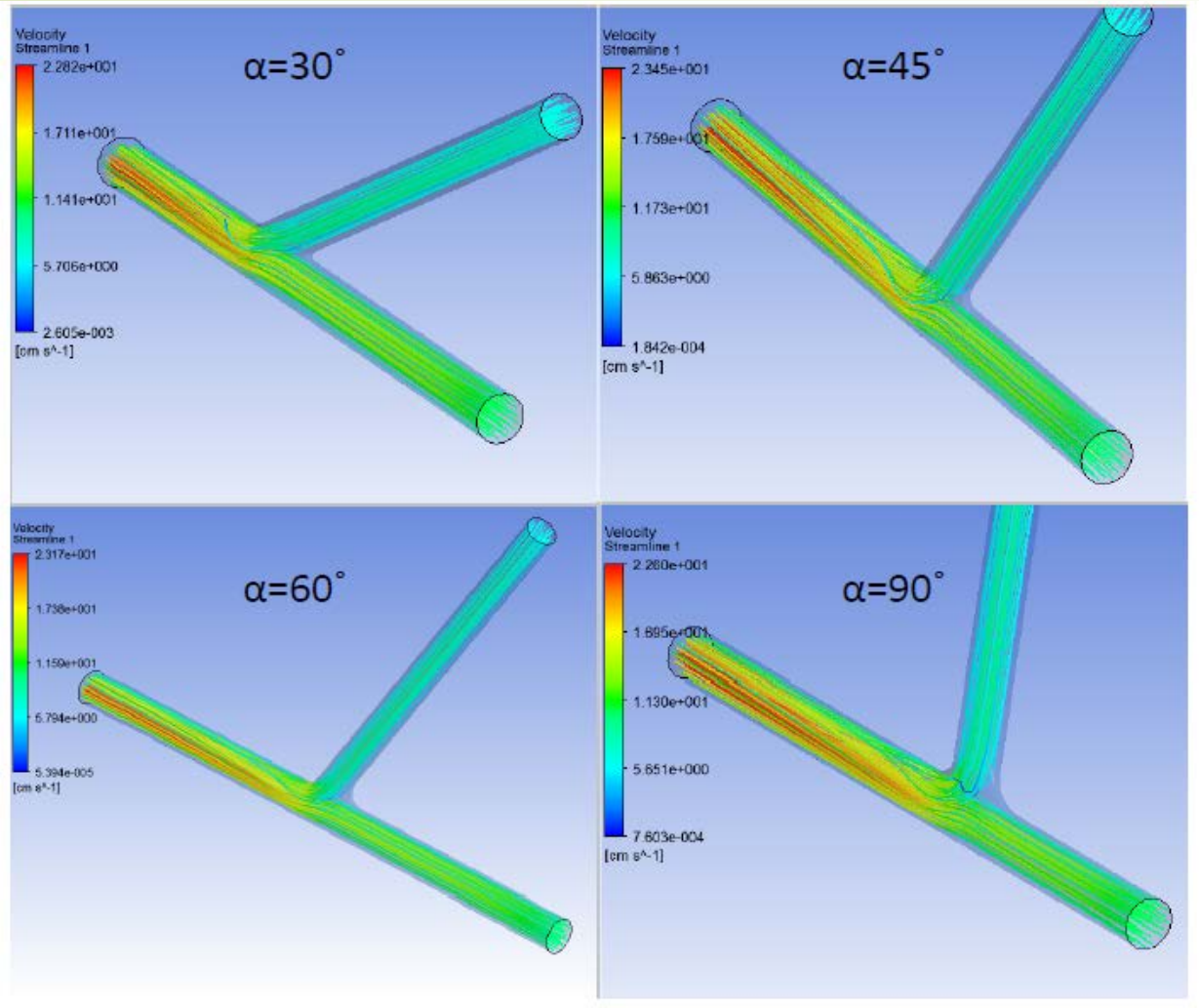
Outline

- **Cerebral circulation**
  - Bypasses
  - Stent deployment
  - Uncertainty of boundary conditions
  - Risk calculation

- **Abdominal circulation**
  - Geometry * hemodynamic factors

- **Hydrodynamics of nonadhesive embolisates**

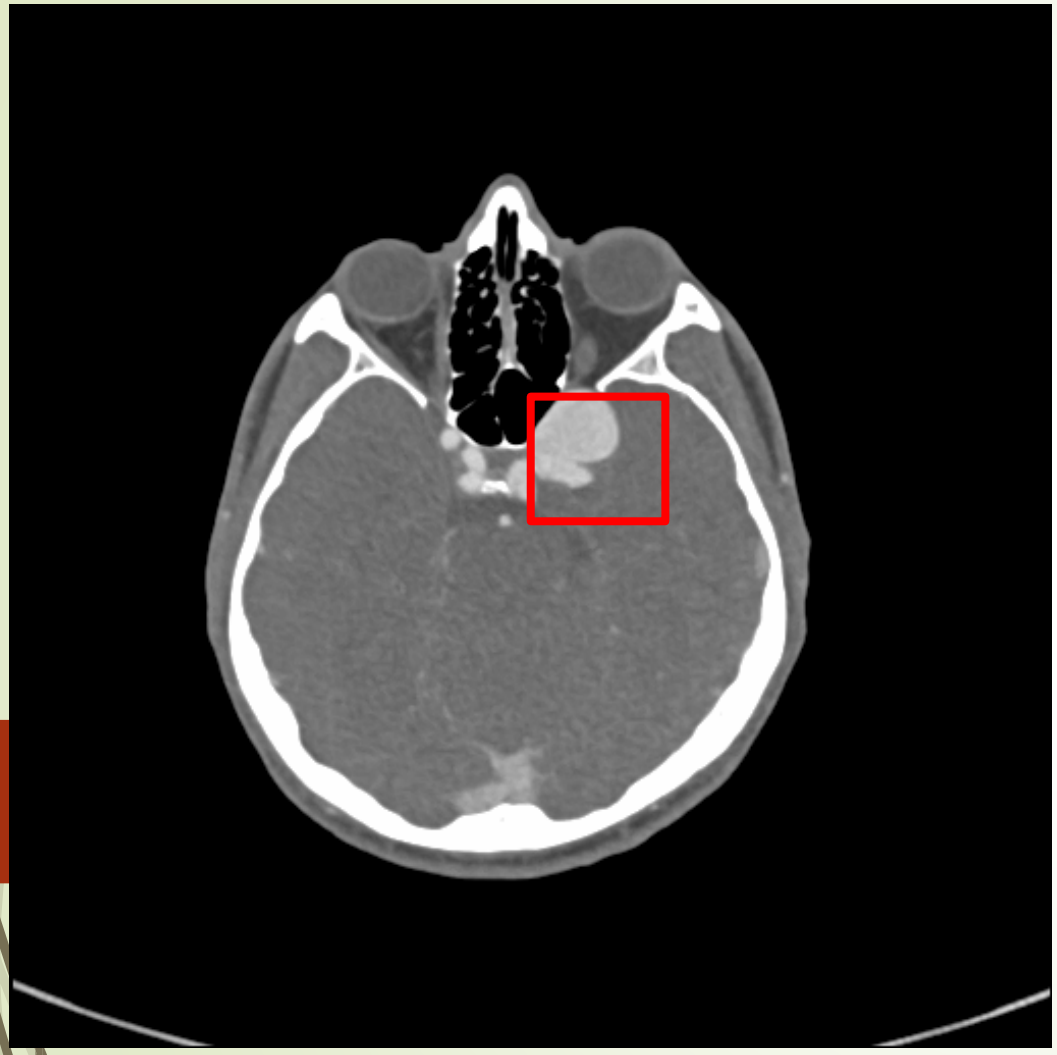
Optimal bypass angle



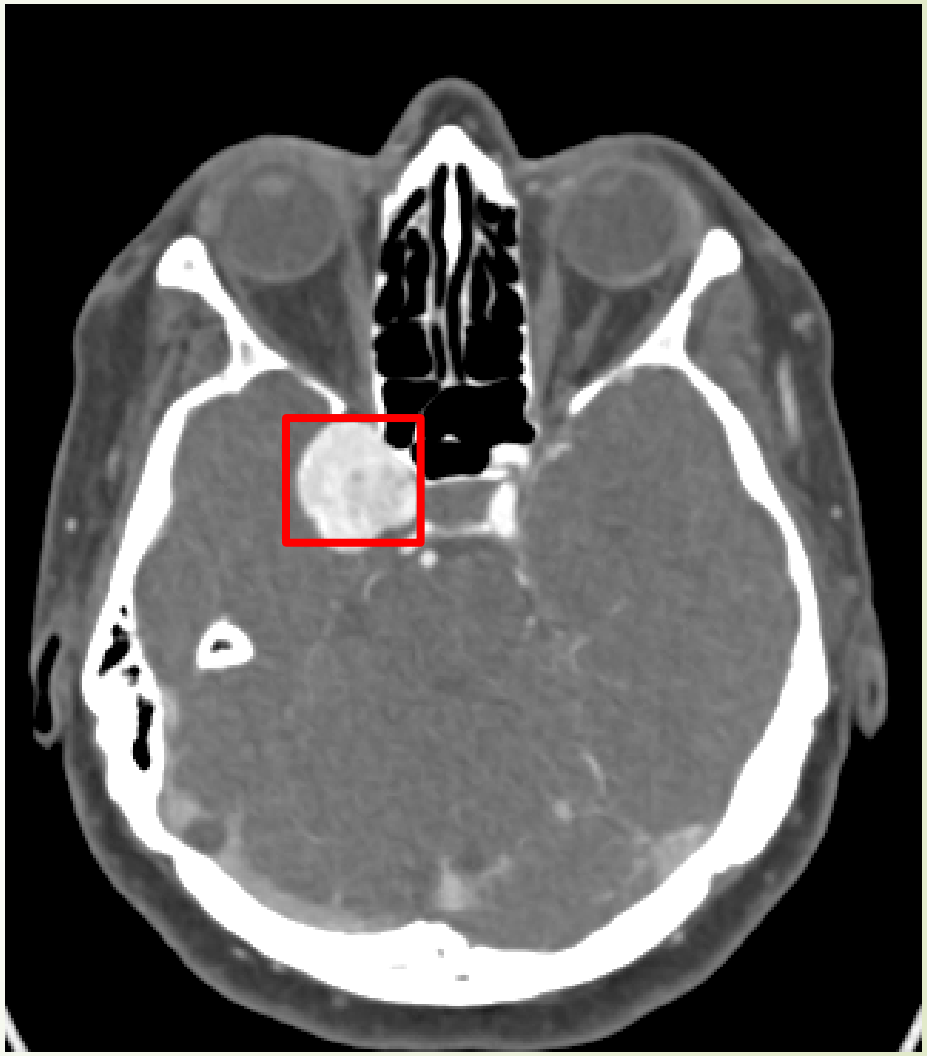
V(cm/s),R(mm)	π/6	π/4	π/3	π/2
Minimal values of D integral, J/s *10^{-7}				
V_1=6, R_1=14	**13523**	17192	**13365**	**13892**
V_1=6 ,R_1=13.896	14799	**16387**	16246	15736
Maximal values of D integral, J/s *10^{-7}				
V_1=14 ,R_1=10,1	**36734**	**48062**	**42211**	**39886**

Kuianova et al, App. Mech. Tech. Phys 2020

Clinical cases

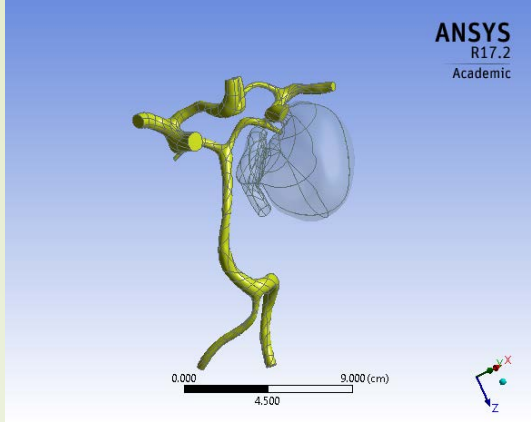


Case1: M,22 ICA aneurysm(L)



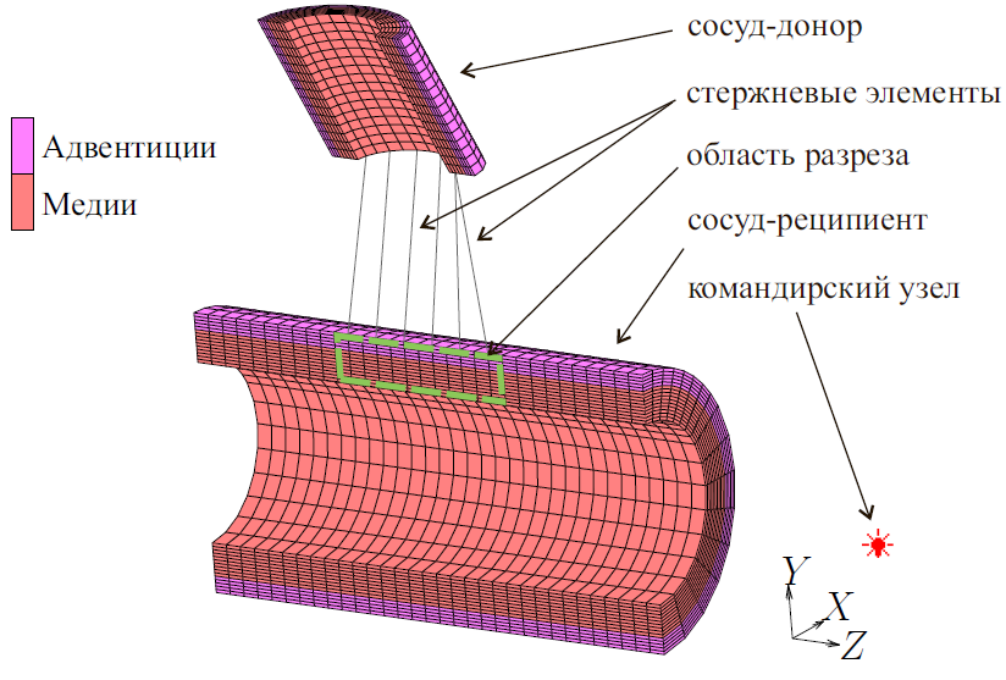
Case2: F, 50 ICA aneurysm (R)

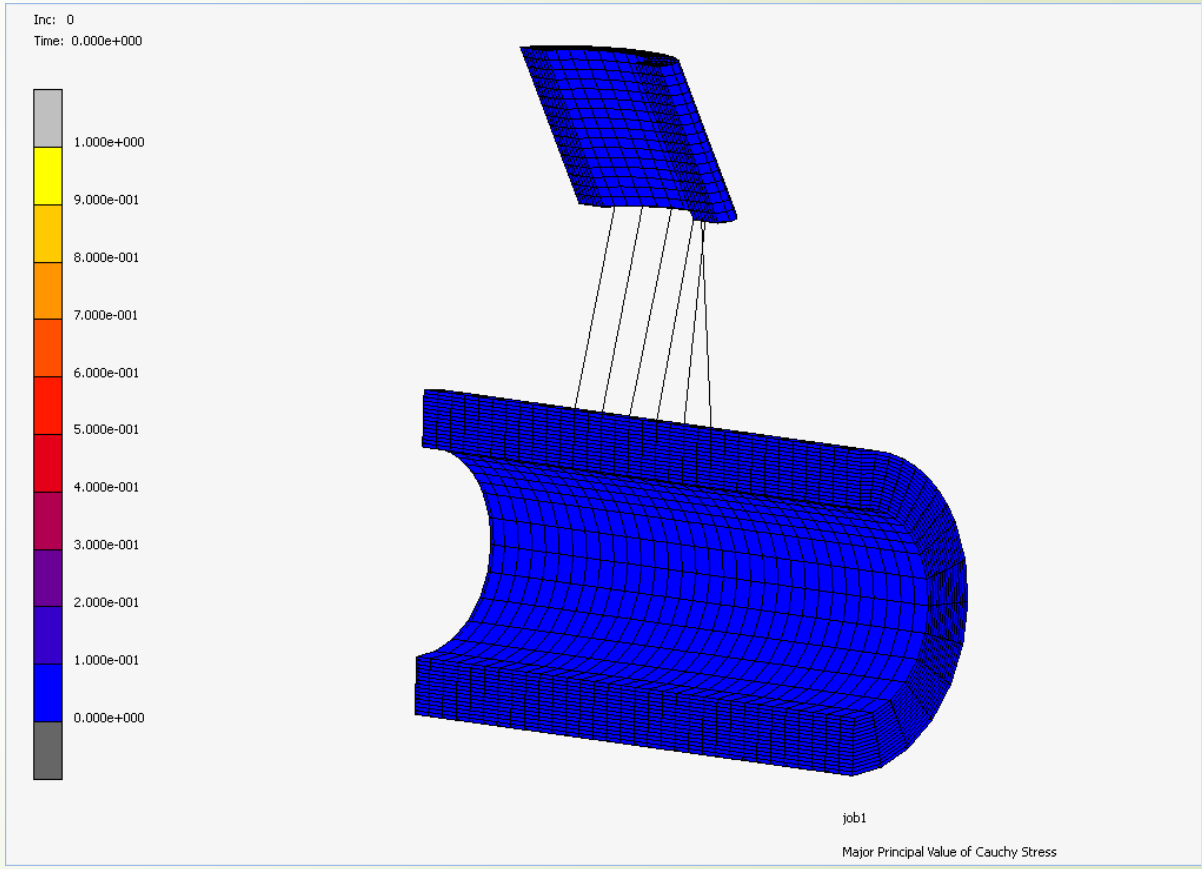
Results of p-s simulations



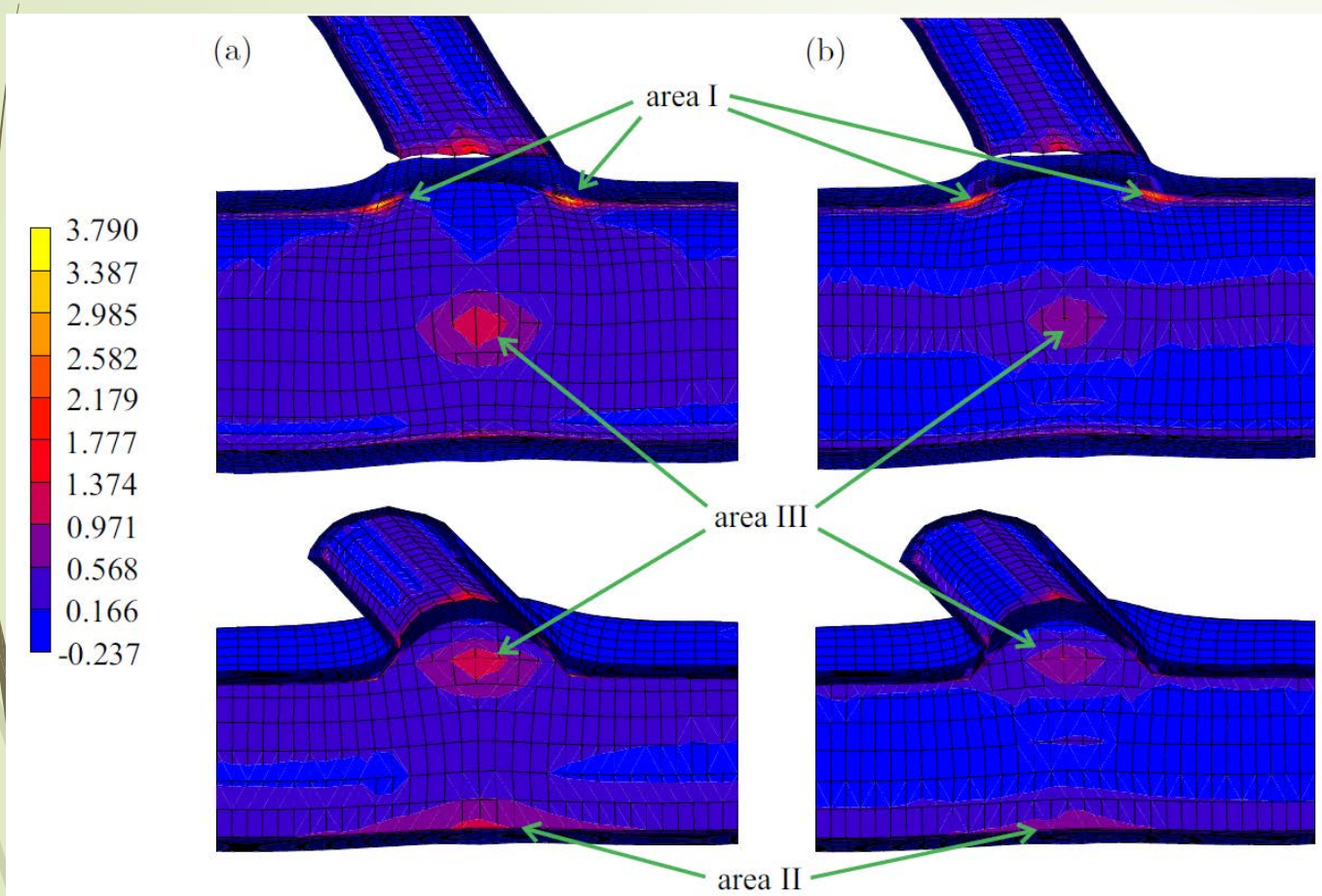
	AcomA cross section	Q through AcomA	Diss Value	Vol	Unit Diss	Diss. Func. Value	Vol.	Unit Diss.
Case1. before	0,2995	0,3253	45293,4	92,365	490,376	35017,5	12,7359	2749,51
Case1. after	0,6427	3,4015	15574,6	21,1752	735,51	-	-	-
Case1. altern.	0,5817	3,2496	21433,4	17,629	1215,81	-	-	-
Case2. before	0,3646	0,1103	28631,6	90,7238	315,591	25045,8	18,474	1355,73
Case2. after	0,2338	0,9456	27552,3	17,3311	1589,76	-	-	-
Case2. altern.	0,243	0,9689	25230,3	14,461	1744,72	-	-	-
		For whole the model				For healthy compartment		

Arteriotomy shaping





The influence of residual stresses and the main areas of concentration of mechanical stresses

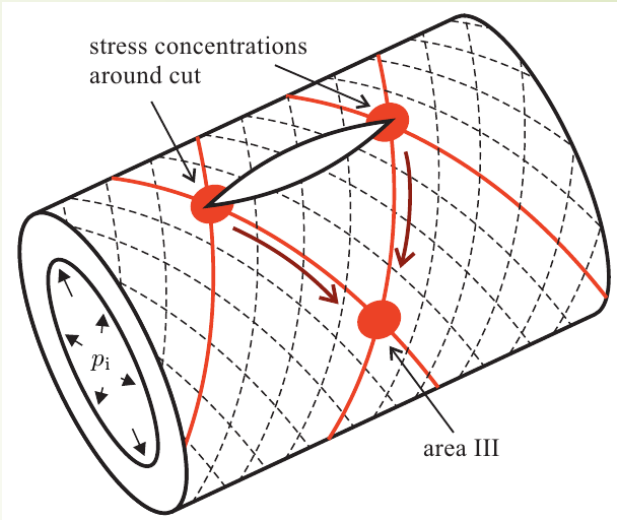


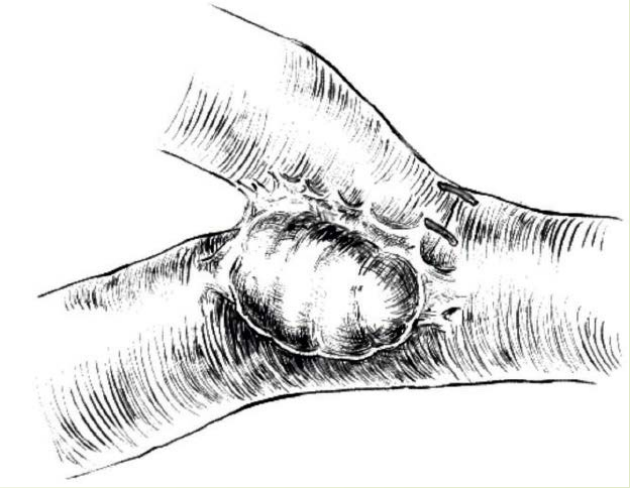
Excluding prestresses

$\mathbf{T}_{major}^{principal} \in [-0.214\ \text{MPa}, 3.790\ \text{MPa}]$

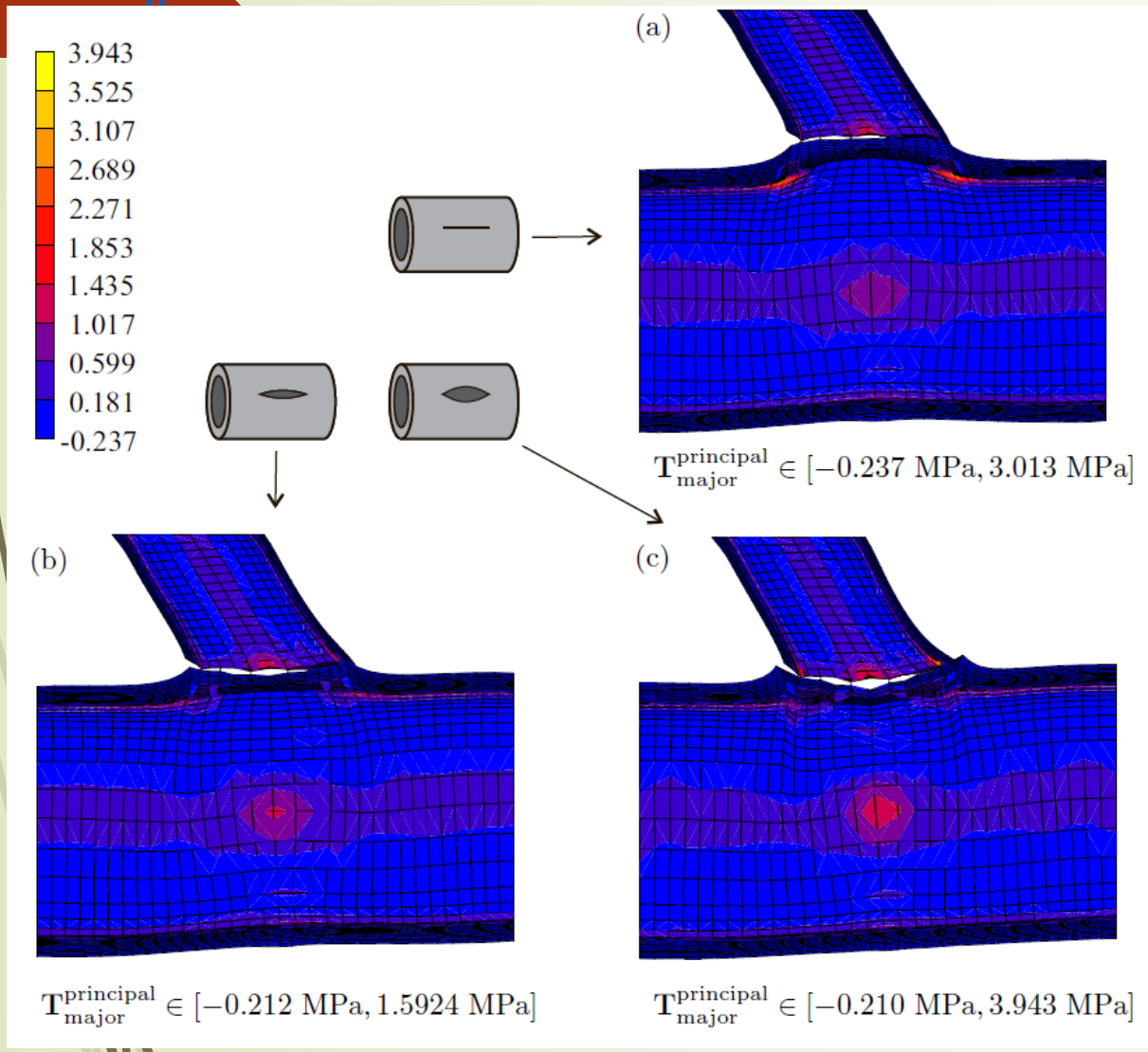
Including prestresses, $\alpha = 160°$

$\mathbf{T}_{major}^{principal} \in [-0.237\ \text{MPa}, 3.013\ \text{MPa}]$





Influence of artereotomy angle



(a) $\varphi_{\max} = 0°$

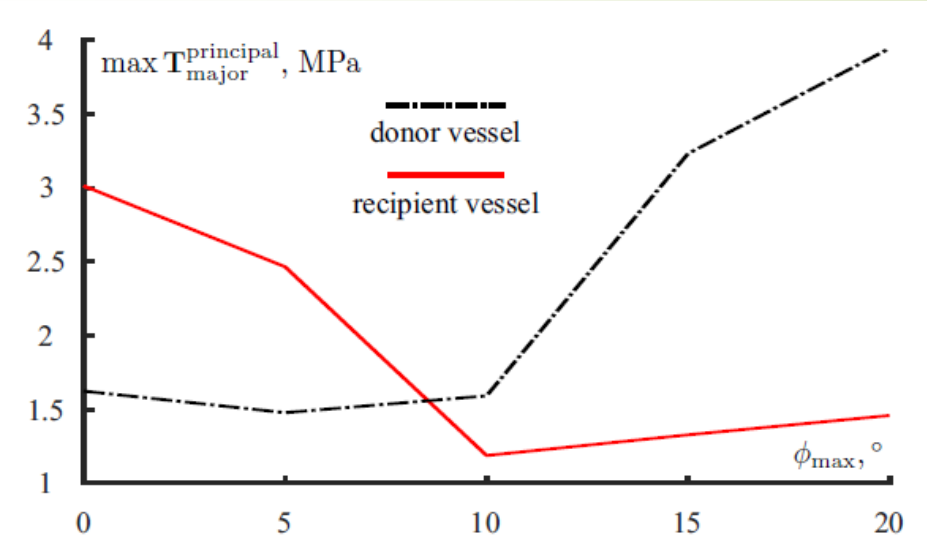
$$\mathbf{T}^{principal}_{major}\Big|_{area\ III} = 1.022\ \text{MPa}$$

(b) $\varphi_{\max} = 10°$

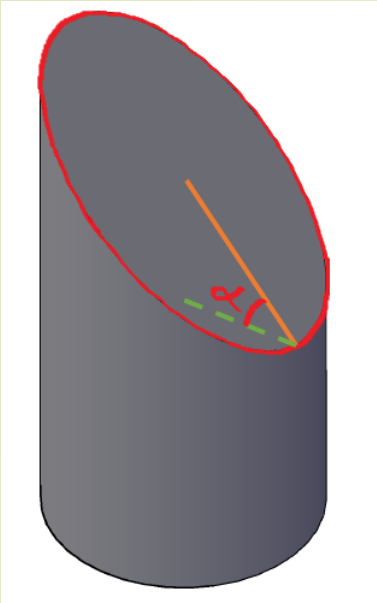
$$\mathbf{T}^{principal}_{major}\Big|_{area\ III} = 1.165\ \text{MPa}$$

(c) $\varphi_{\max} = 20°$

$$\mathbf{T}^{principal}_{major}\Big|_{area\ III} = 1.459\ \text{MPa}$$



Tagiltsev, Parshin, Shutov, Math Mod Nat Phenom, 2022



P - The length of contact curve

r – Radius of the cylinder

α – angle, means how flat intersect cylinder

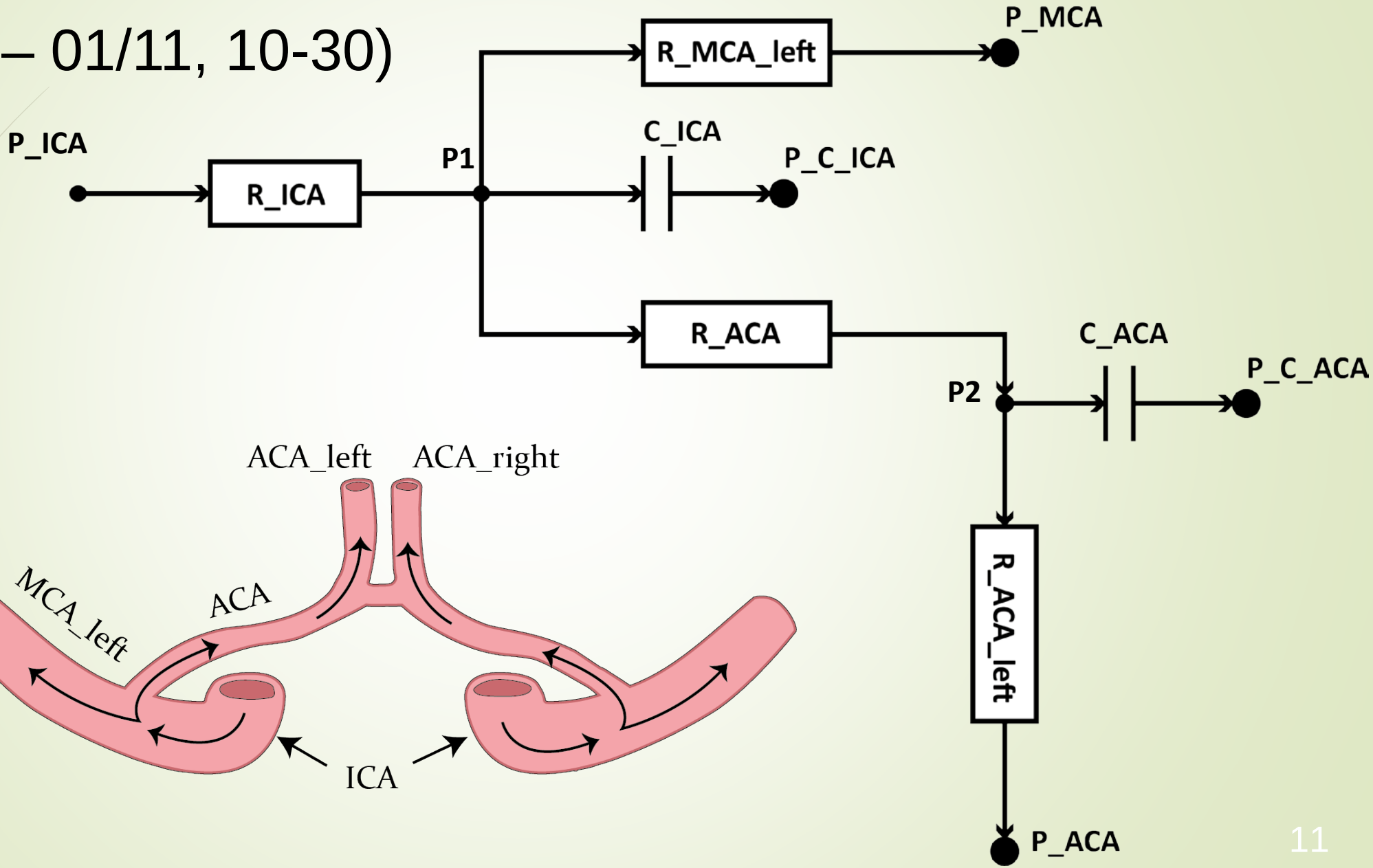
$$P(\alpha) = \pi r\left(1 + \frac{1}{\cos\alpha}\right)$$

Curve lengths depending on the radius of the cylinder and the angle of inclination of the plane

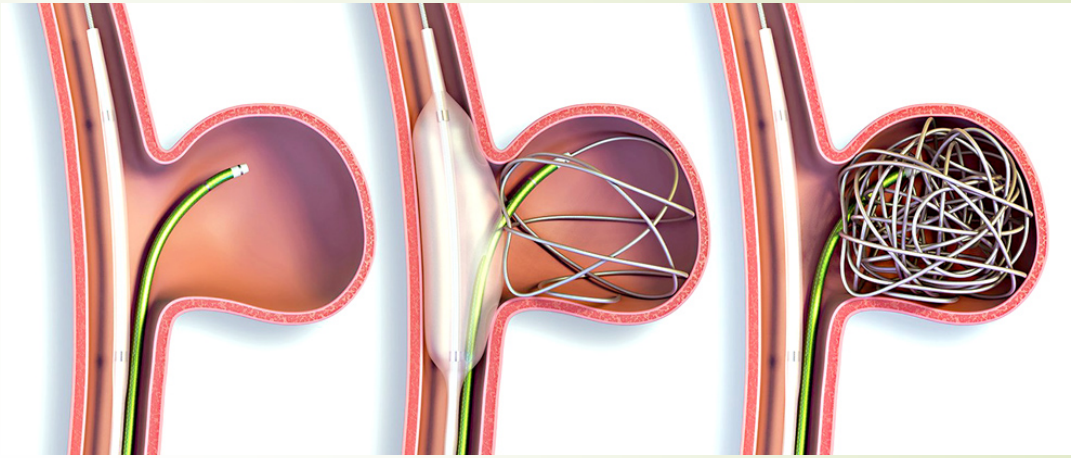
Degrees\ Diameter	0,5мм	1 мм	1,5мм	2мм	2,5мм	3мм	3,5мм	4мм	4,5мм	5мм	5,5мм	6мм	6,5мм	7мм	7,5мм	8мм
15°	3,20	6,39	9,59	12,79	15,99	19,18	22,38	25,58	28,77	31,97	35,17	38,36	41,56	44,76	47,96	51,15
30°	3,38	6,77	10,15	13,54	16,92	20,31	23,69	27,08	30,46	33,85	37,23	40,62	44,00	47,38	50,77	54,15
45°	3,79	7,58	11,38	15,17	18,96	22,75	26,55	30,34	34,13	37,92	41,71	45,51	49,30	53,09	56,88	60,68
60°	4,71	9,42	14,14	18,85	23,56	28,27	32,99	37,70	42,41	47,12	51,84	56,55	61,26	65,97	70,69	75,40
75°	7,64	15,28	22,92	30,56	38,20	45,84	53,48	61,12	68,76	76,40	84,04	91,68	99,32	106,96	114,60	122,24

Electrical model of circulations

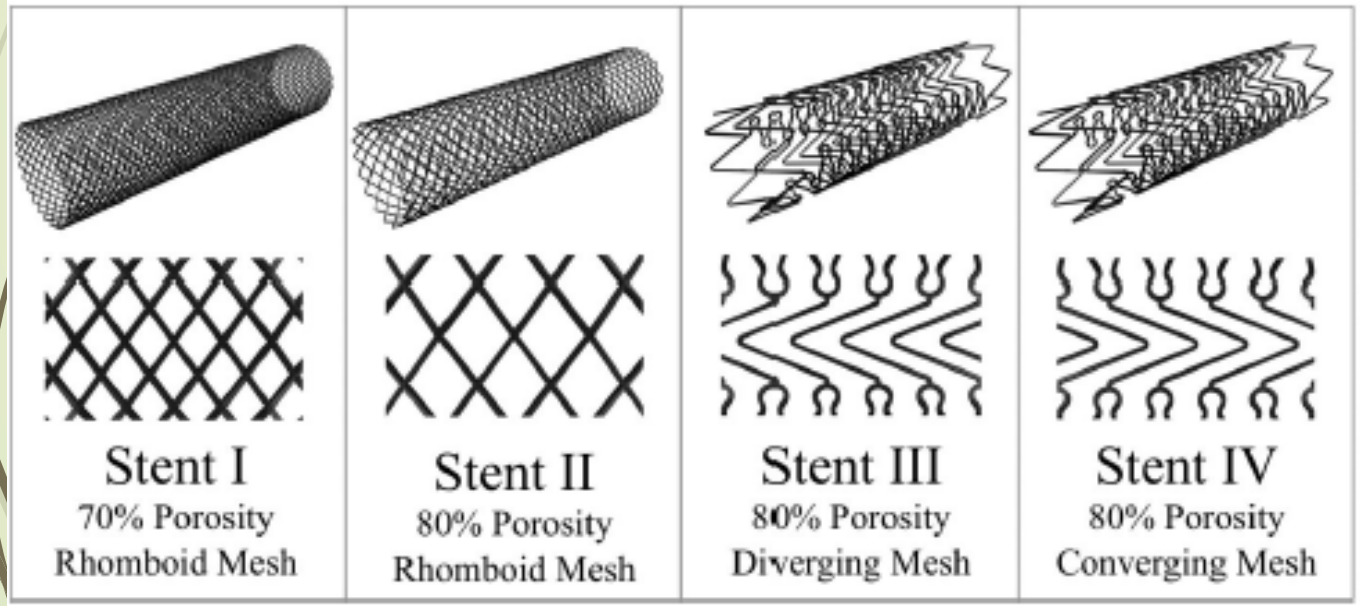
(I. Kuianova – 01/11, 10-30)

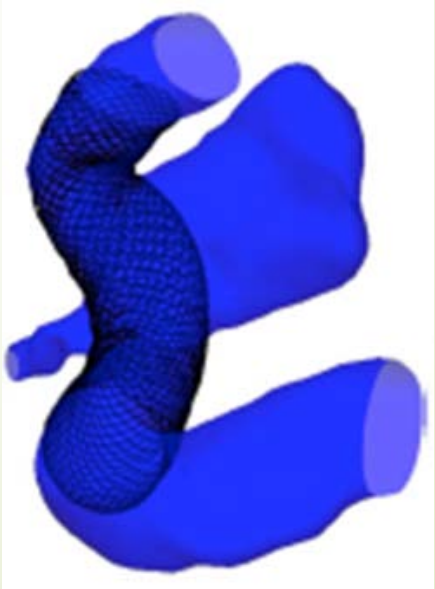


Examples of devices for the treatment of aneurysms and the principle of their work



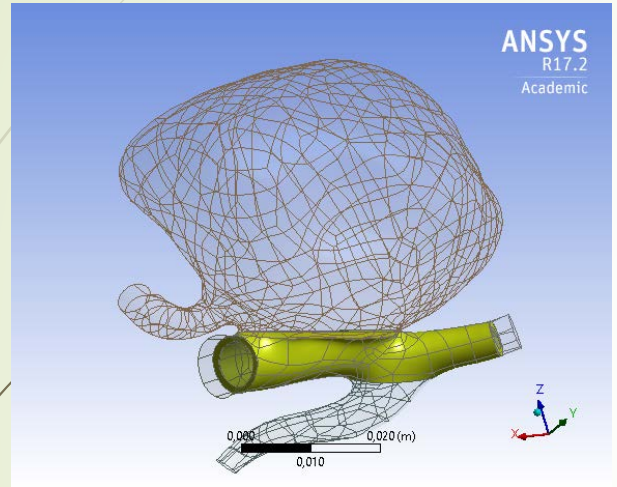
Installation of spirals by an neurosurgeon in aneurysm [5]

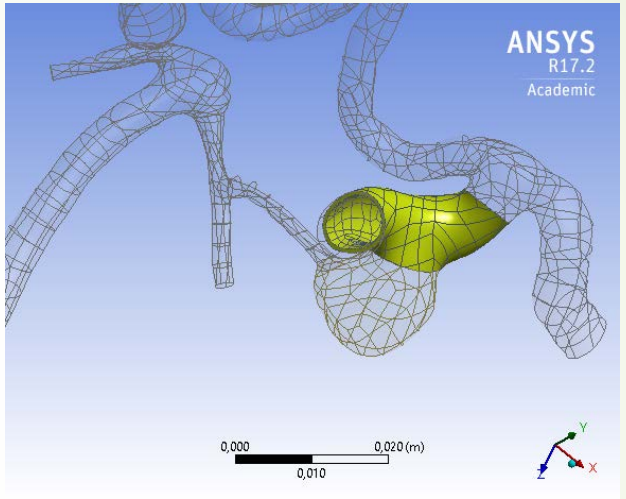


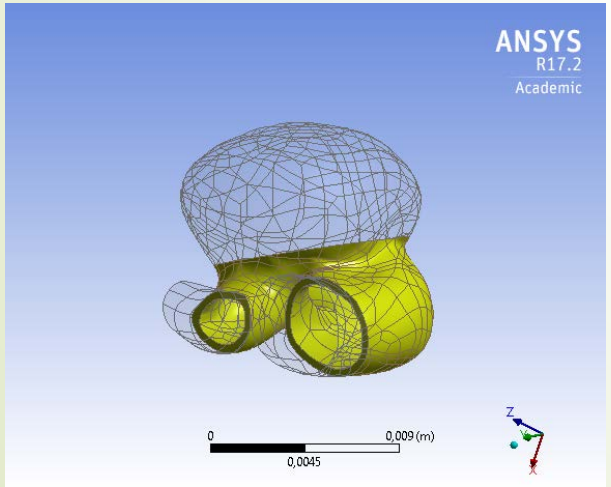


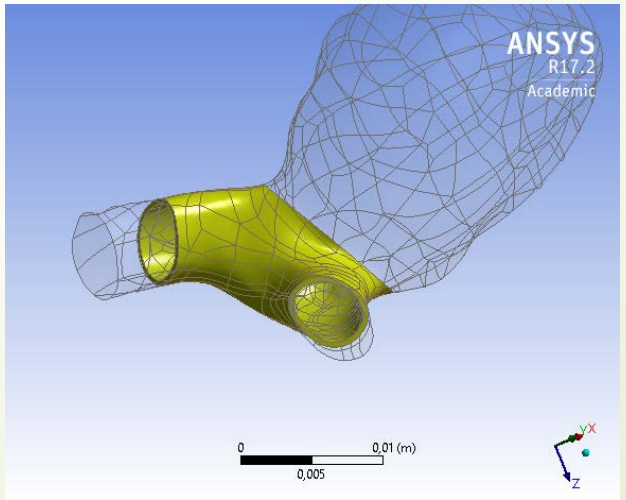
Virtual Stent Installation Model © Int. J. Numer. Meth. Biomed. Engng. 2014; 30:1387–1407

Virtual Stent deployment for 4 patient specific domains









Patient #1 - simulations

Flow profile

Difference WSS (0,001–1,9 Pa)

Velocity streamlines (0,0001– 0,14

Velocity values at the aneurysm and in stent zones

Maximum ΔWSS values for selected

The patients	T1	T2	T3	T4	Result
Patient 3	19.02 Pa	26.93 Pa	26.62 Pa	20.01 Pa	In stent stenosis
Patient 4	1.421 Pa	1.918 Pa	1.899 Pa	1.491 Pa	
Patient 1	1.141 Pa	1.667 Pa	1.660 Pa	1.226 Pa	Normal occlusion
Patient 2	0.997 Pa	1.432 Pa	1.426 Pa	1.067 Pa	no occlusion case

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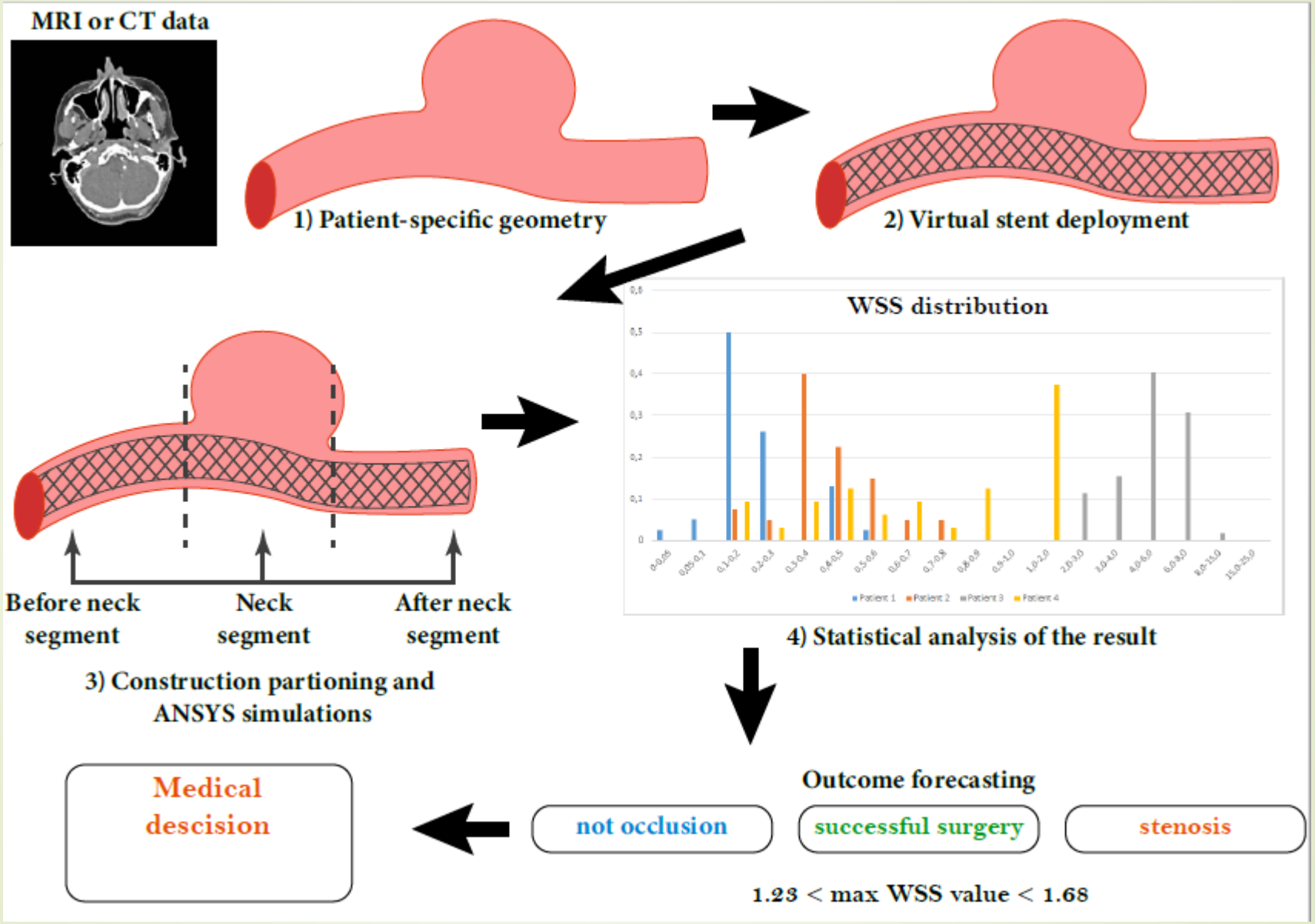
Virtual stent deployment roadmap



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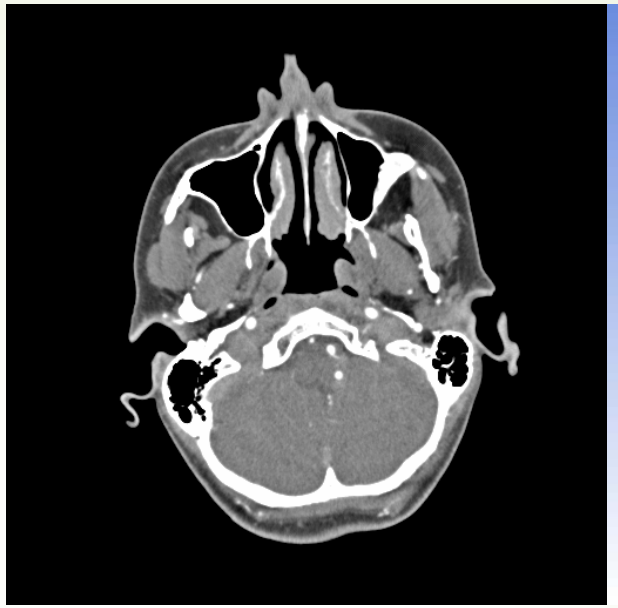
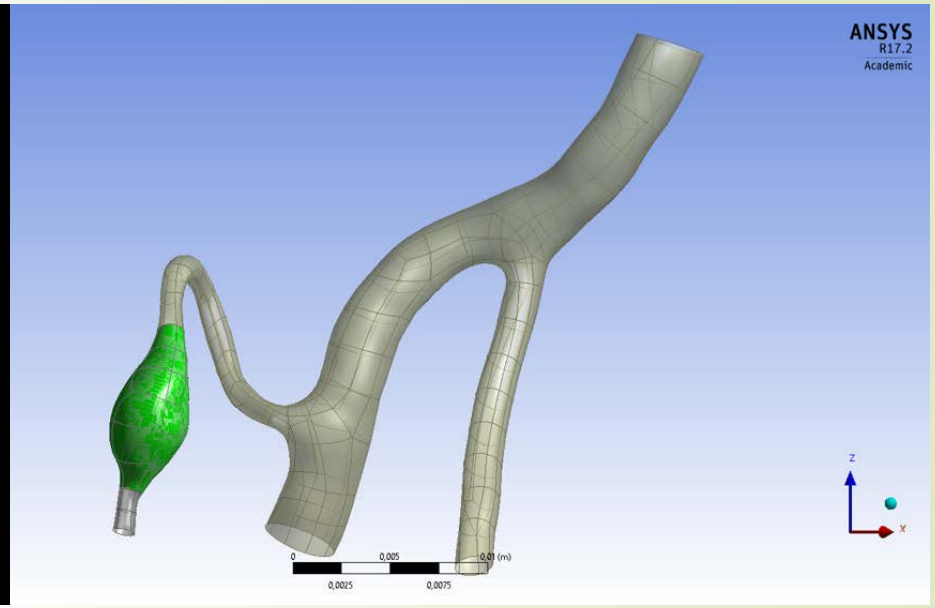
Uncertainty of boundary conditions setup

- ANSYS Experiment setup:
- Steady \ Unsteady
- Inlet: 3 pathways
- Outlet condition: P = 0
- No slip condition
- N-S equations for fluid domain.
- Finite volumes method for fluid domain
- Rigid vs Hooks law and FEM for wall mechanics modelling.

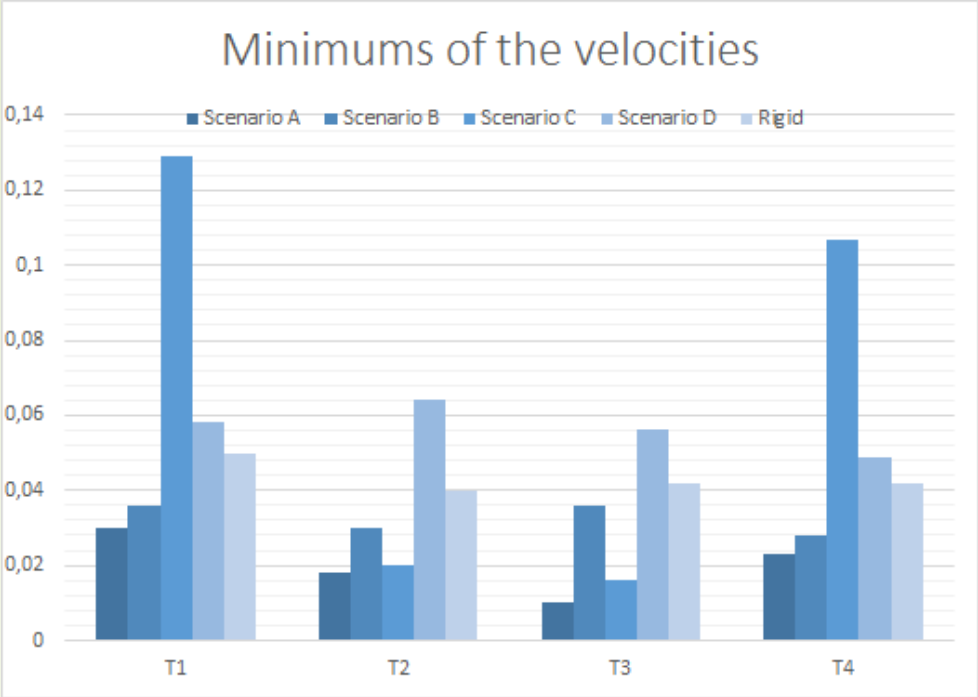


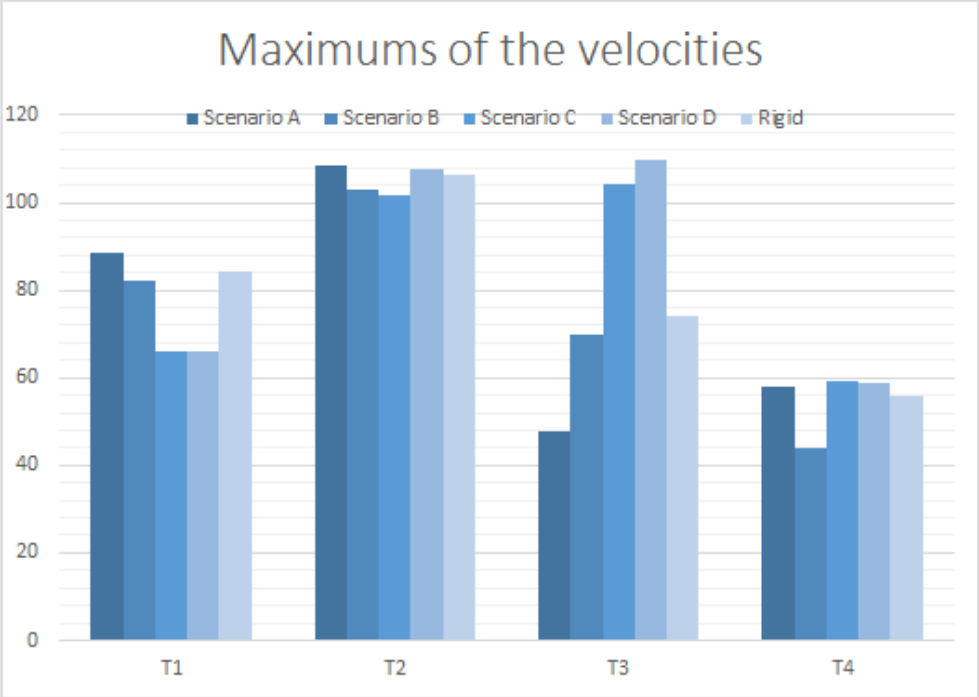


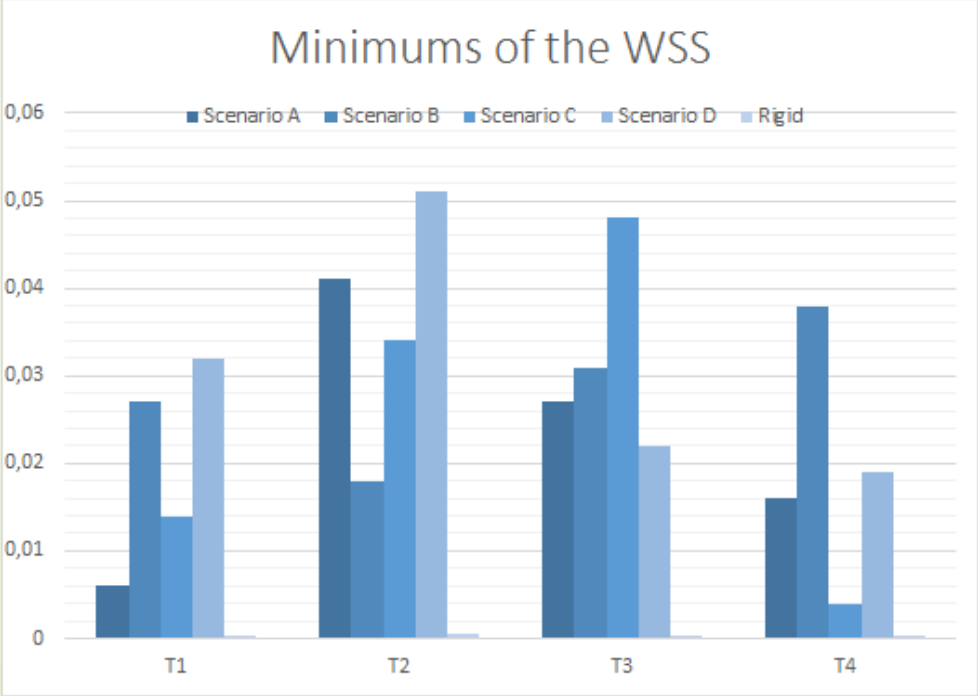
Conditions x Scenarios	Rigid walls	FSI scenarion A	FSI scenarion B	FSI scenarion C	FSI scenarion D
Inlet	flow rate	flow rate	flow rate	$V_0 + V_a \sin 2\pi t$	$V_0 + V_a \sin 2\pi t$
Outlet	Pressure	Pressure	Pressure	Pressure	Pressure
Surface type	Rigid	Elastic	Elastic	Elastic	Elastic
Surface condition	No slip	No slip +displacement	No slip +displacement	No slip +displacement	No slip +displacement
Blood vessel wall	-	Non-homogeneous	Homogeneous	Non-homogeneous	Homogeneous
Fluid - structure coupling	-	Pressure	Pressure	Pressure	Pressure

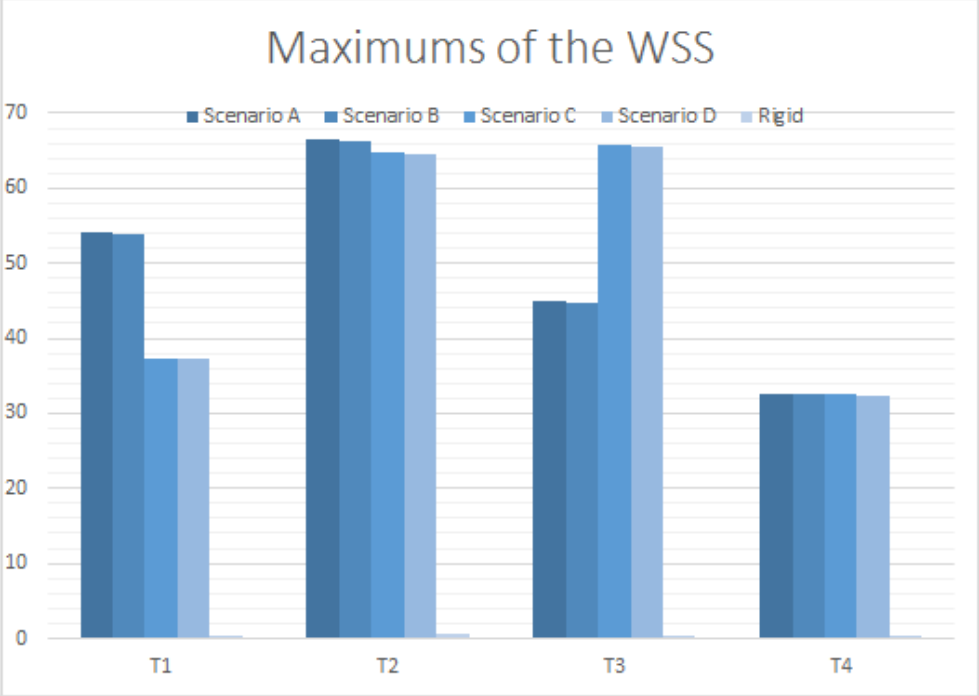
Results

Graphics of hydrodynamic parameters for A-D simulation schemes и жесткой стенки for time points T1-T4.







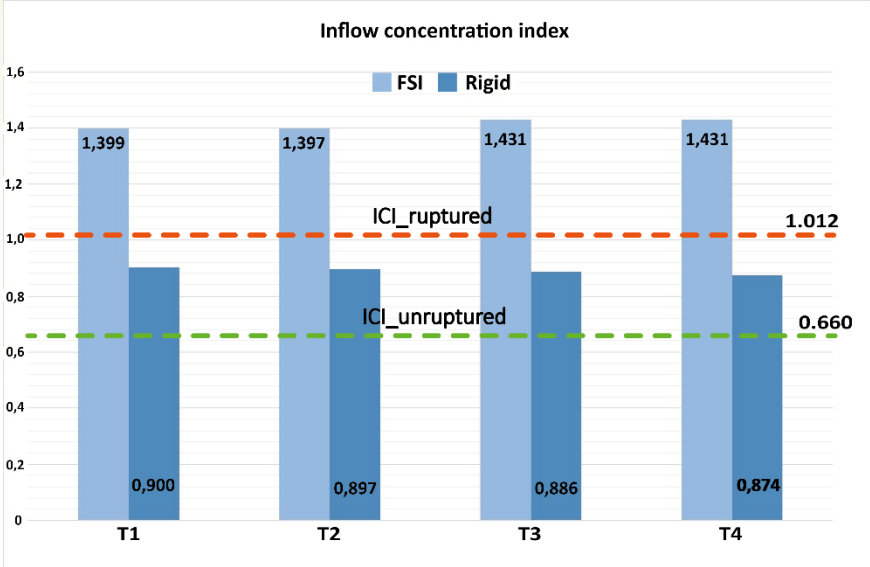


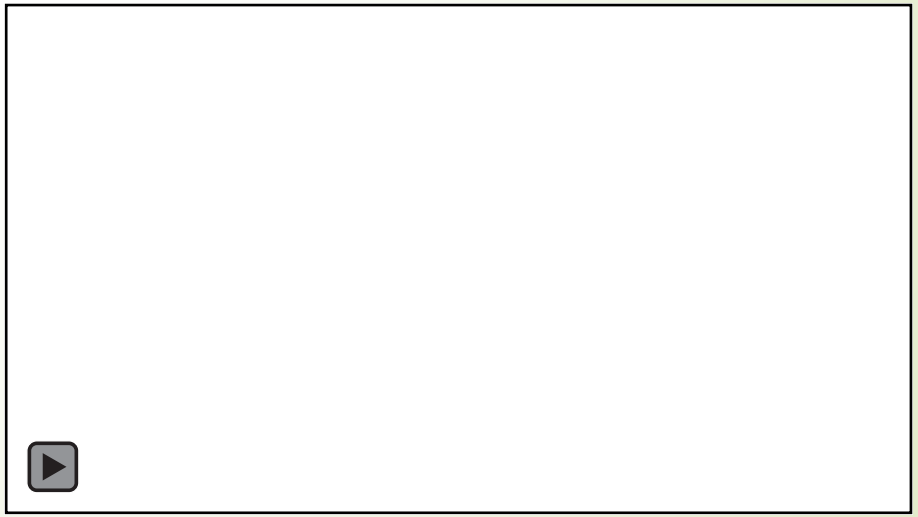
Results. ICI value

ICI –is a flowrate index that could be calculated by the following formula:

$$ICI = \frac{Q_{in}/Q_v}{A_{in}/A_o}$$

where Q_{in} -is a flux through the aneurysm (inflow), Q_v maternal artery flowrate, A_{in} area of the duct into the aneurysm, и A_o - area of the aneurysm neck.

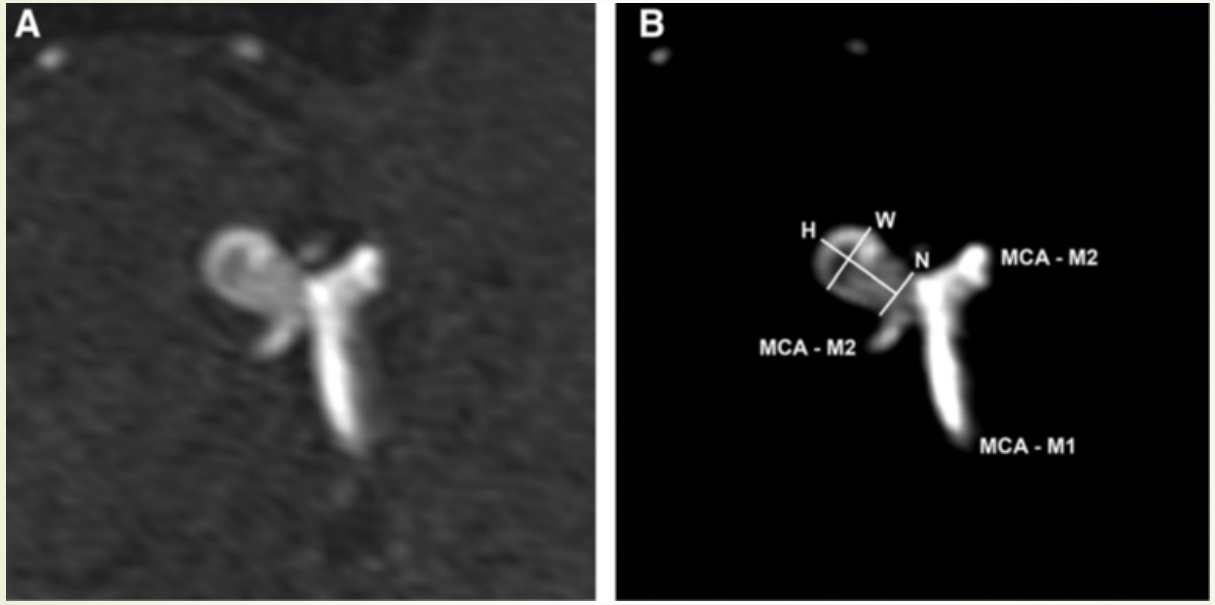




Parshin et al. submitted 2022

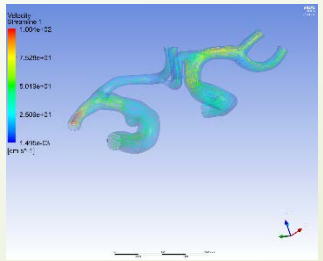
RISK calculation

- Phases grade - Morphology

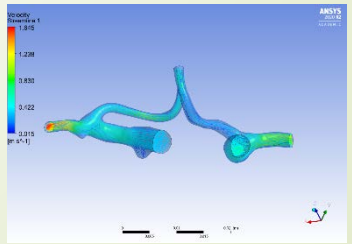


D. Tikhvinsky – 1/11, 17-50

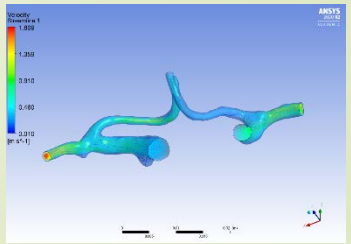
2018



2020



2022



AAA rupture risk assessment

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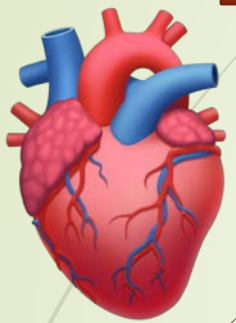
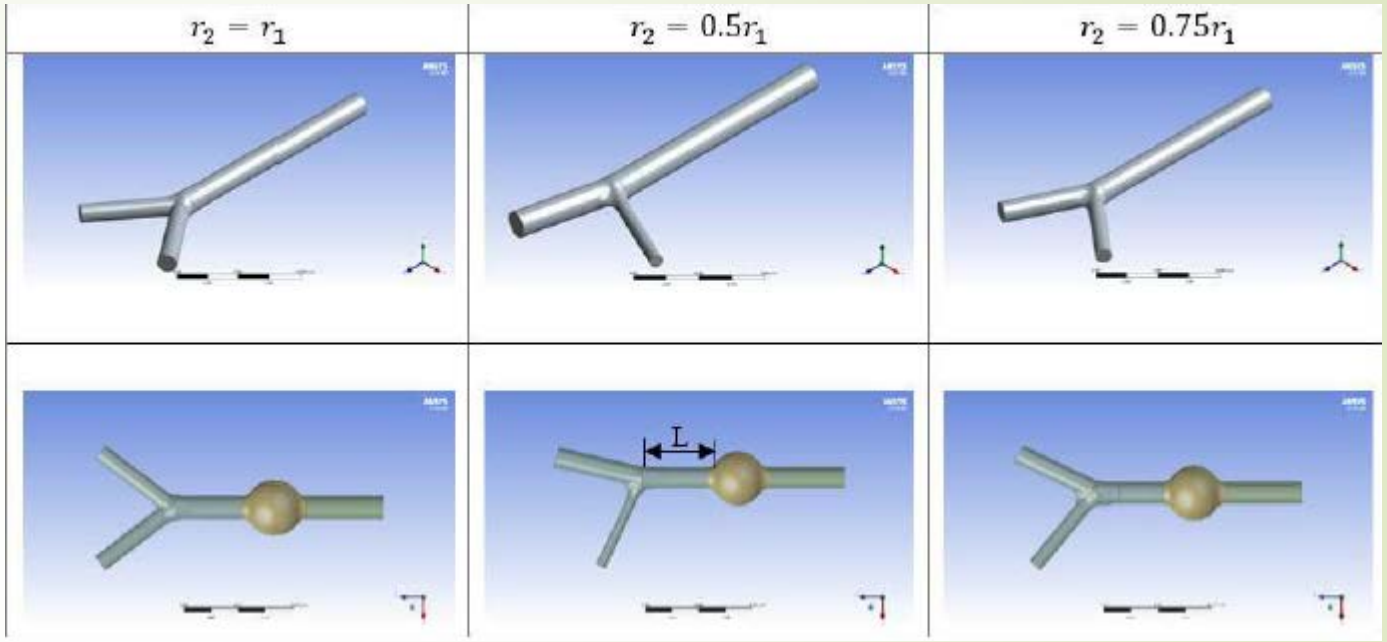
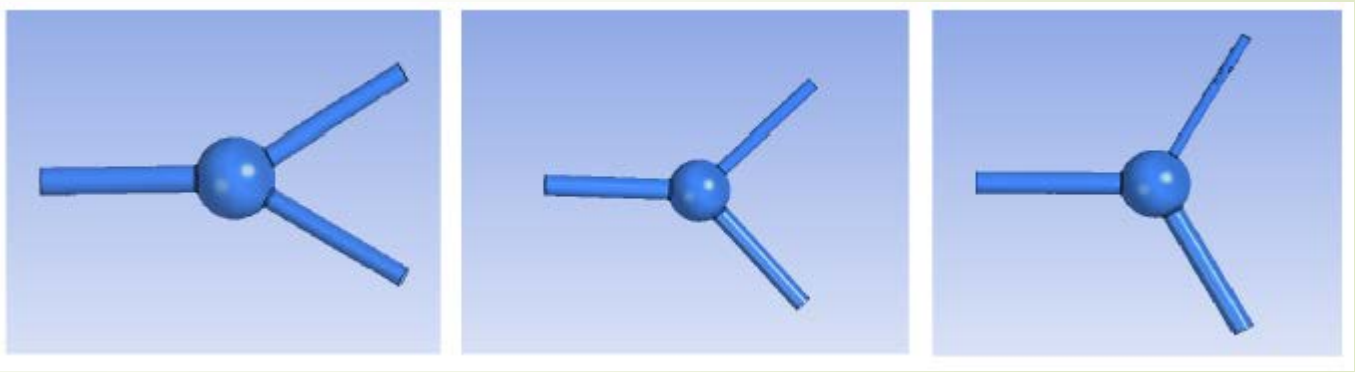
Considered problem & configurations

P-increasing?







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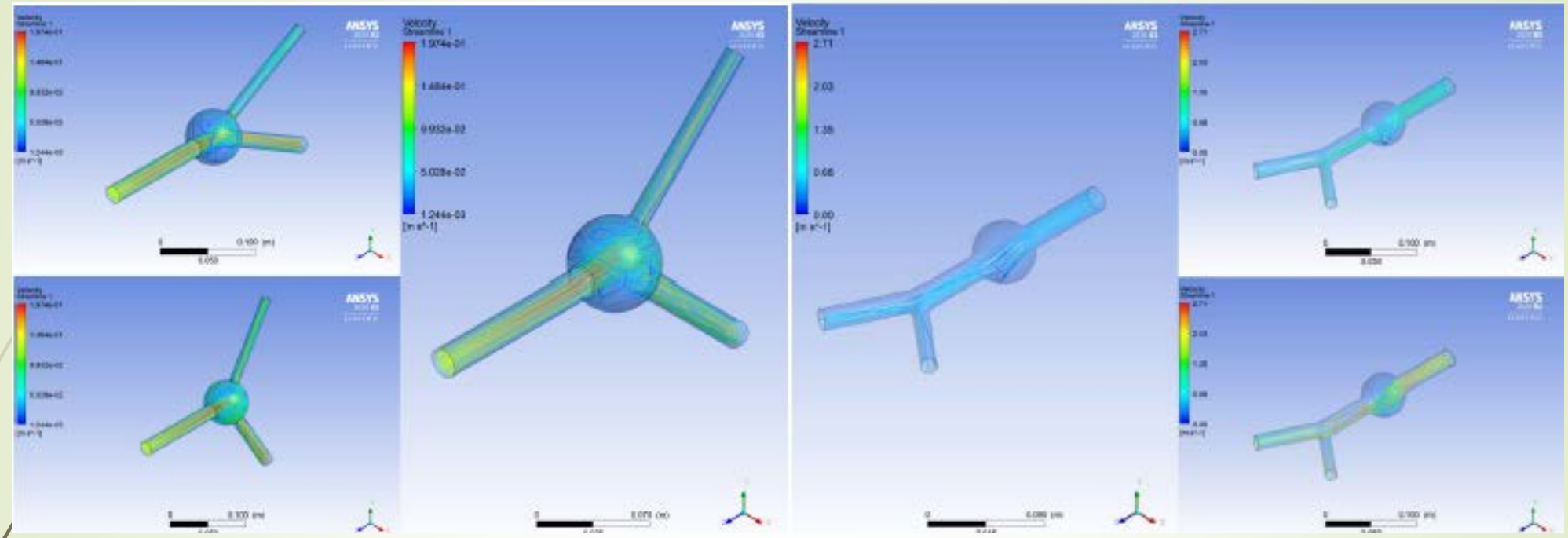
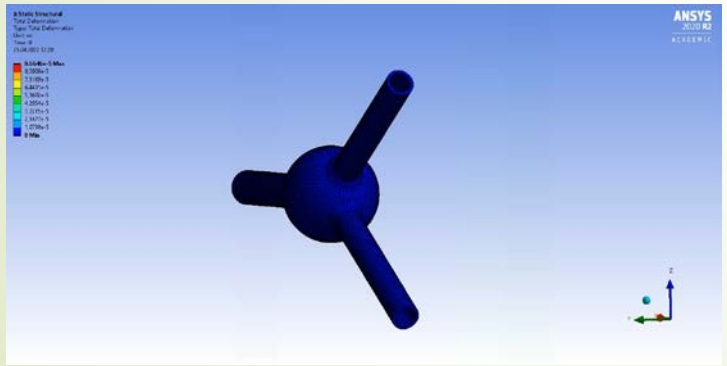
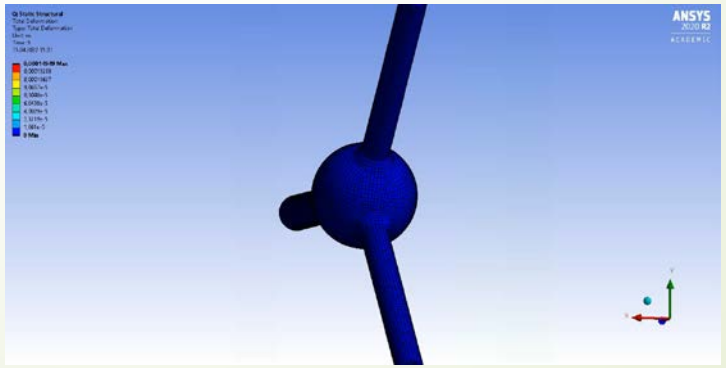
CFD simulation







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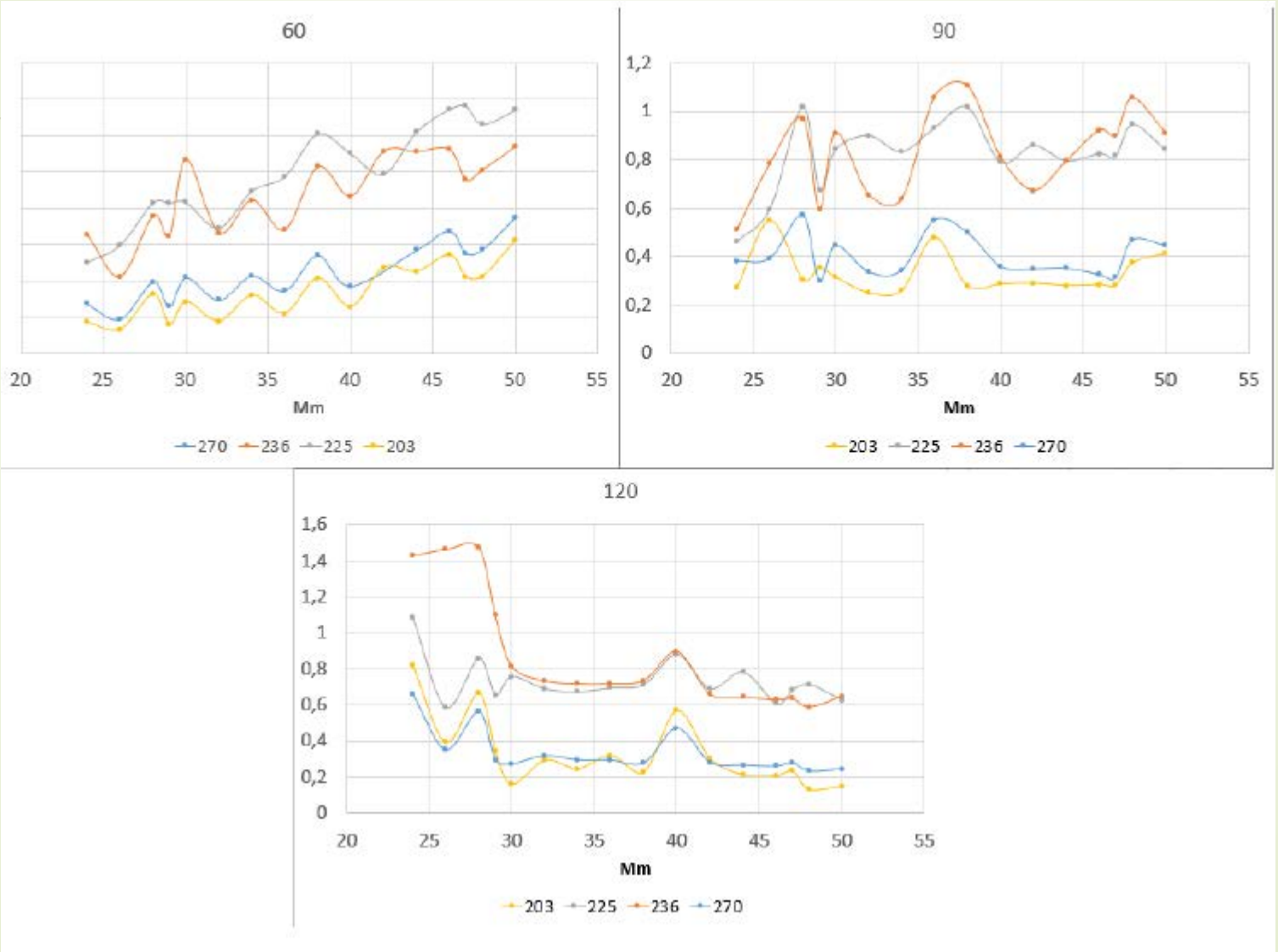
P var rel calculation



$$P_{var\ rel} = \frac{P_a - P_n}{P_n},$$

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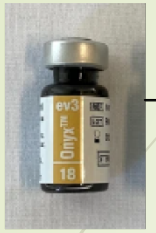
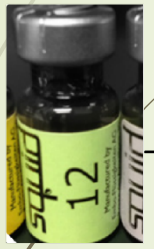
Non-adhesive embolic agents rheology



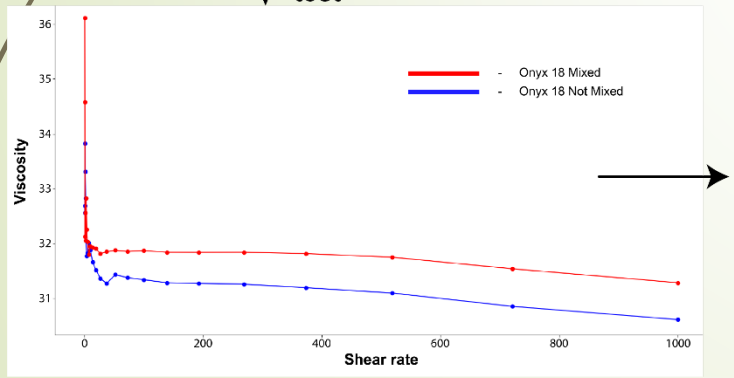
Onyx ®



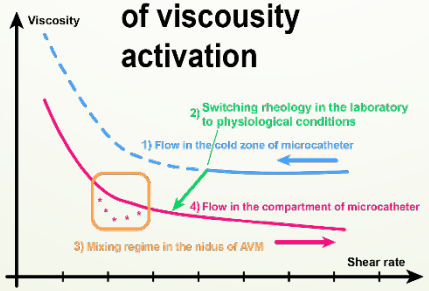
Squid ®

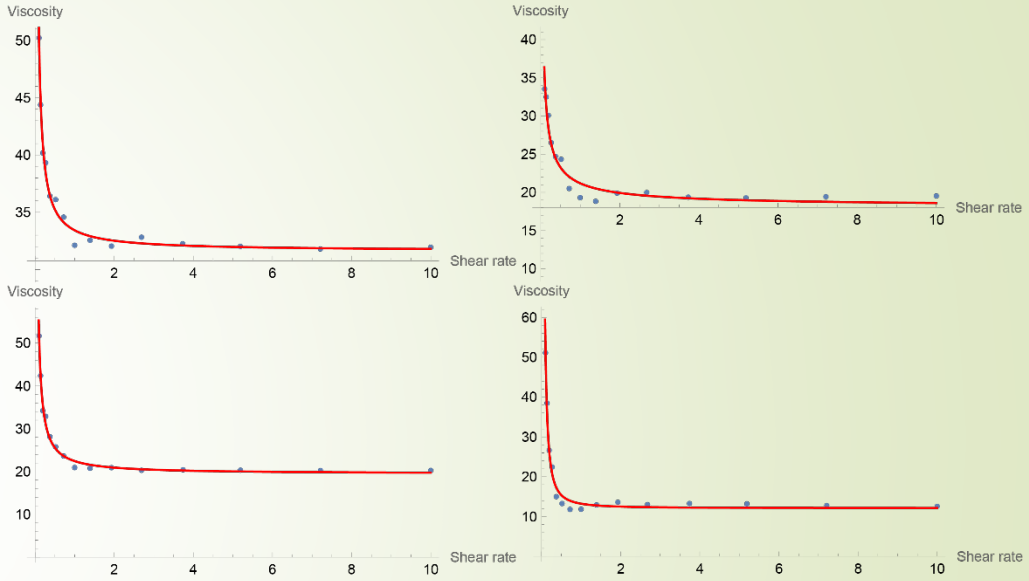
Numerical simulation

Rheology test



Understanding the mechanism of viscousity activation



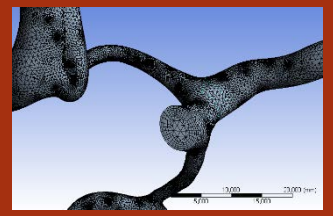


$$\mu_{eff} = \mu_0 + kU^{n-1}$$

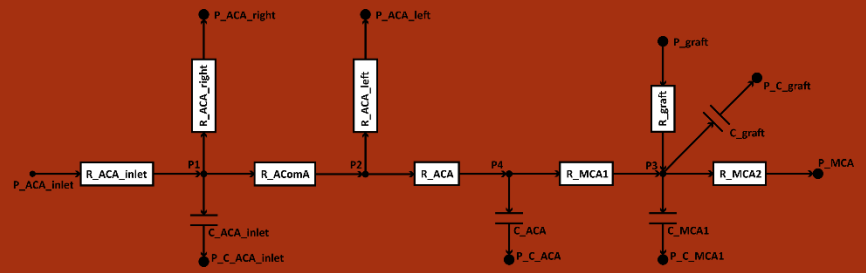
Cisco's rheological model

Kuianova et al, Polymers 2022 (under review)

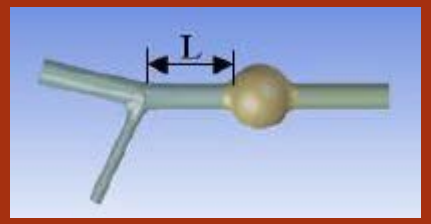
General pathway



Using patient specific data for model construction

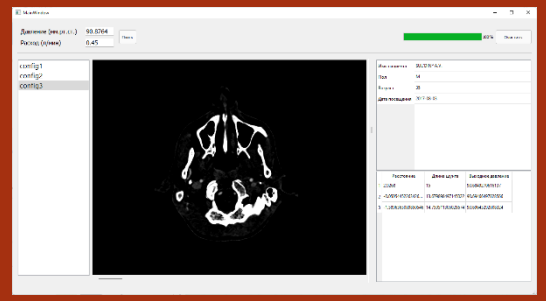


Reduced model configuration



General phenomena

Parameters estimating from experiments



Software for making decisions

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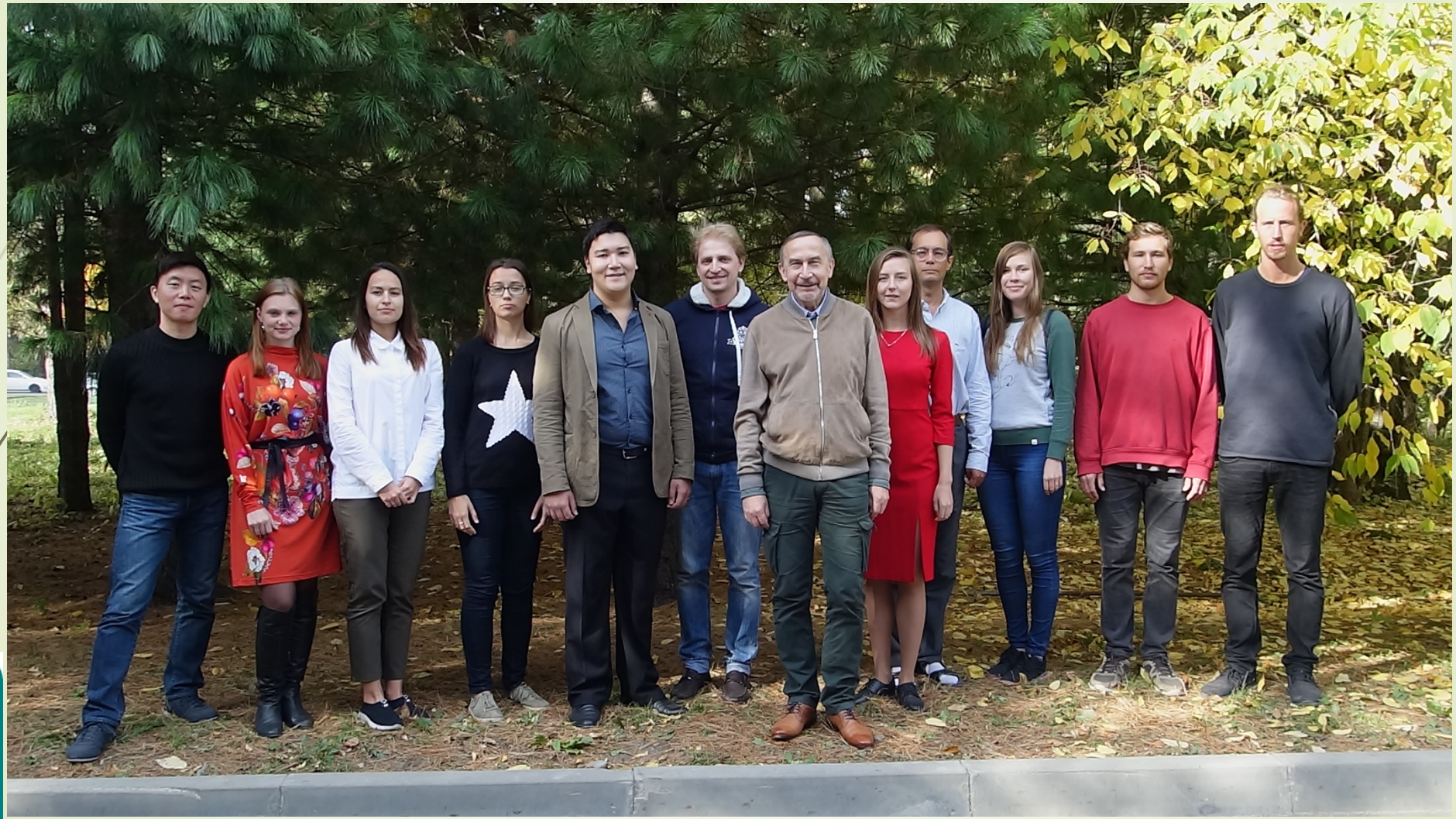
Thank you for your attention!



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