Patient-specific simulations of stroke and syringomyelia

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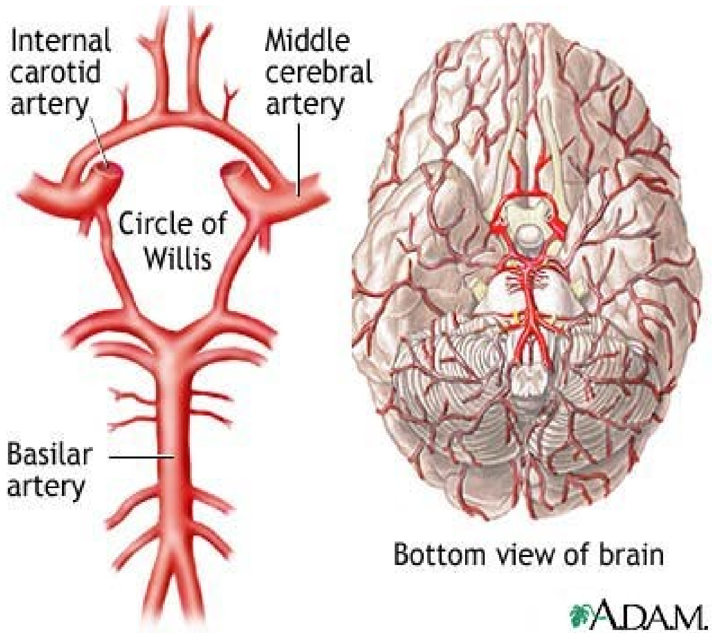
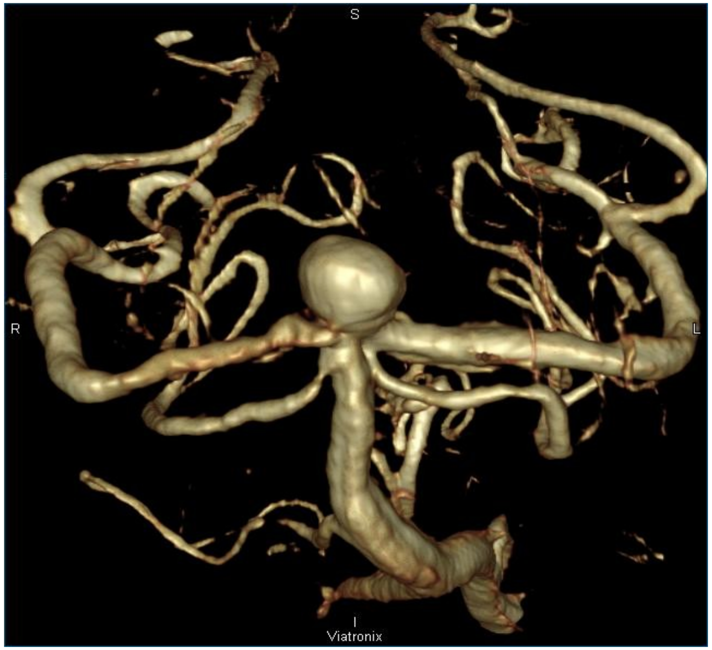
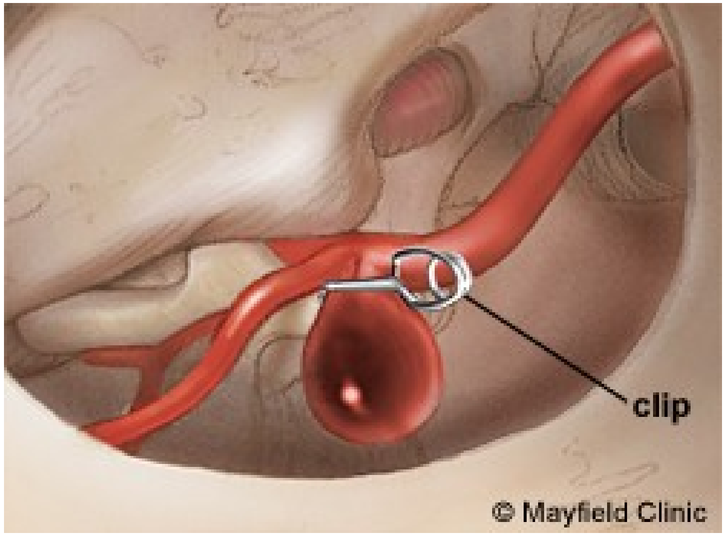
The Circle of Willis (CoW) is the main supplier of blood to the brain – 1-6% of us get aneurysms here, which may rupture and cause stroke



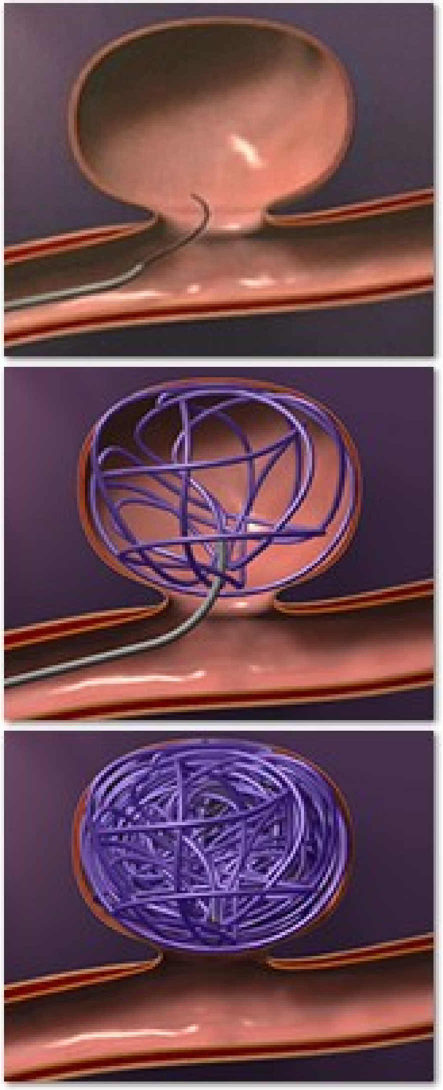


Annual risk of rupture < 1%

A neurosurgeon's dilemma: few aneurysms rupture; do surgery or not?



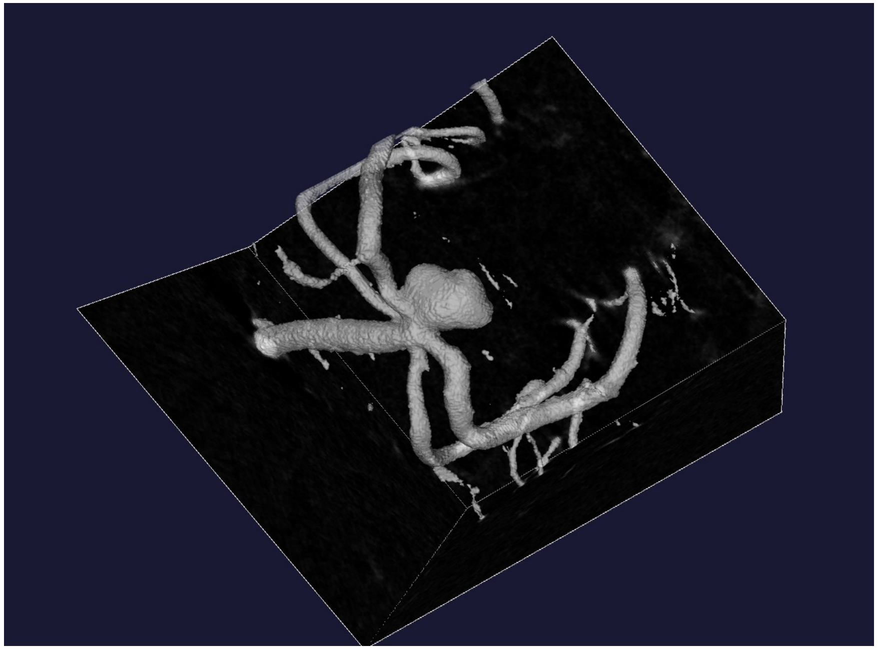
Clipping?



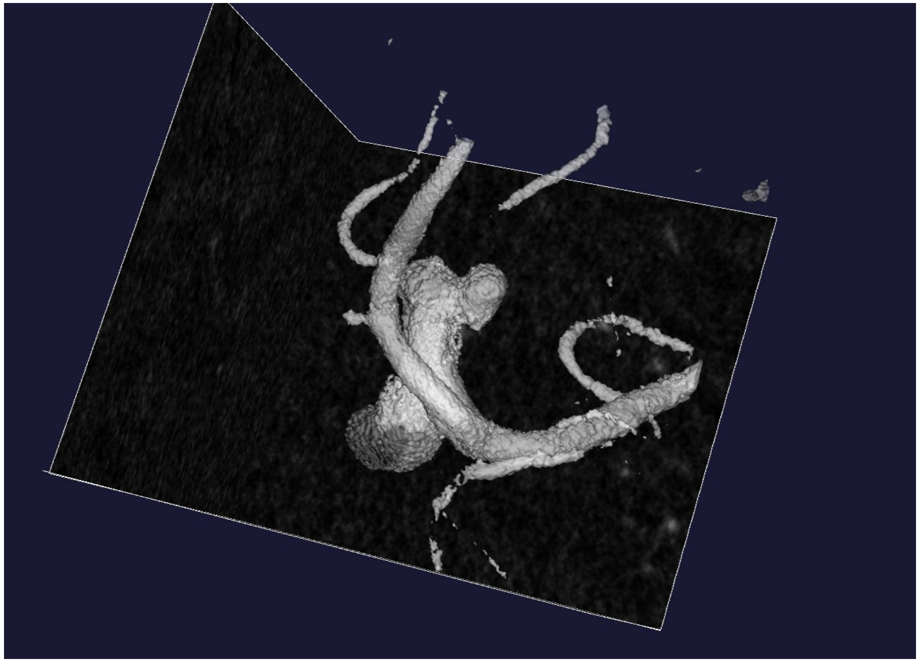
Do nothing?

Coiling?

Clinical Problem: Which aneurysms are at risk of rupture?



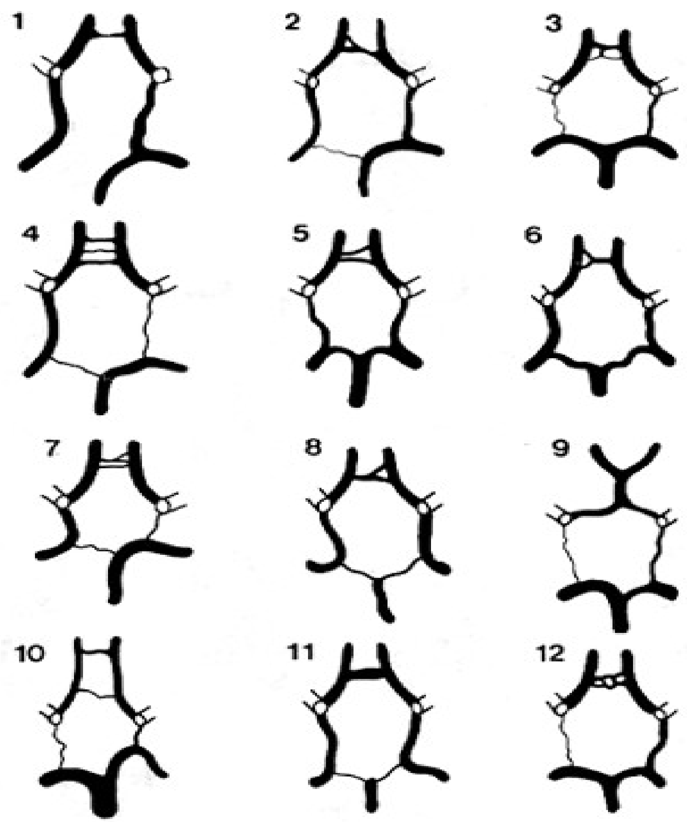
The biggest?



The one with the statistically most dangerous location?

Can flow simulations help to assess the risk?

What causes aneurysm development and rupture?



We use CFD to test hypothesis of medical researchers

Focus: geometric variations

Only 50% of us have a well-balanced cirle (!)

Hypothesis: abnormal anatomy → abnormal flow

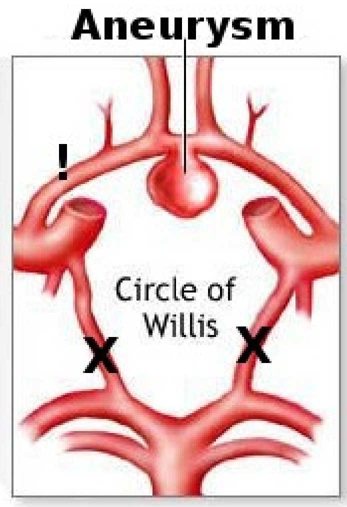
Four different aneurysms

sim by kvs

Validation and testing in a patient specific case

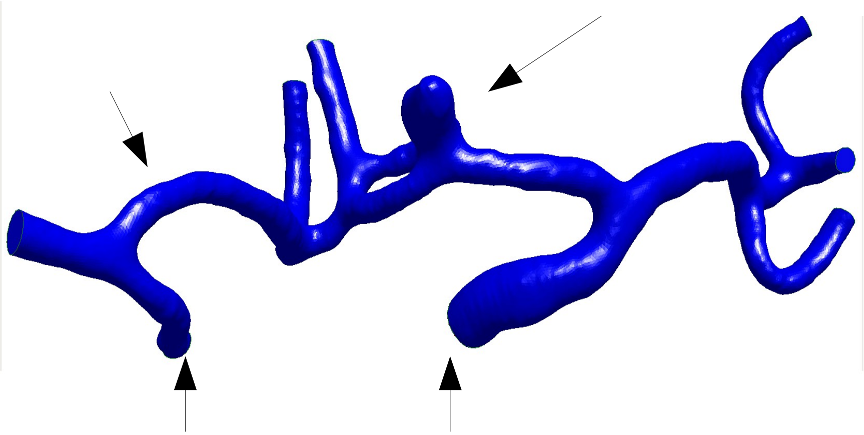
She has limited blood supply to the left part of the brain.

At the same time a growing aneurysm was discovered.

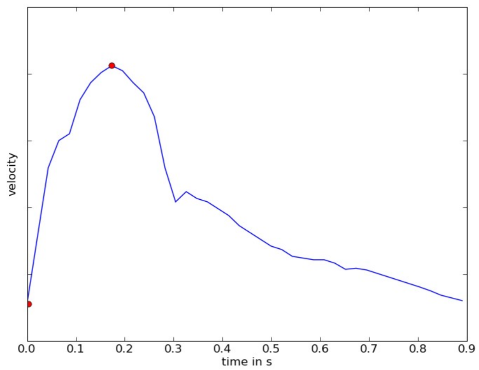


Problem that is to be evaluated:

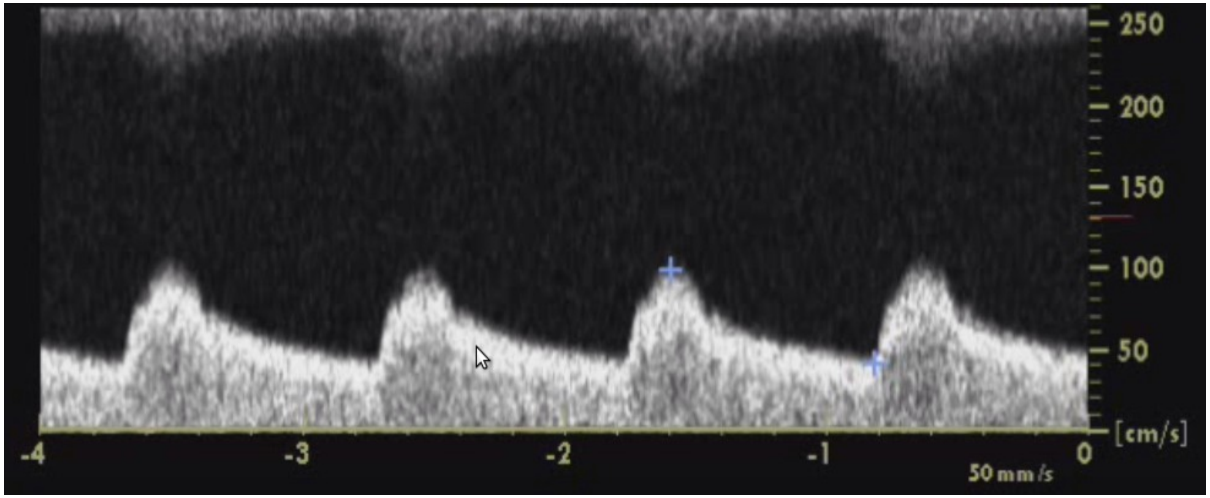
Can we compute a flow that is similar to the measured flow?

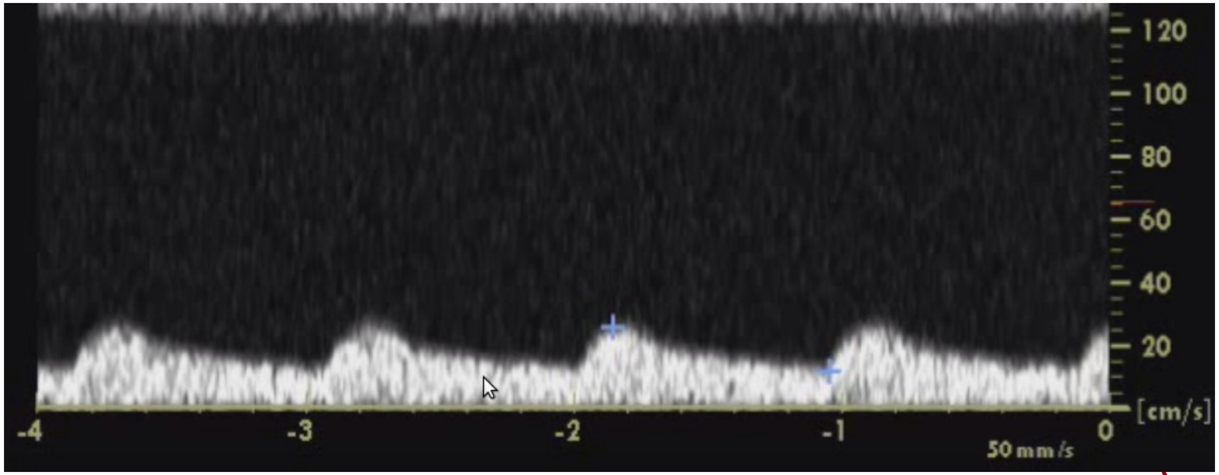


Doppler measurements on the left and right MCA



Used flow curve, adjusted to measurements with min and max flow (red dots)

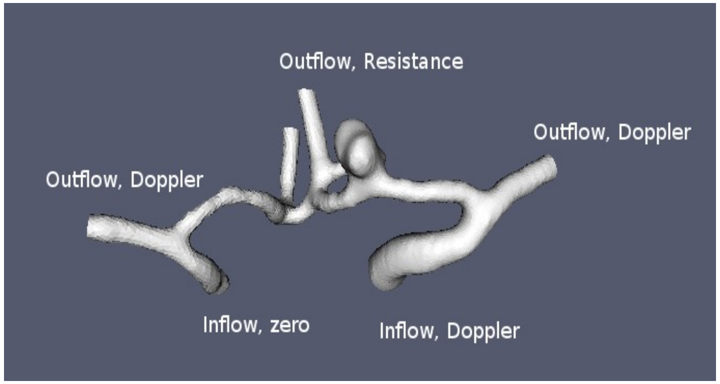




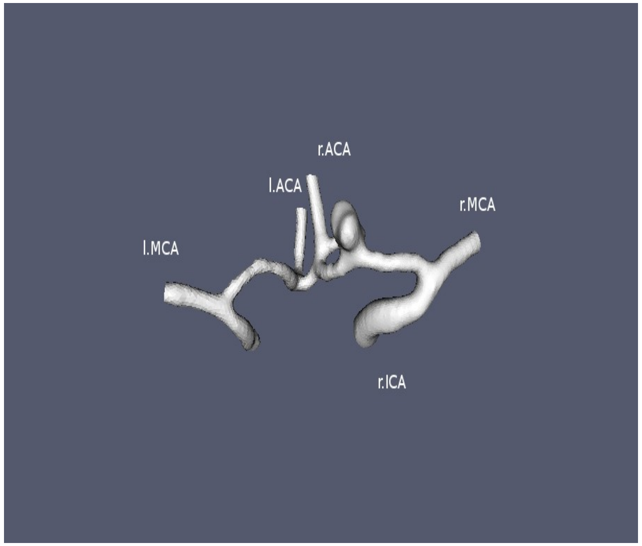
Is resistance boundary condititions sufficients or is patient-specific conditions needed ?

Resistance boundary conditions

Patient specific boundary conditions



The flow is quite different when using patient specific boundary conditions!



place	cross sec area mm^2	vol flux in ml/s	C
r. ICA	12.4	+3.8	-
r. MCA	3.6	-1.2	6.0
l. MCA	2.5	-0.9	6.0
r. ACA	2.3	-0.8	8.5
l. ACA	2.6	-0.8	8.5

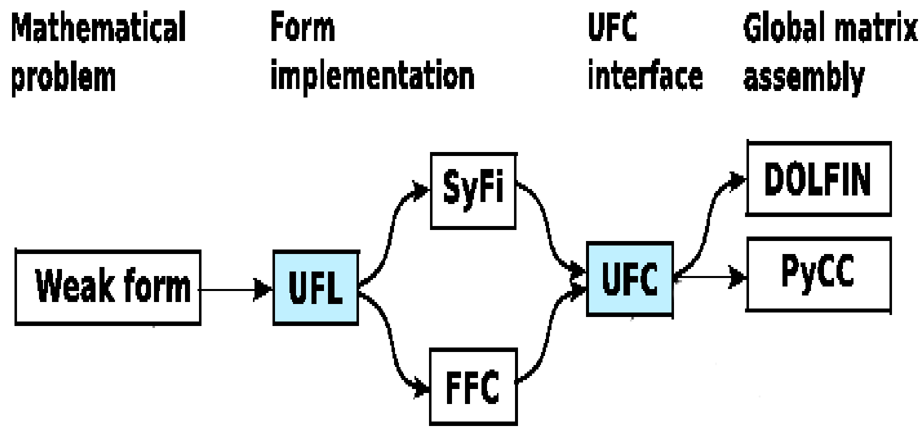
Table 4: Resistance boundary conditions at all outlets at Systole.

place	cross sec area mm^2	vol flux in ml/s	C
r. ICA	12.4	+3.8	-
r. MCA	3.6	-1.7	4.4
l. MCA	2.5	-0.3	22.5
r. ACA	2.3	-0.8	8.5
l. ACA	2.6	-0.8	8.5

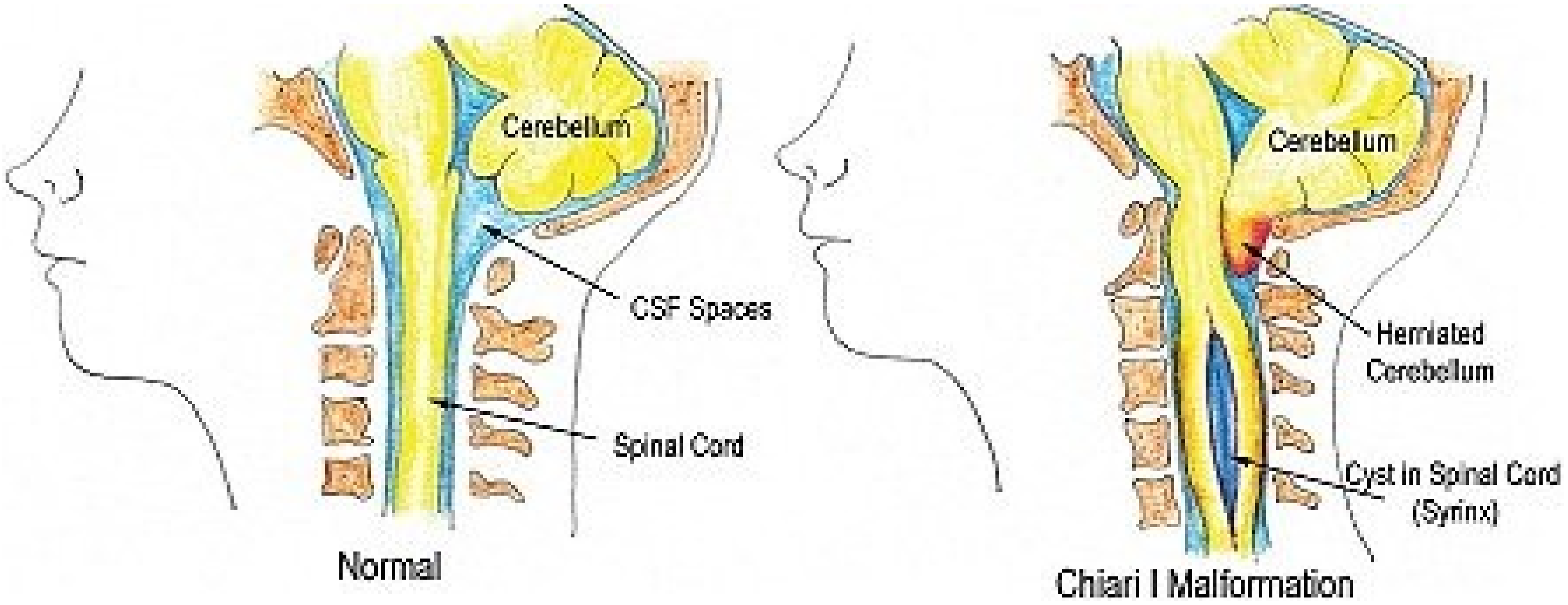
Table 3: Patient Specific boundary conditions at left and right MCA at Systole.

FEniCS: Chorin solver for Navier-Stokes equations

```
# Tentative velocity step
a0 = dot(v, u)*dx + k*nu*dot(grad(v), grad(u))*dx
L0 = dot(v, u0)*dx + k*dot(v, f)*dx - k*dot(v, mult(grad(u0), u0))*dx

# Poisson problem for the pressure
a1 = 1.0e-6*p*q*dx + dot(grad(q), grad(p))*dx
L1 = -(1.0/k)*q*div(us)*dx

# Velocity update
a2 = dot(v, u)*dx
L2 = dot(v, us)*dx - k*dot(v, grad(p1))*dx

# Assemble matrices
A0 = assemble(a0, mesh)
A1 = assemble(a1, mesh)
A2 = assemble(a2, mesh)

while t < problem.T:

    # Propagate values to next time step
    t += dt
    u0.assign(u1)

    # Compute tentative velocity
    b = assemble(L0, mesh)
    [bc.apply(A0, b, a0) for bc in problem.bcv]
    solve(A0, us.vector(), b, gmres, ilu)

    # Compute p1
    b = assemble(L1, mesh)
    print len(problem.bcp)
    if len(problem.bcp) == 0: normalize(b)
    [bc.apply(A1, b, a1) for bc in problem.bcp]
    solve(A1, p1.vector(), b, gmres, amg)
    if len(problem.bcp) == 0: normalize(p1.vector())
```



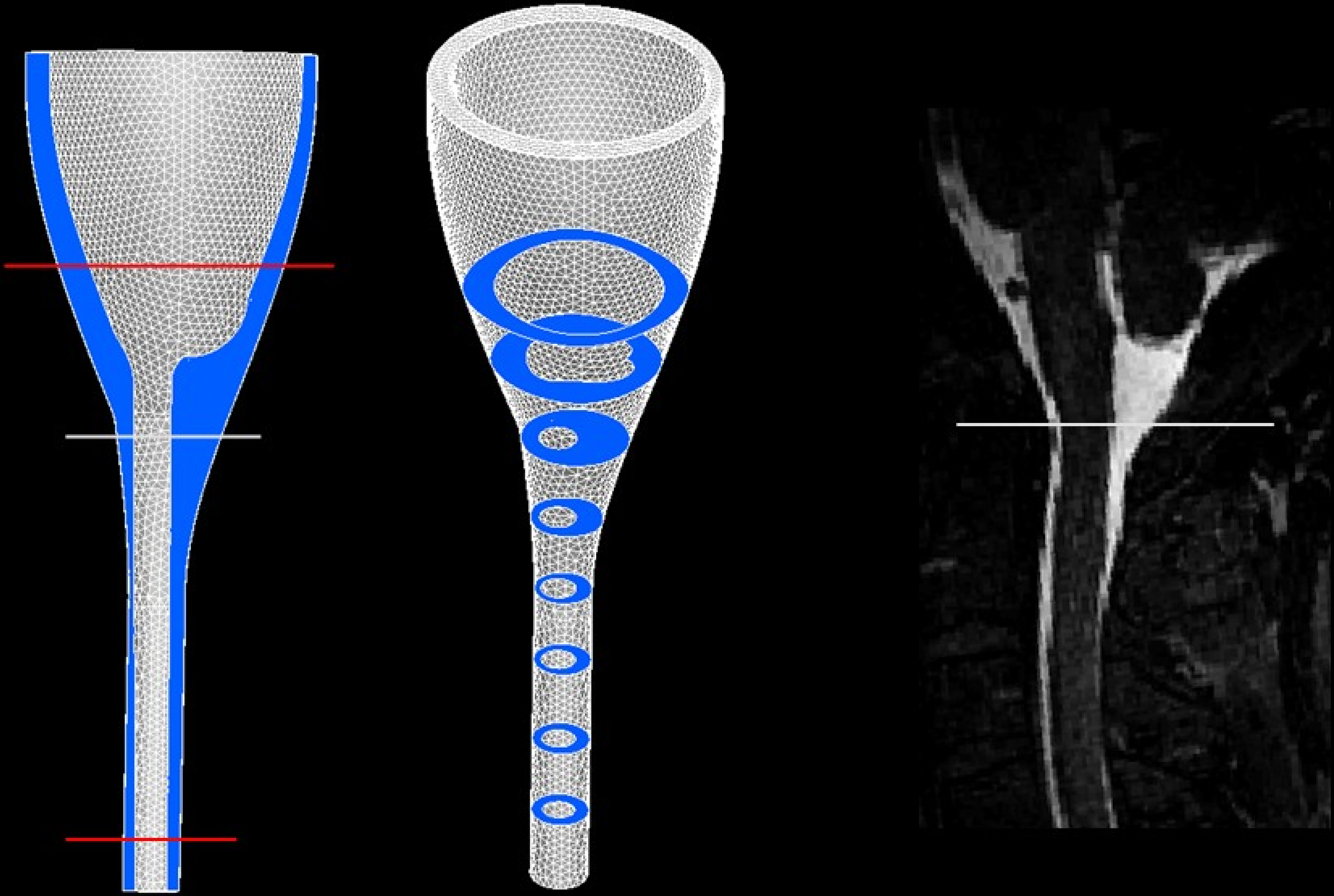
The Chiari I malformation is more common the previously assumed



” Until recent years, CM1 was regarded as a rare condition. With the increased availability of magnetic resonance imaging, the number of reported cases has risen sharply. Current estimates range from 200,000 to 2 million Americans with the condition. ”

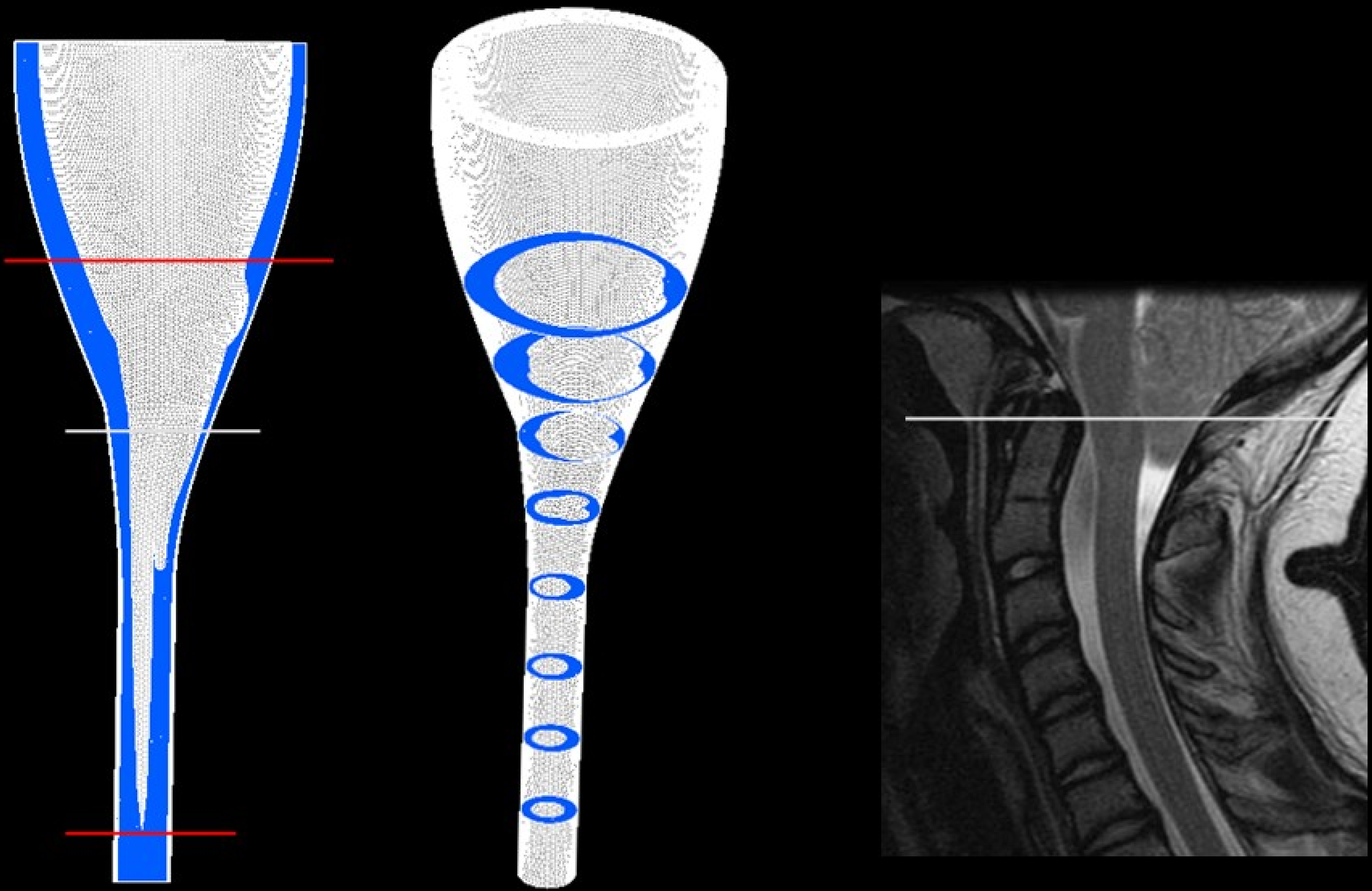
- The Chiari Institute, NY

"Normal"



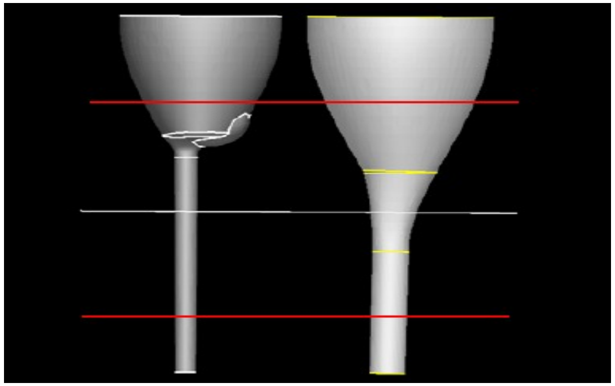
a)

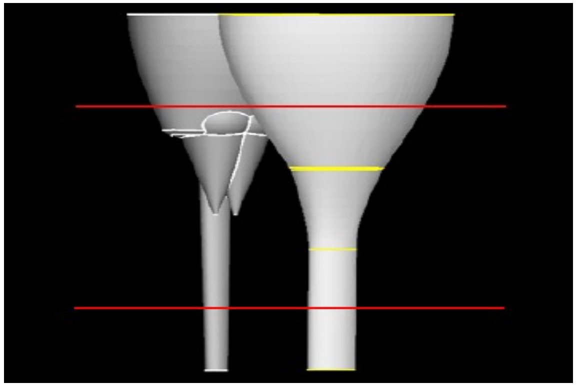
”Herniated tonsils”

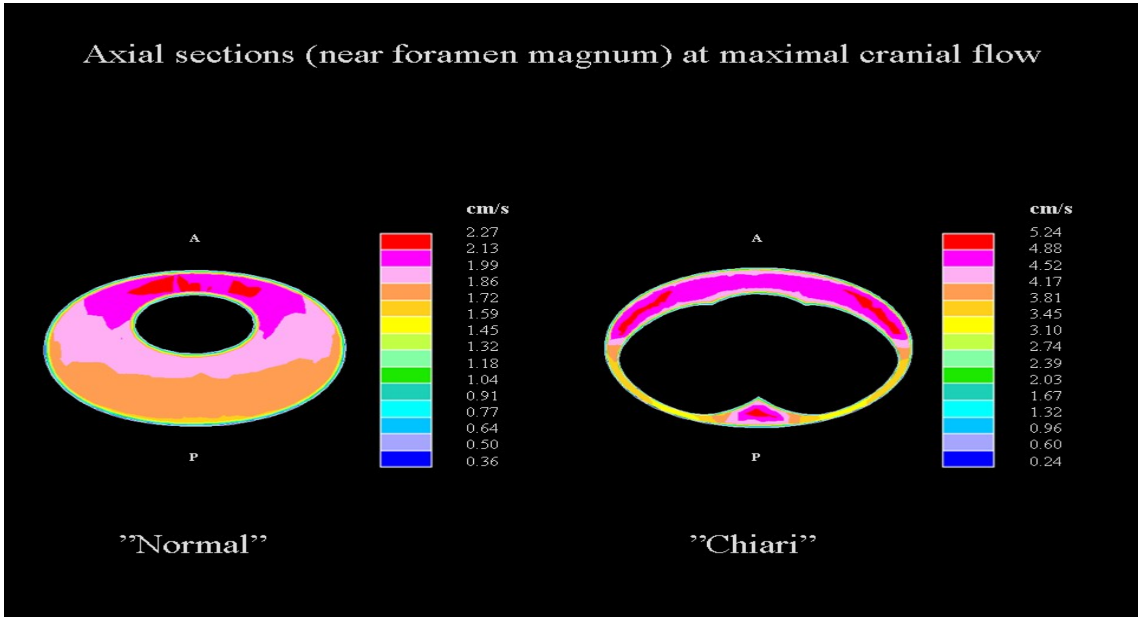


b)

The Chiari I malformation causes increased velocities (and pressures)







Flow simulation in the normal case

Summary and conclusions

Medical researchers have hypothesis where CFD can be an important tool for a deeper understanding

Anatomy differs from person to person and so does the flow

Whether turbulence is important is an open issue (in the mentioned applications)

Wall roughness is an issue