

# Biomechanics from Neurosurgery

**Fukasaku K, Negoro M, Himeno R, Cho H**

# Clinical Application of Biomechanics or Human Simulator in Neurosurgery

#1 Diseases

#2 Treatment Modalities

# Neurosurgical Diseases

---

- Stroke
- Neoplasm
- Congenital Anomaly
- Degenerative Disease
- Inflammatory
- Traumatic Lesions
- others

# Treatments in Neurosurgery

---

- Craniotomy
- Endovascular Surgery
- Radiosurgery
- Others
  - Spinal Surgery
  - Burr Hole Surgery
  - Stereotaxic Surgery
  - others

# Stroke

---

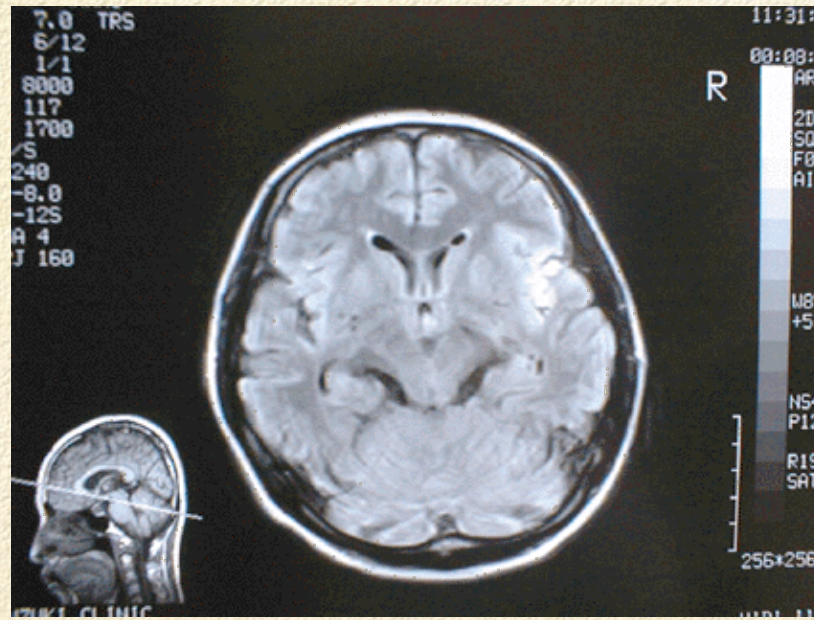
- Subarachnoid Hemorrhage (SAH)
- Hematoma (Intracerebral)
- Ischemia
- Others

# SAH

---

- Rupture of Intracranial Anrusysms >80%
- Others
  - AVM, dural AVF
  - Brain tumor
  - Head Injury
  - Bacterial Aneurysm

# Diagnosis (SAH)



- CT Scan
- MRI
- Lumbar Tap

# Prognosis of SAH

---

- ❑ 15 % of Sudden Death
- ❑ 27% of SAH is NOT Indication of Treatment
- ❑ 37 % Death in SAH Patients



# Prognosis of SAH

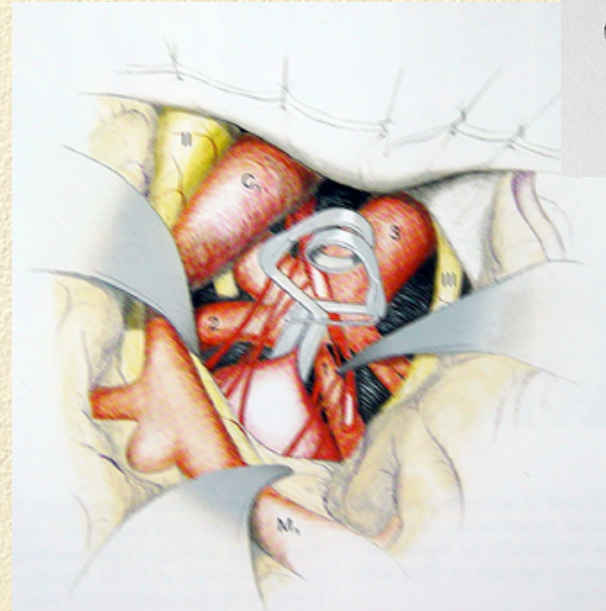
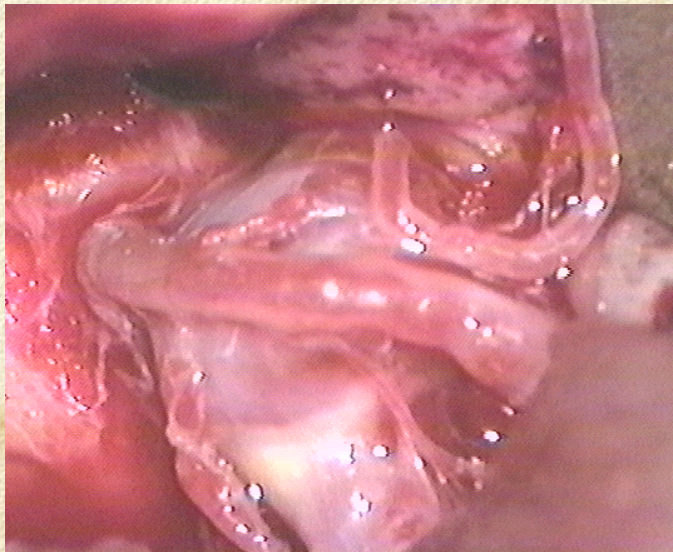
---

- ❑ 10 - 20 SAH per Year per 100000 Population
- ❑ 10 % of Cerebrovascular Accident
- ❑ 50% of Hemorrhagic Stroke
- ❑
- ❑ 32 - 67 % Death
- ❑ 30 % Need Support
- ❑ 10 - 50 % Can NOT Come to Hospital?

# Aneurysm

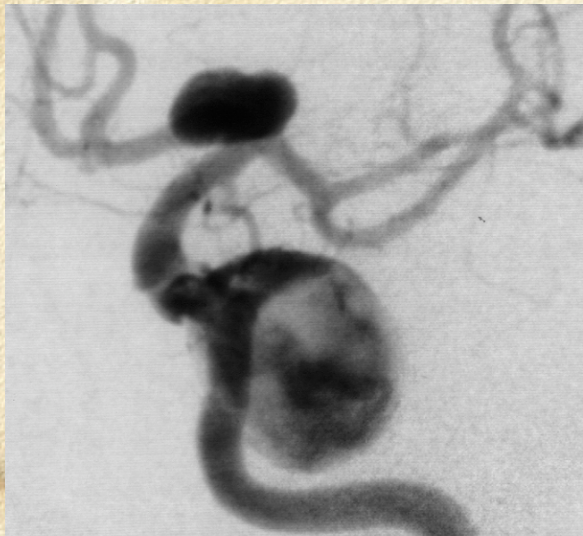
---

- Dilated Arterial Wall (Near Bifurcation)



# Diagnosis (Aneurysms)

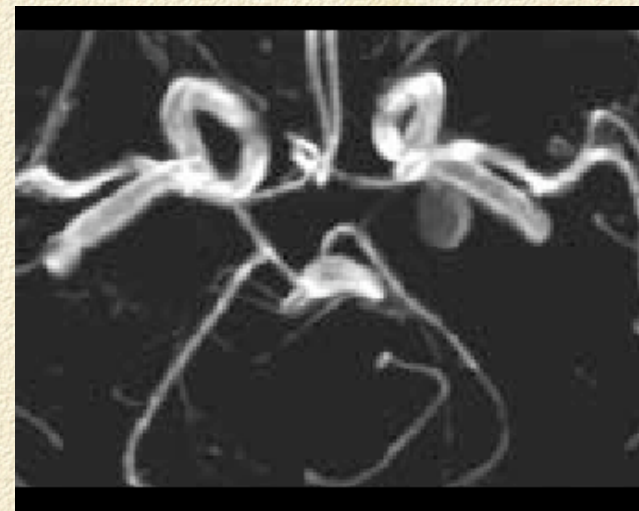
---



DSA



3D CTA



3D MRA (TOF)

# Prognosis (Aneurysms)

---

- ❑ Rupture Rate: 1 - 2 % per year
- ❑ Risky Aneurysms
  - ❑ > 5 or 10 mm
  - ❑ Irregular Shape
  - ❑ Daughter or Bleb
  - ❑ Location (Basilar Tip or Anterior Communicating)
- ❑ Rupture Case : Regular Shaped Aneurysms, too.

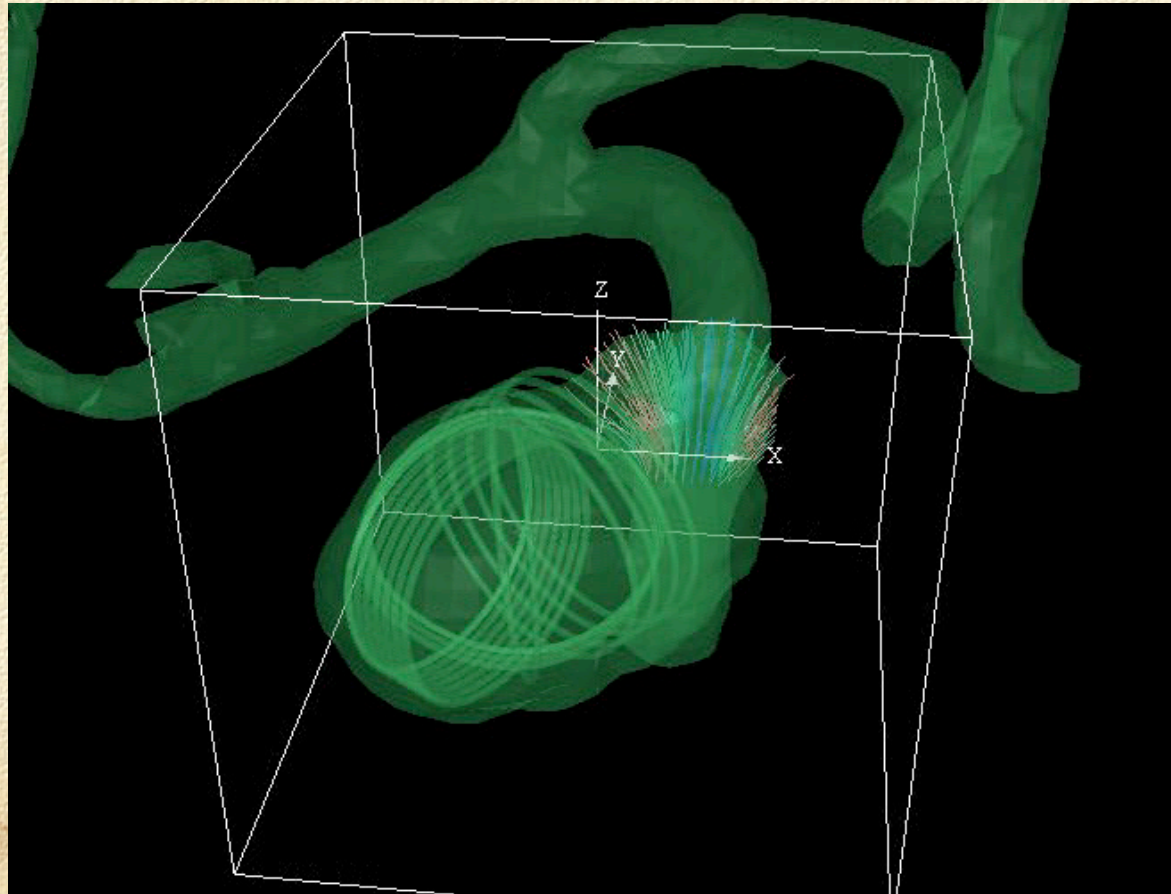
# CFD for Aneurysms

---

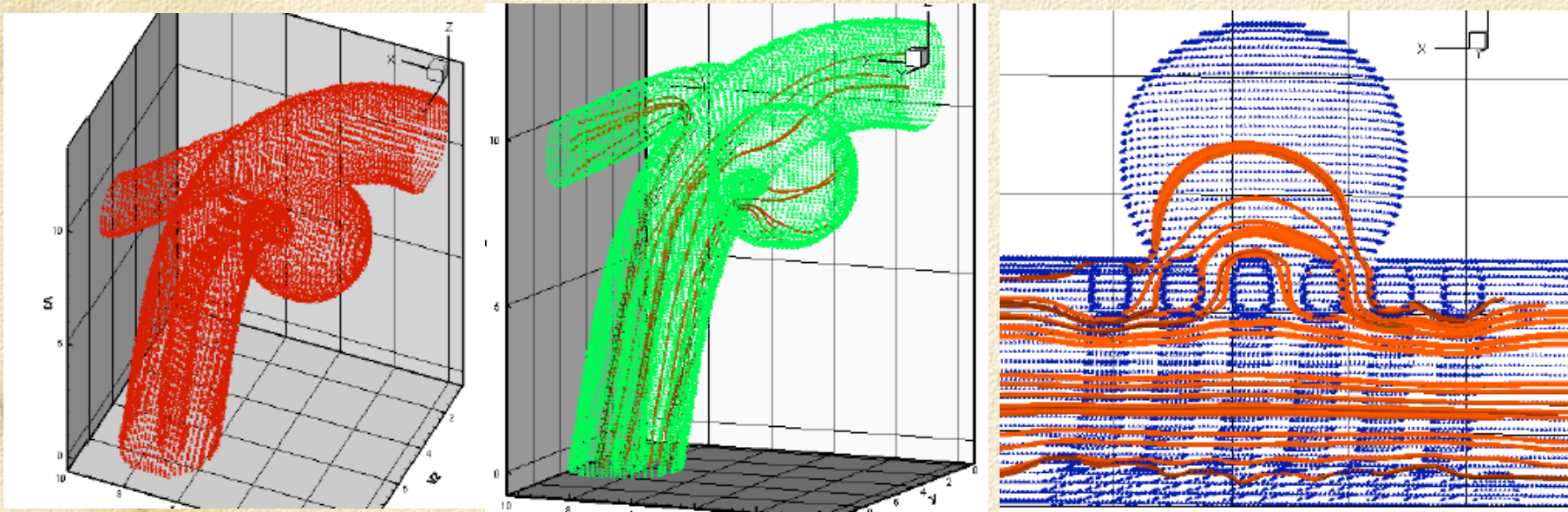
- Three Dimensional Data Acquisition
  - 3D CTA, MRA, DSA(Rotation DSA)
- Smoothing
- Computational Analysis
- Problems
  - Elasticity
  - Boundary Condition
  - BLOOD IS NOT WATER

# CFD for Aneurysms

---

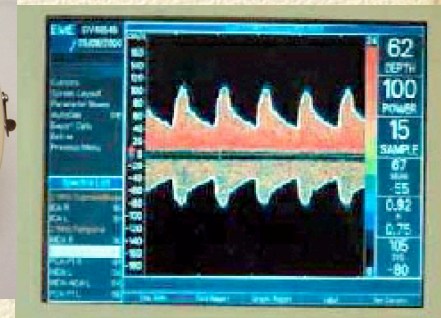
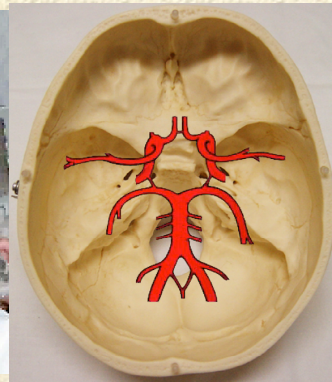


# CFD for Aneurysms



# CFD for Aneurysms

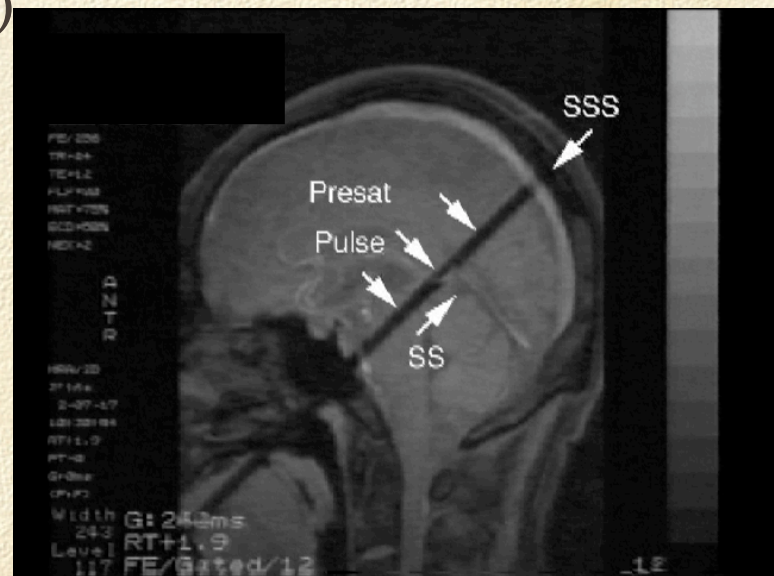
- Boundary Condition
  - Flow Pattern
    - Echo (Doppler)
    - MR (Phase Contrast, Tagging)
  - Pressure
    - via Catheter?
    - Smart Wire?



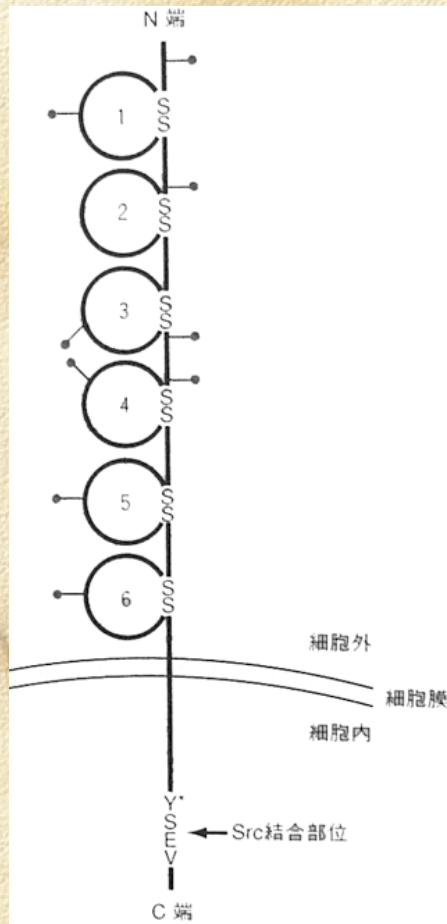


# CFD for Aneurysms

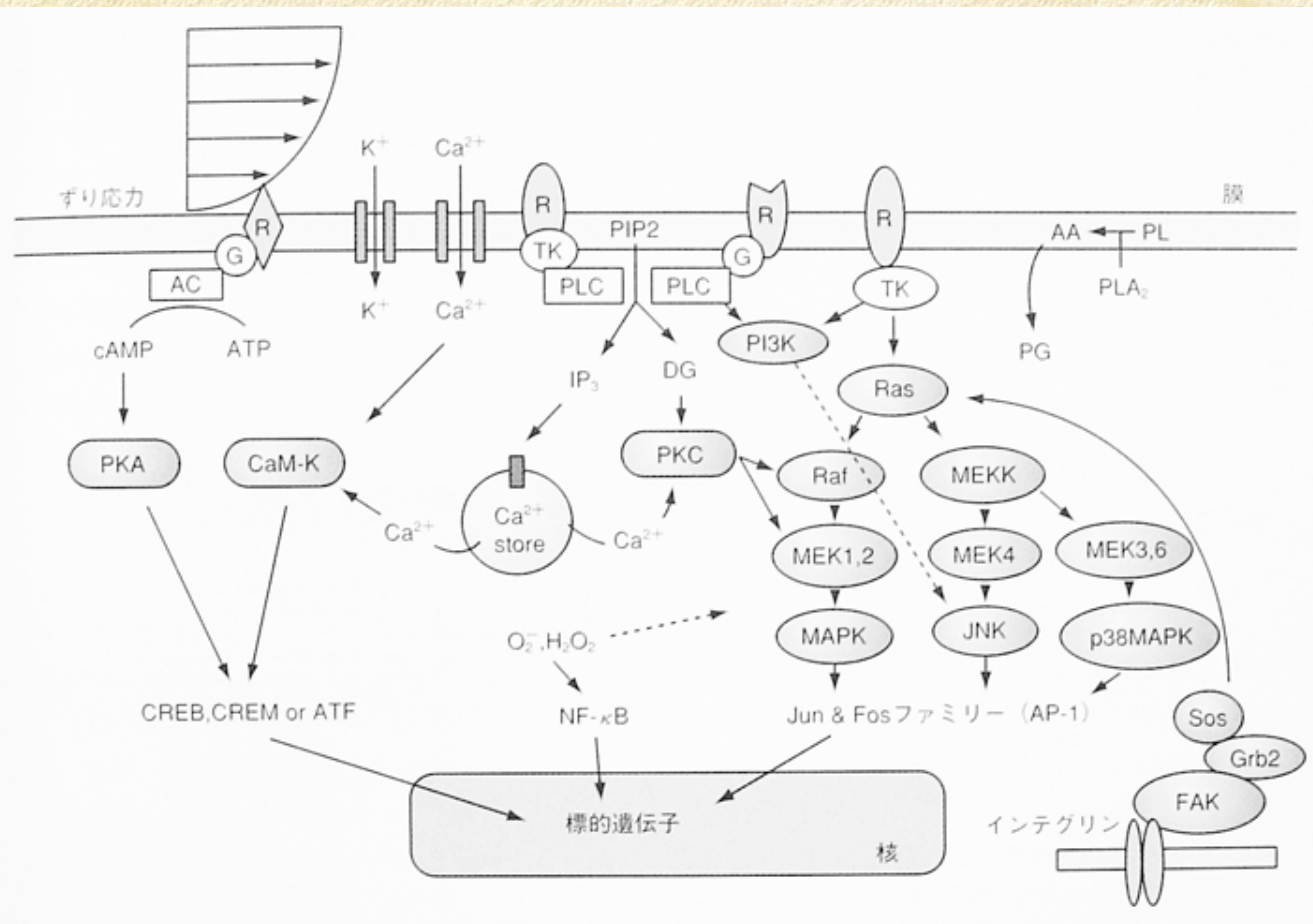
- Boundary Condition
  - Flow Pattern
    - Echo (Doppler)
    - MR (Phase Contrast, Tagging)
  - Pressure
    - via Catheter?
    - SmartWire?



# Biological Response Induced by Flow



Shear Stress Receptor



Biological Response in Endothelial Cells

# Biological Response Induced by Flow

---

- Increase Intracellular Ca Level
- Opening  $K^+$  Channel
- Increase NO Level
- Increase Growth Factor
- Increase tPA, Collagen
- Then, Why Produce Vessel Wall or Aneurysm Wall

# CFD for Aneurysms

---

- Biological Response Induced by Flow
  - Detectable Amount of Chemical Products?
  - CFD must be the Key
  
- Tailor Made Medicine for Indication
  - and Strategy for Treatment

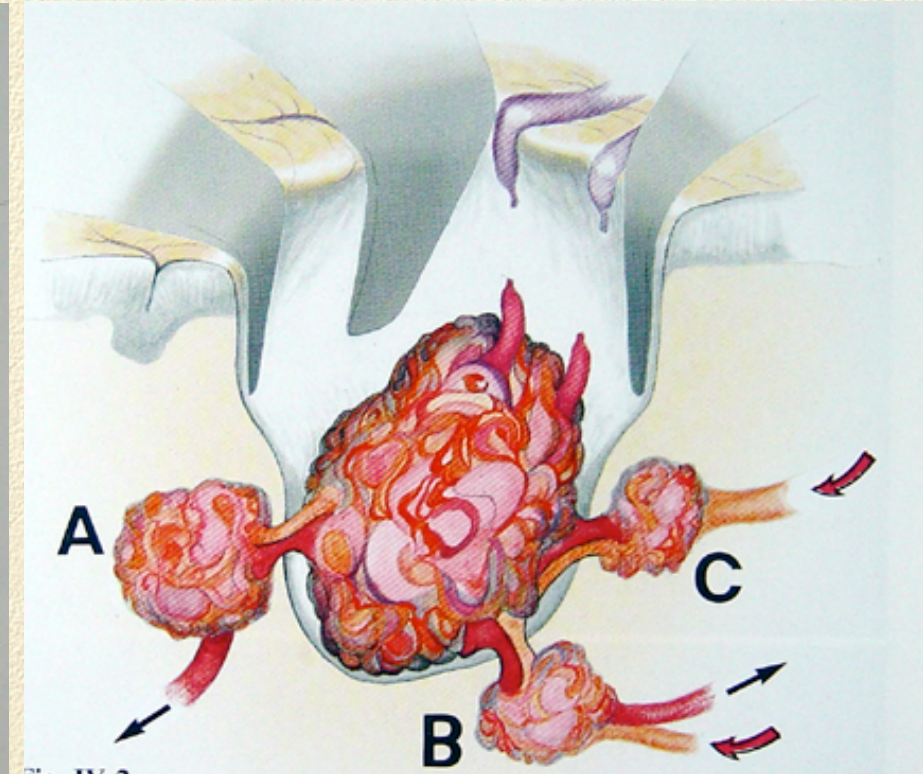
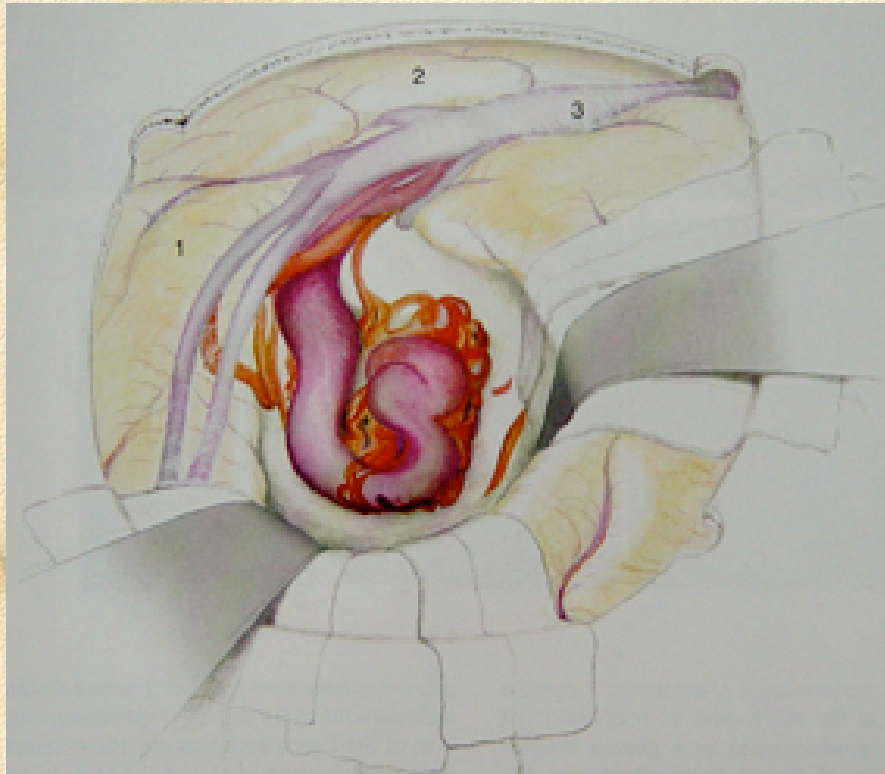
# AVM (Arteriovenous Malformation)

---

- ❑ Direct Shunt of Artery to Vein
  - ❑ WithOUT Capillary
  - ❑ Pathological Vascular Network called Nidus
- ❑ Complex Angio Architecture
  - ❑ Aneurysm, Flow Related Aneurysm, Varix, Venous Stenosis, Direct Fistula, etc
- ❑ Clinical Problems
  - ❑ Hemorrhage (Intracerebral, SAH)
  - ❑ Epilepsy, Ischemia

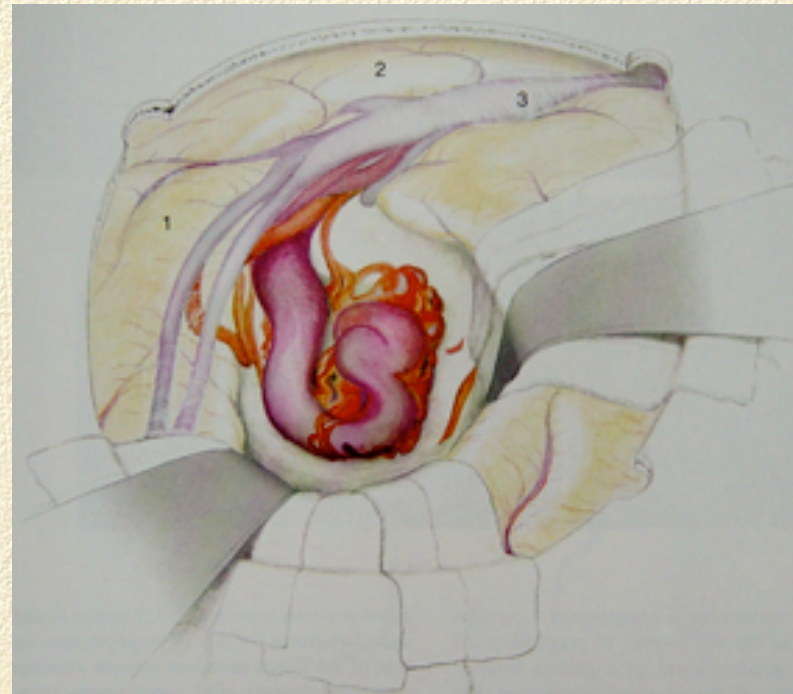
# AVM

---



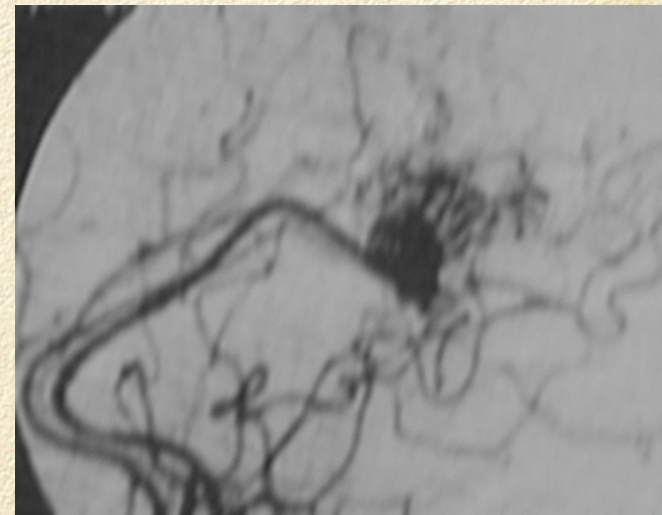
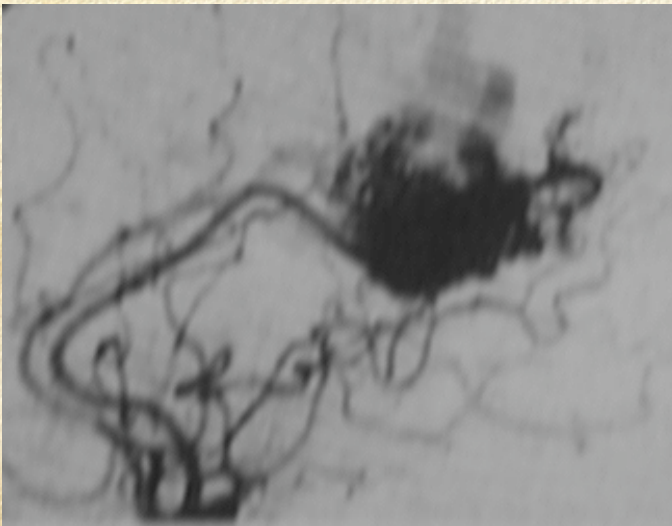
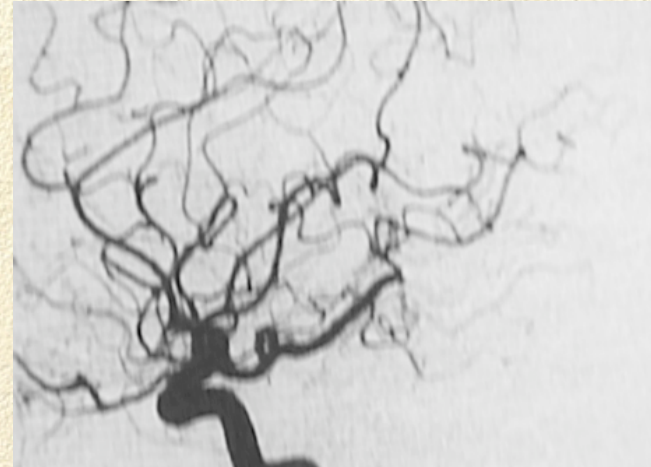
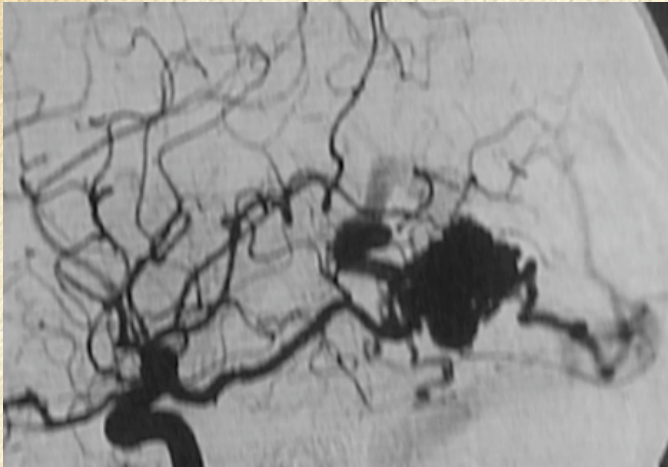
# AVM

---



# AVM

---





# AVM

---

- ❑ Indication of Treatment
  - ❑ Rupture or Not, Inducing Ischemia?
- ❑ Where to Start Treatment?
  - ❑ Most Risky for Bleeding
  - ❑ Most Effective to Improve Ischemia
  - ❑ Can Improve Venous Hypertension?
- ❑ Conservative Embolisation
  - ❑ Most Effective Location?

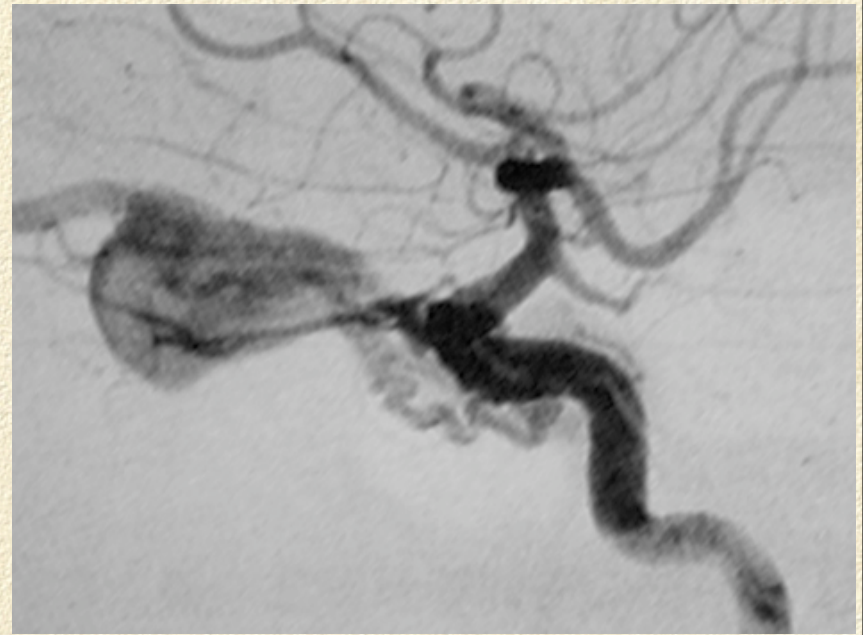
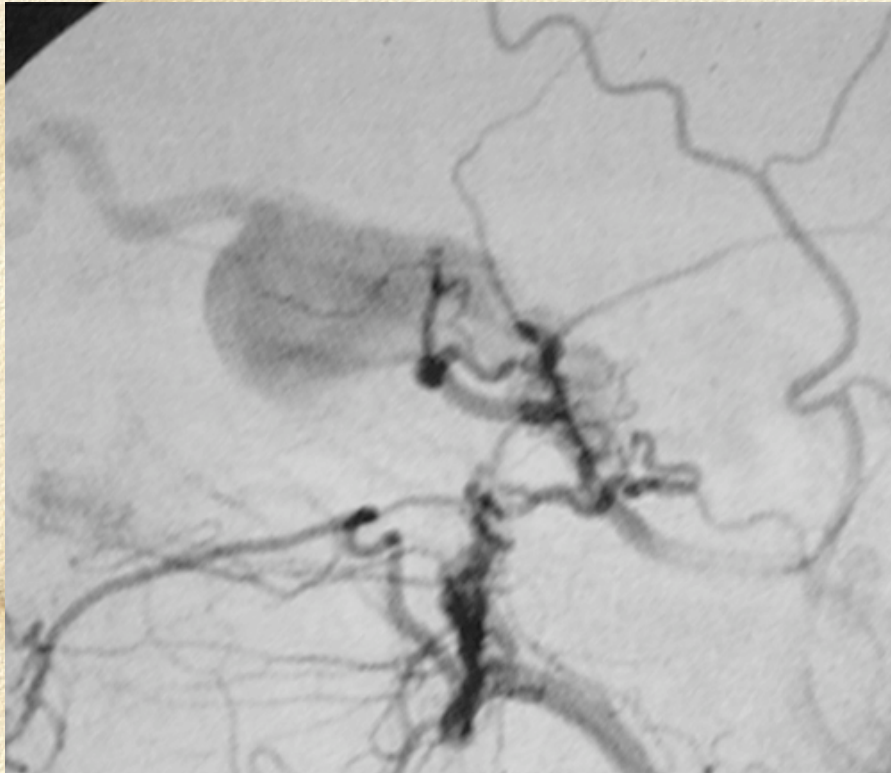
# Dural Arteriovenous Fistulae

---

- Direct Shunt at the Dura
  - Simplified Model of AVM?
  - Feeding Artery; Dural Artery
  - Draining Vein; Dural Sinus (or Cortical Vein)
- NO Nidus
- Direct Shunts and Venous (Sinus) Stenosis or Occlusion
- Possible to Induce Artificially

# Dural AVF

---



# Syringomyelia

---

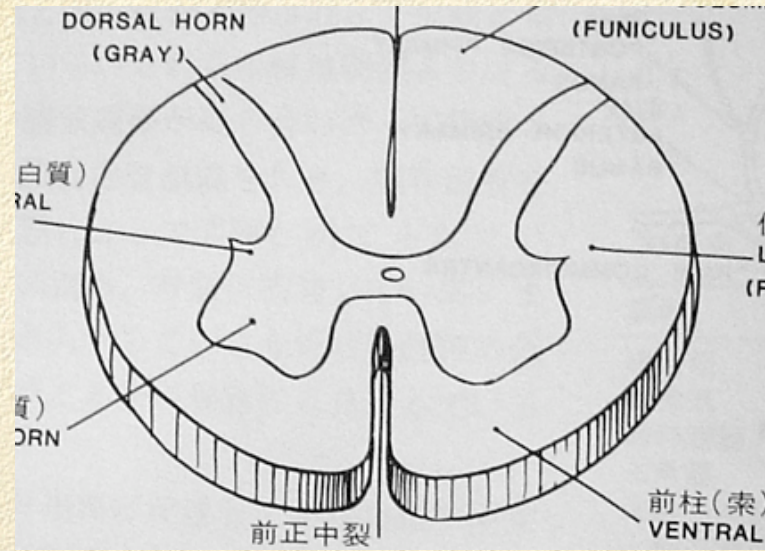
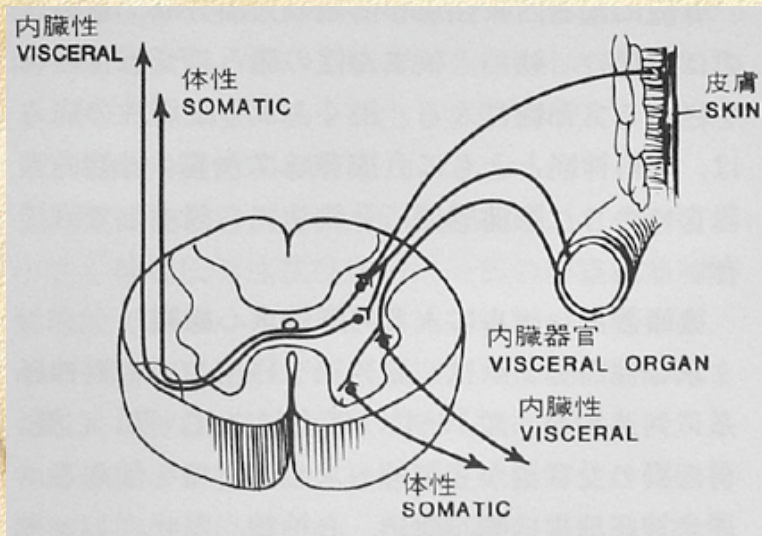
- ❑ Fluid-Filled Cavities at Cervical Cord
- ❑ Symptoms
  - ❑ Spasticity
  - ❑ Sensory Disturbances
- ❑ Level of Symptoms
  - ❑ Shoulder

# Syringomyelia

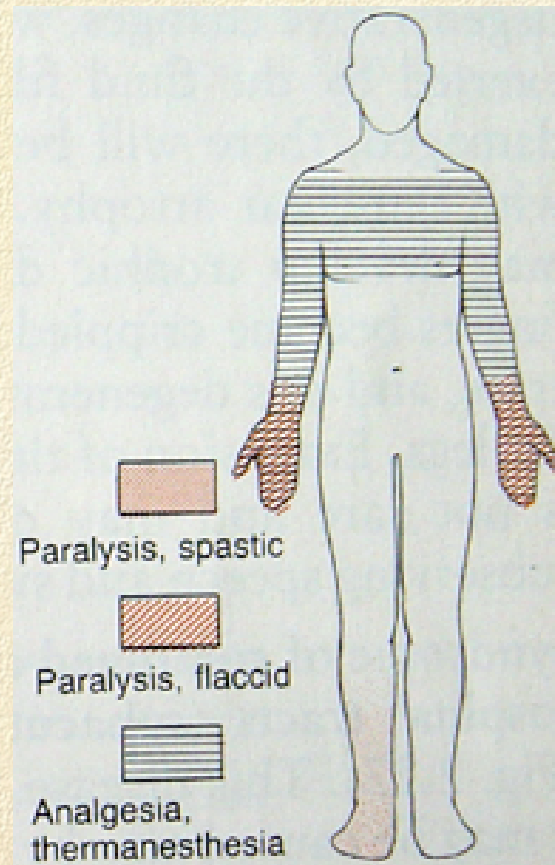
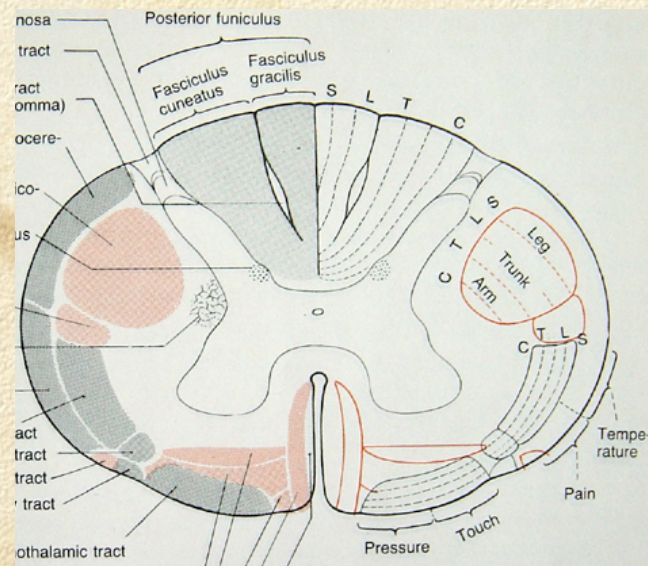
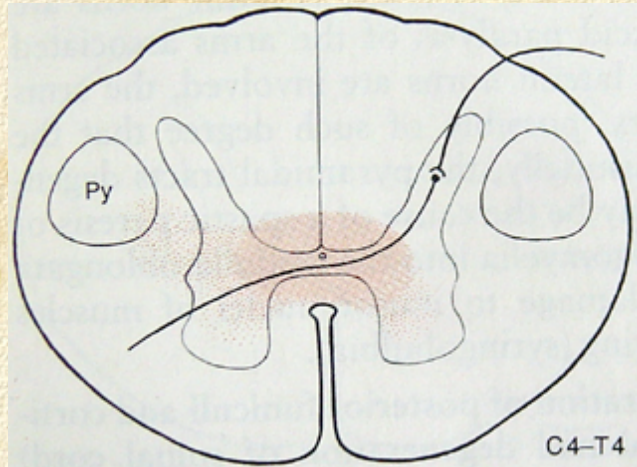
---

- Chari Malformation - related
  - Hydrodynamic Theory
- Others
  - Check Valve?
  - Inflammatory?
  - others?

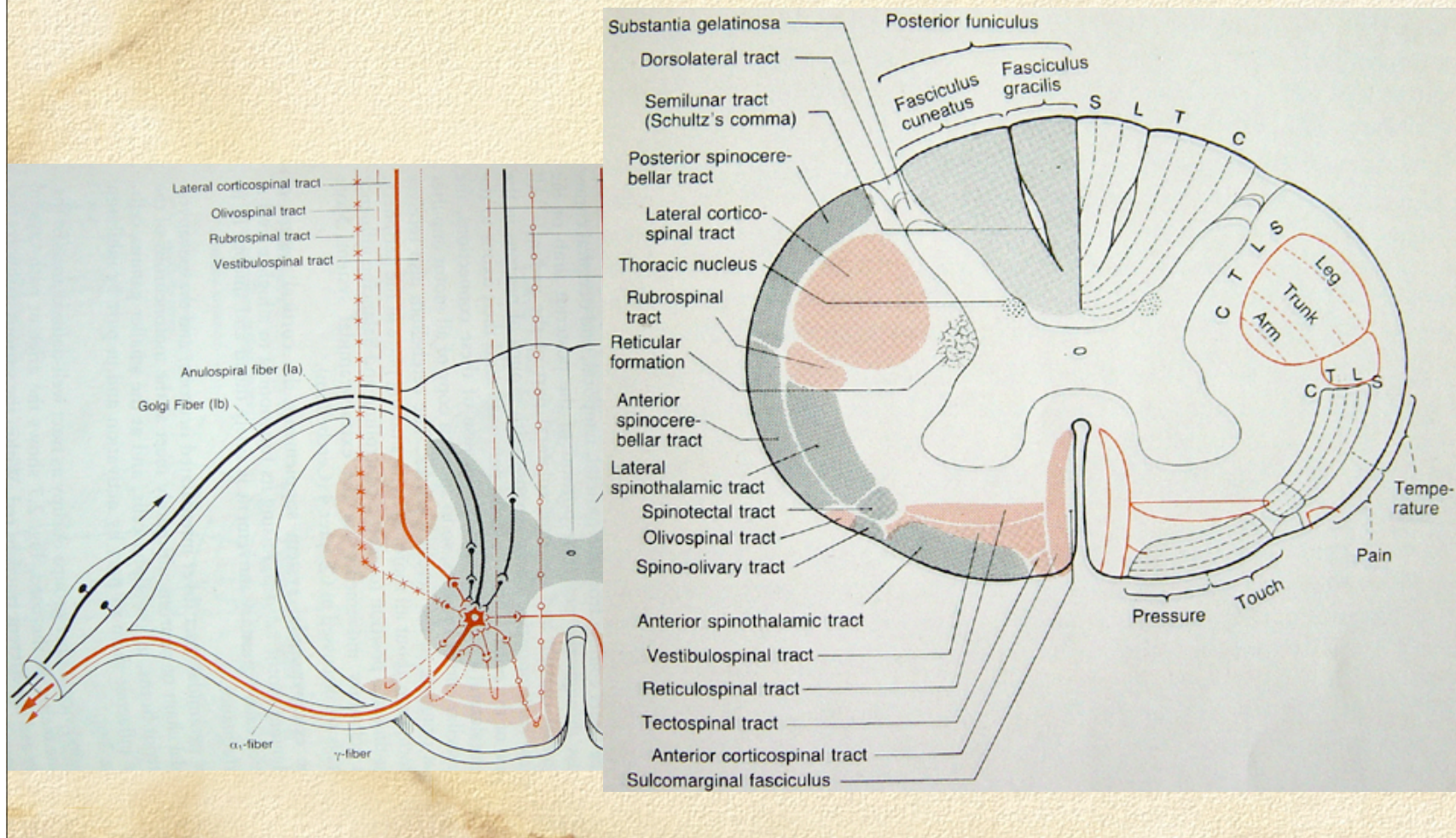
# Syringomyelia



# Syringomyelia

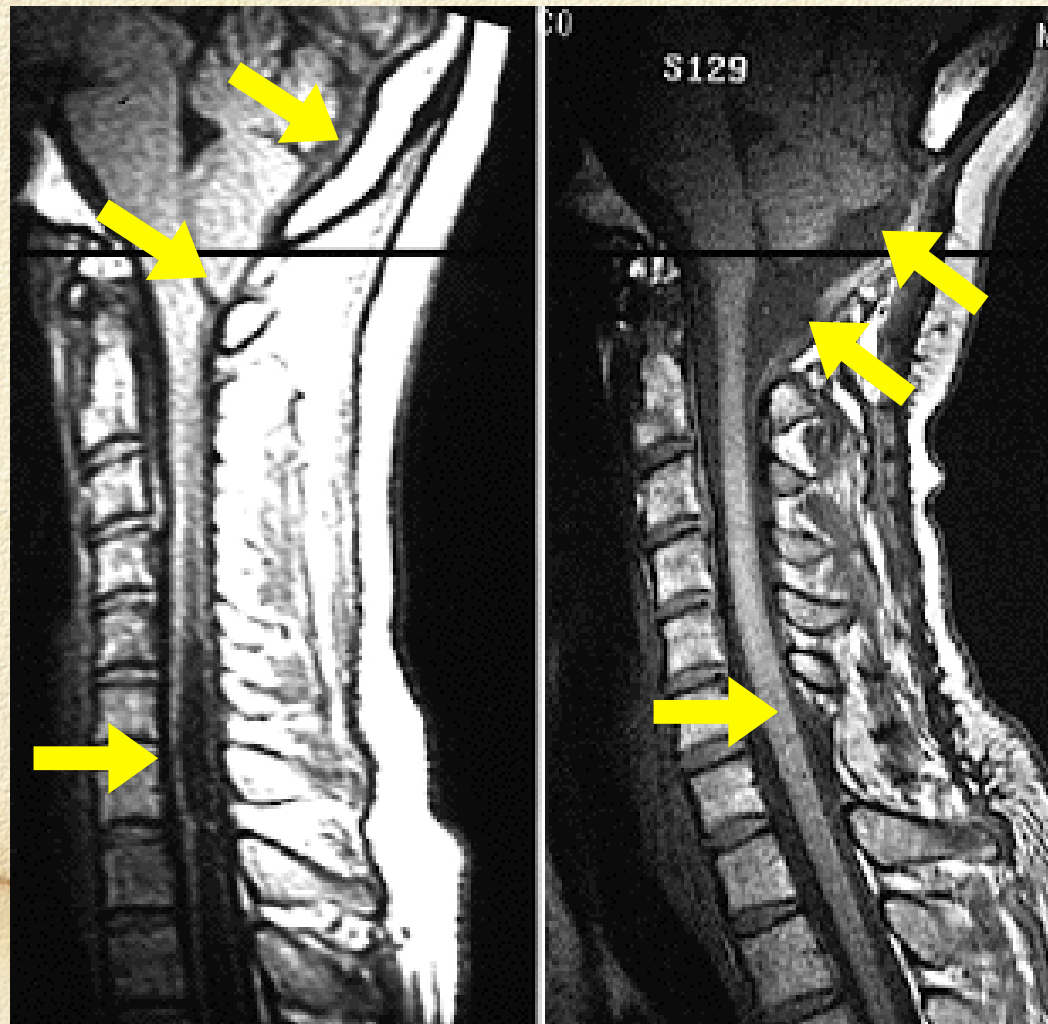


# Syringomyelia





# Syringomyelia

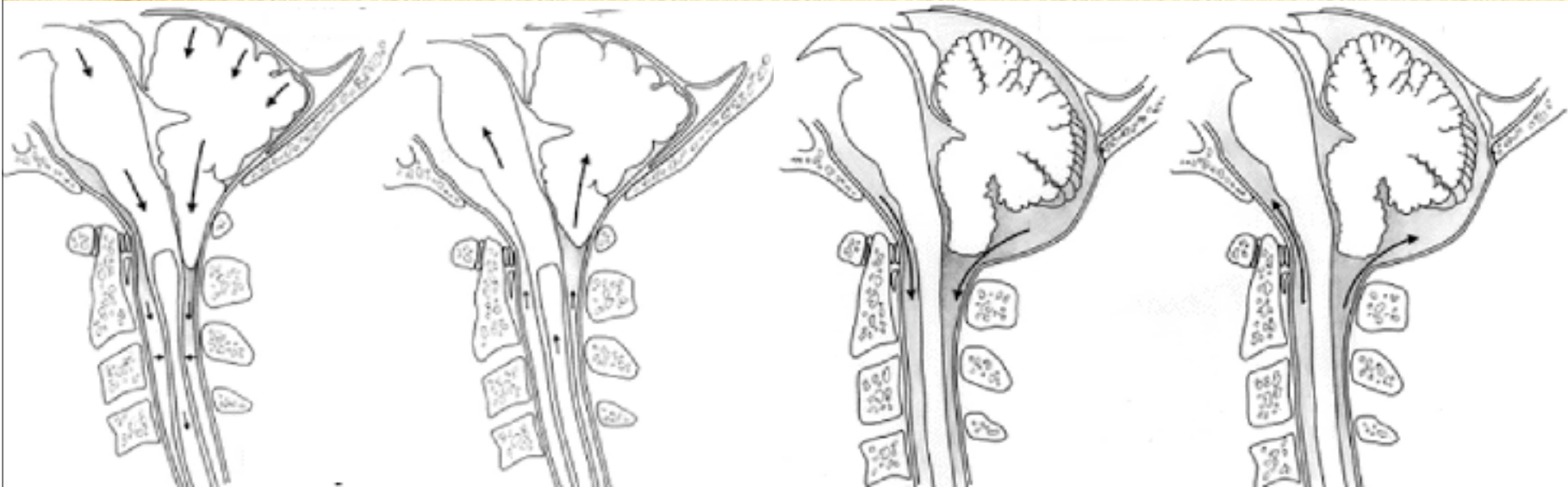


# Syringomyelia



- ❑ Heart Beat -> Pulsation of Brain, Pulsation of Cerebro-Spinal Fluid
- ❑ Disturbed Pulsatile Flow at Cisterna Magna

# Syringomyelia



- Surgically Made (Suboccipital Craniectomy)  
Cisterna Magna is Also Effective for Free  
Cerebra-Spinal Fluid Flow

# Syringomyelia

---

- Cause of Disease and Surgical Strategy are Compatible with Biomechanics or Fluid Dynamics Very Well.
- How about Other Causes of this Disease?

# Dissecting Aneurysm

---

- Dissection of Arterial Wall Itself
  - Dissection or Bleeding to the Arterial Wall
- Clinical Problems
  - Severe SAH
  - Arterial Occlusion

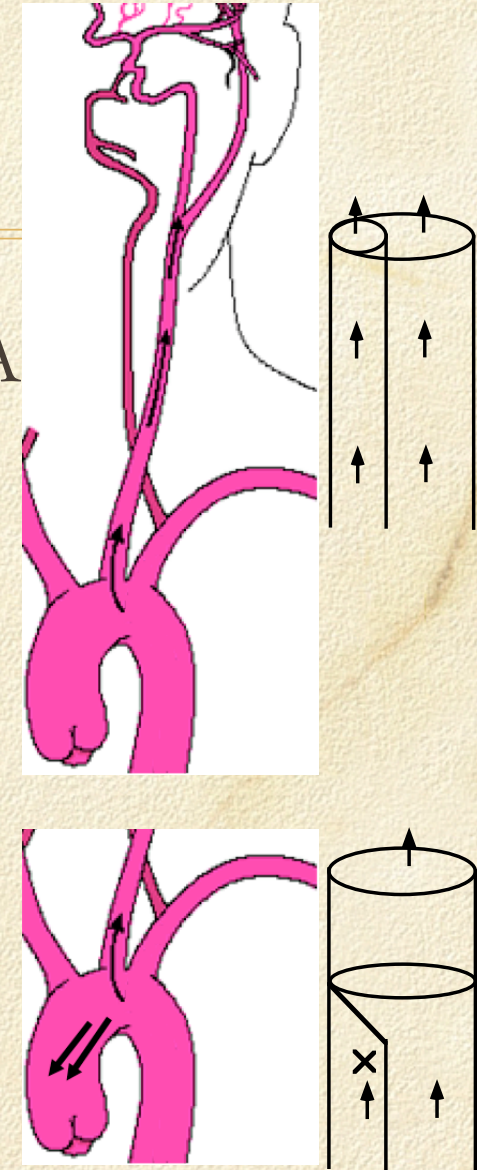
# Dissecting Aneurysm

---



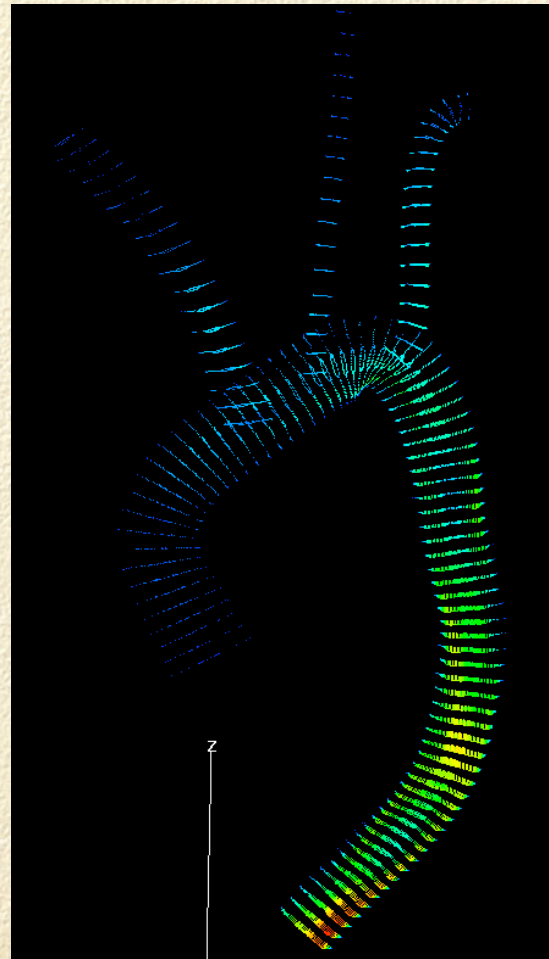
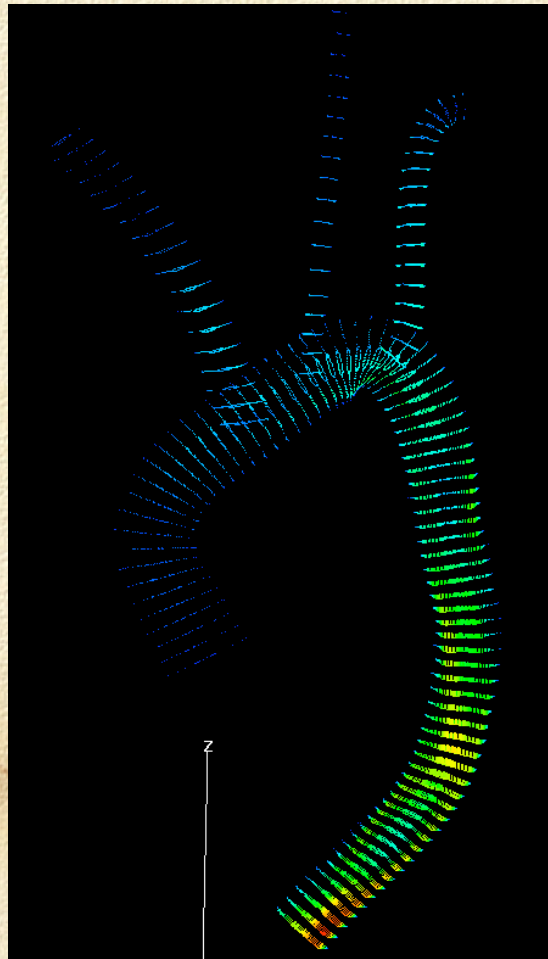
# Dissecting Aneurysm

- ❑ Painless Dissection of Aorta Spreading to ICA
- ❑ Painless Dissection at Which Layer?
- ❑ Cause of Death?
  - ❑ Occlusion of Re-entry at Carotid Artery?
  - ❑ Rupture of Dissection?
  - ❑ Occlusion of Coronary Origin?



# Dissecting Aneurysm

- Dissection from Aorta to Carotis, Where the Location is?





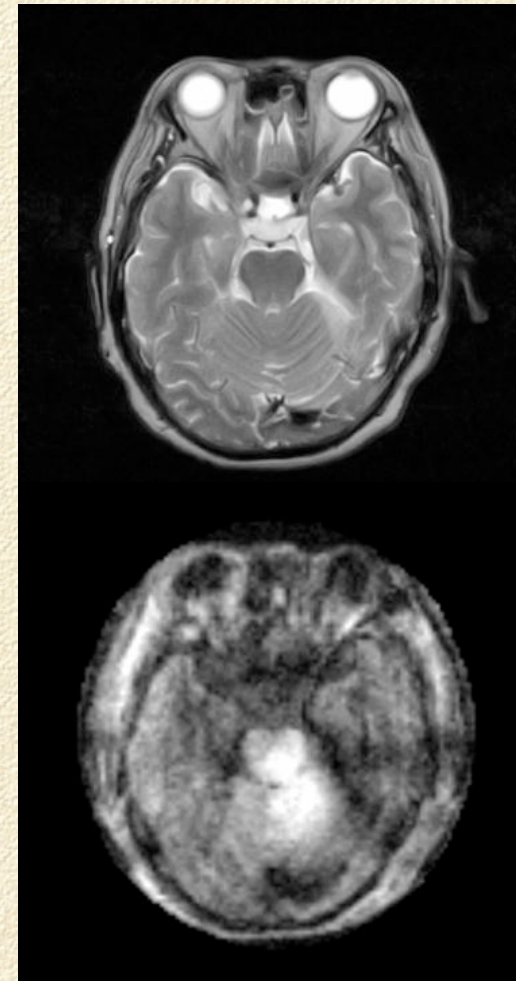
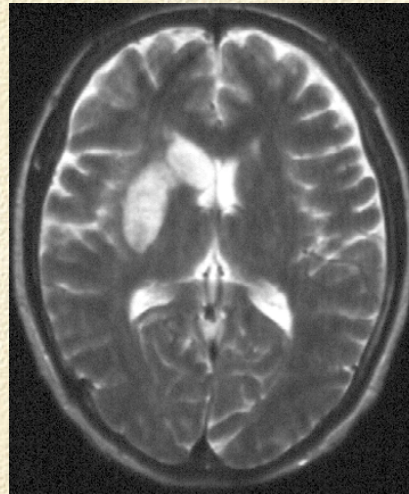
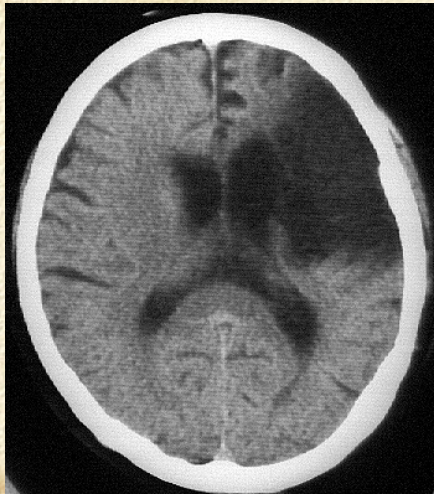
# Ischemia

---

- Hypoperfusion of Brain
  - Occlusion of Brain Arteries
    - Thrombosis
    - Embolism
  - Decreased Perfusion Pressure
    - Stenosis/Occlusion of Neck Artery(es)
- Dissection (Discuss Later)

# Ischemia

---



# Hematoma

---

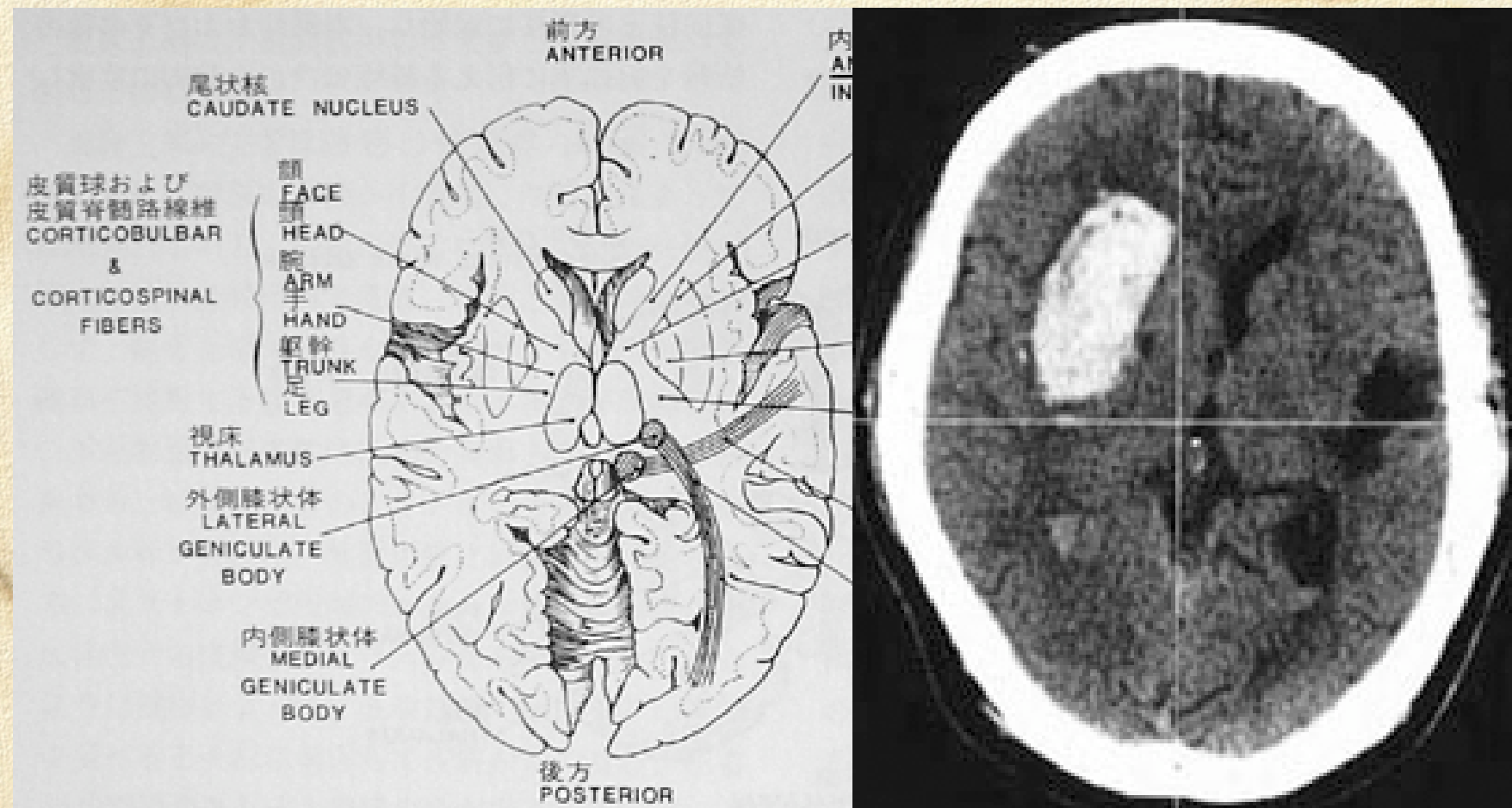
- Angionecrosis/Microaneurysm at Perforators
- Others
  - Arterio-venous Malformation
  - Sinus Thrombosis (Stenosis?)
  - Amyloidosis
  - Brain Tumor
  - Others

# Hematoma

---

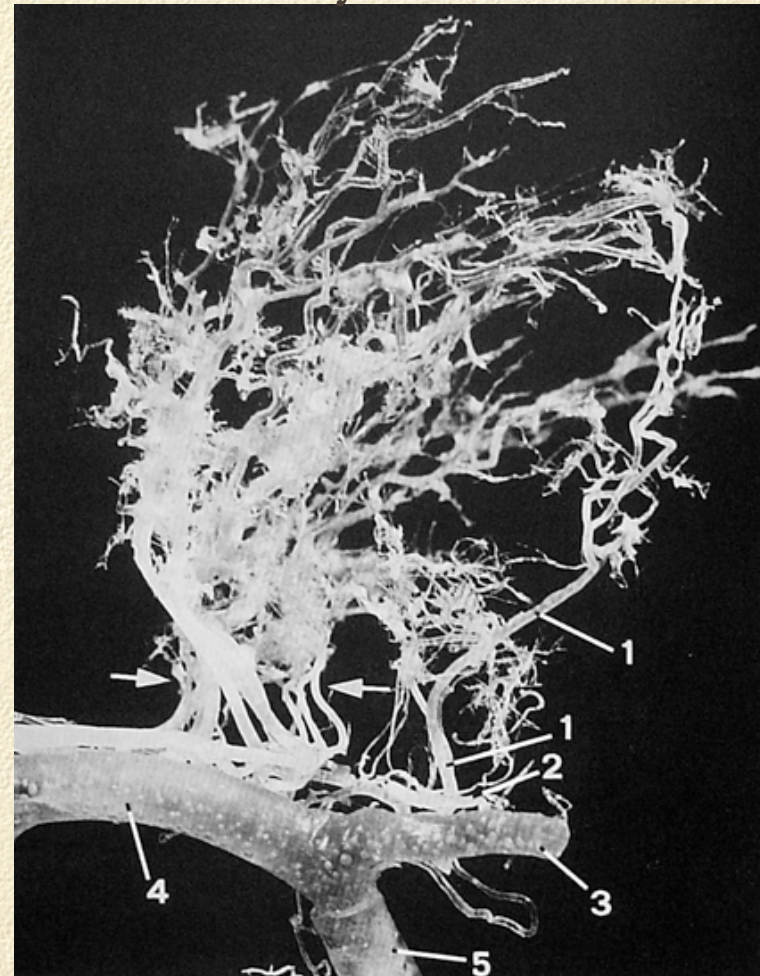
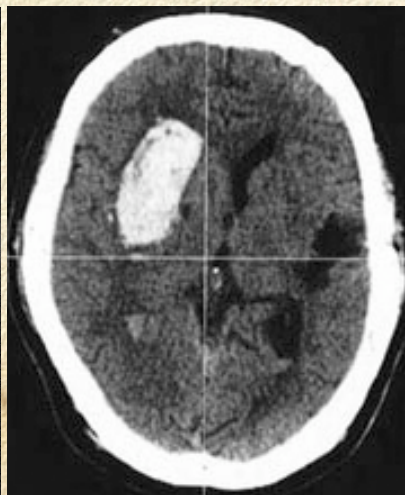
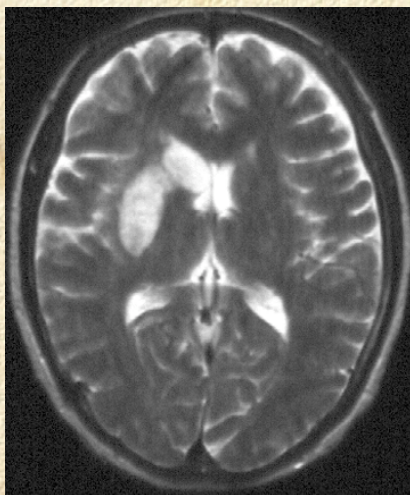
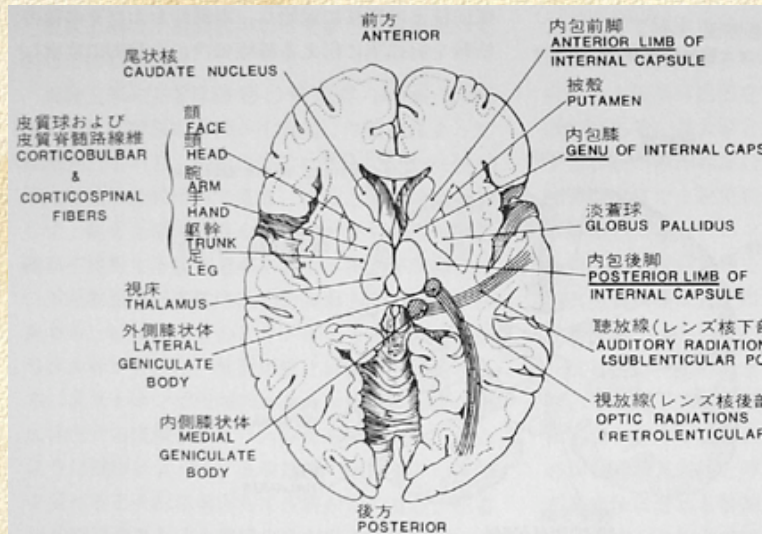


# Hemiparesis



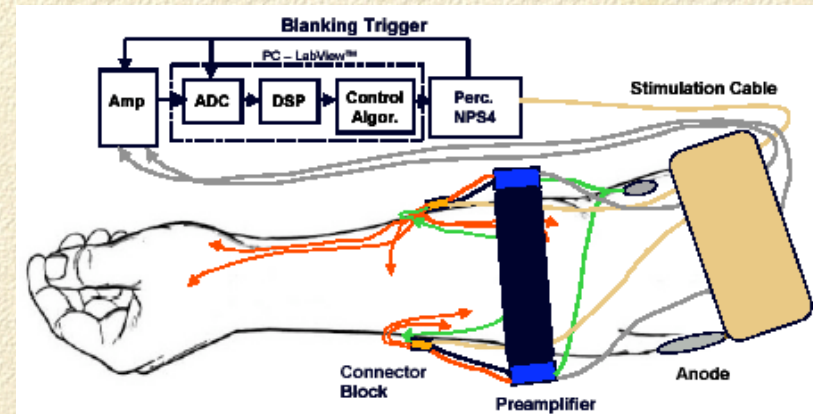
# Hemiparesis

- Lesion Location of Hematoma and Infarction
- Destroy Pyramidal Tract (Voluntary Movement)



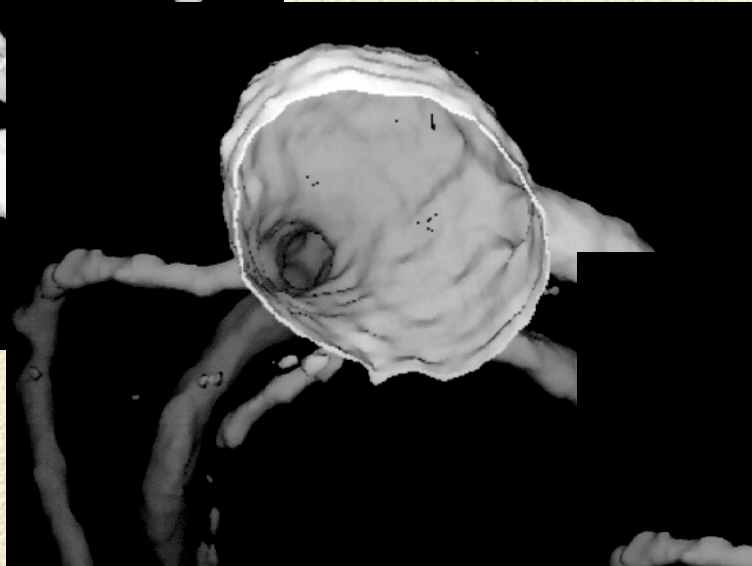
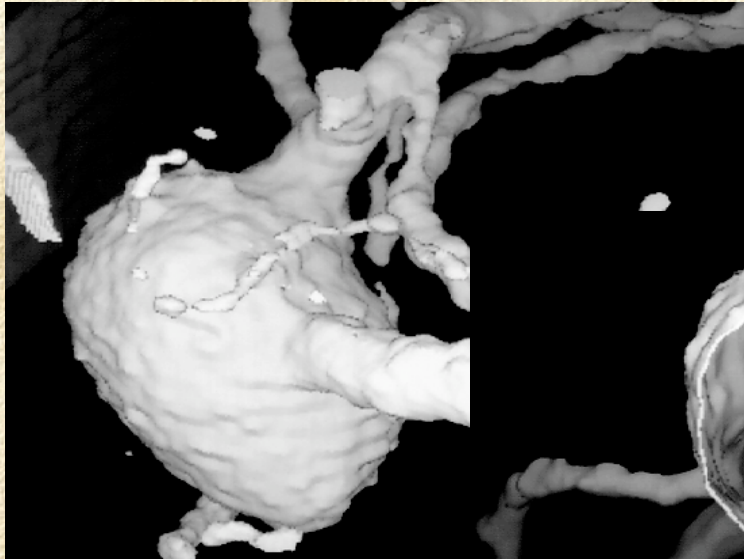
# Hemiparesis

- Treatment for Hemiparesis, Destroyed Brain
- NOTHING (Rehabilitation)



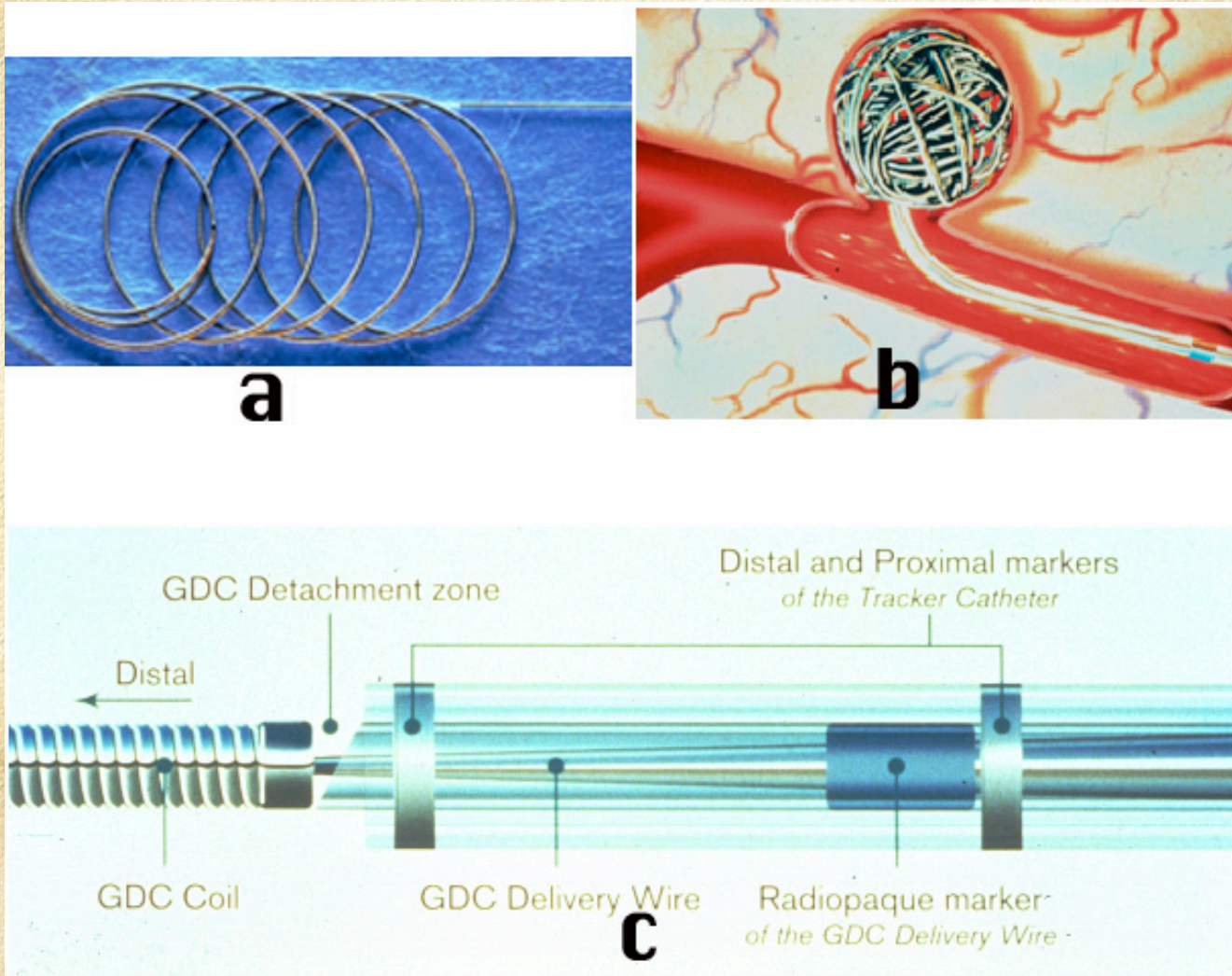
- Electrical Stimulation to the Peripheral Nerves; FES (Functional Electrical Stimulation)
- Collab. with Health Side, Feedback Sensation

# Coil Embolization for Aneurysms

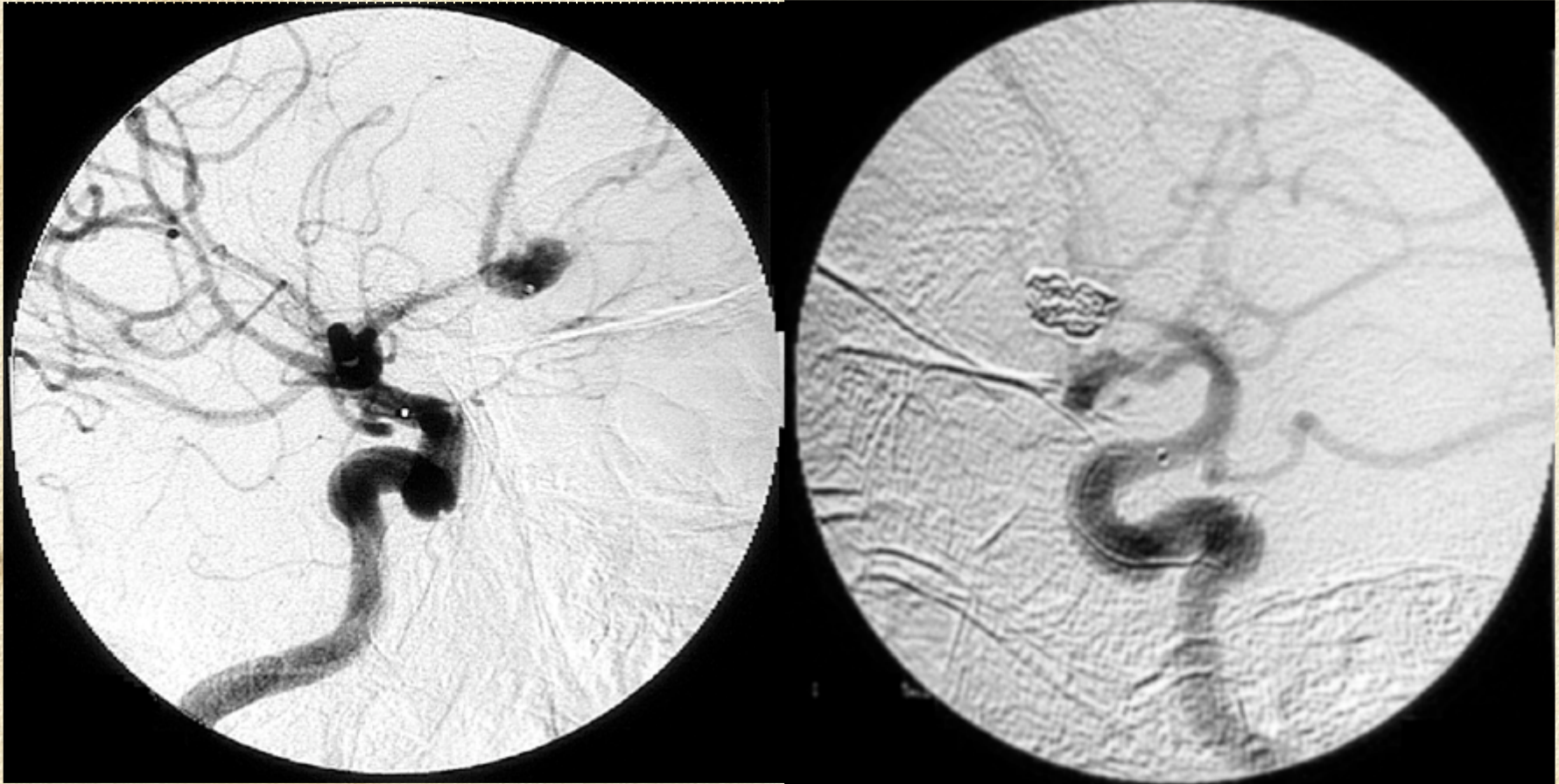




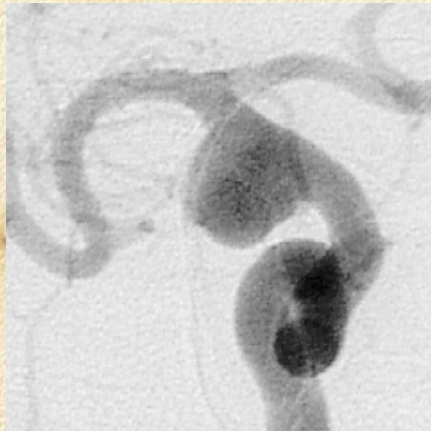
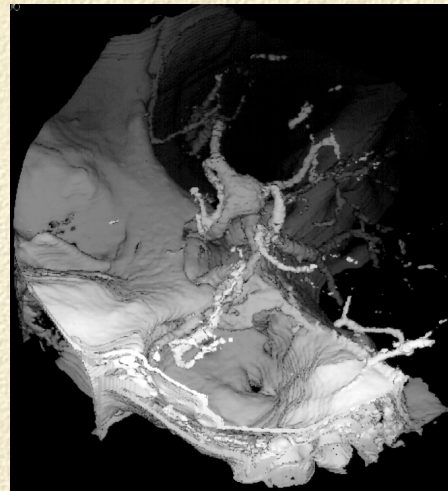
# Coil Embolization for Aneurysms



# Coil Embolization for Aneurysms



# Coil Embolization for Aneurysms



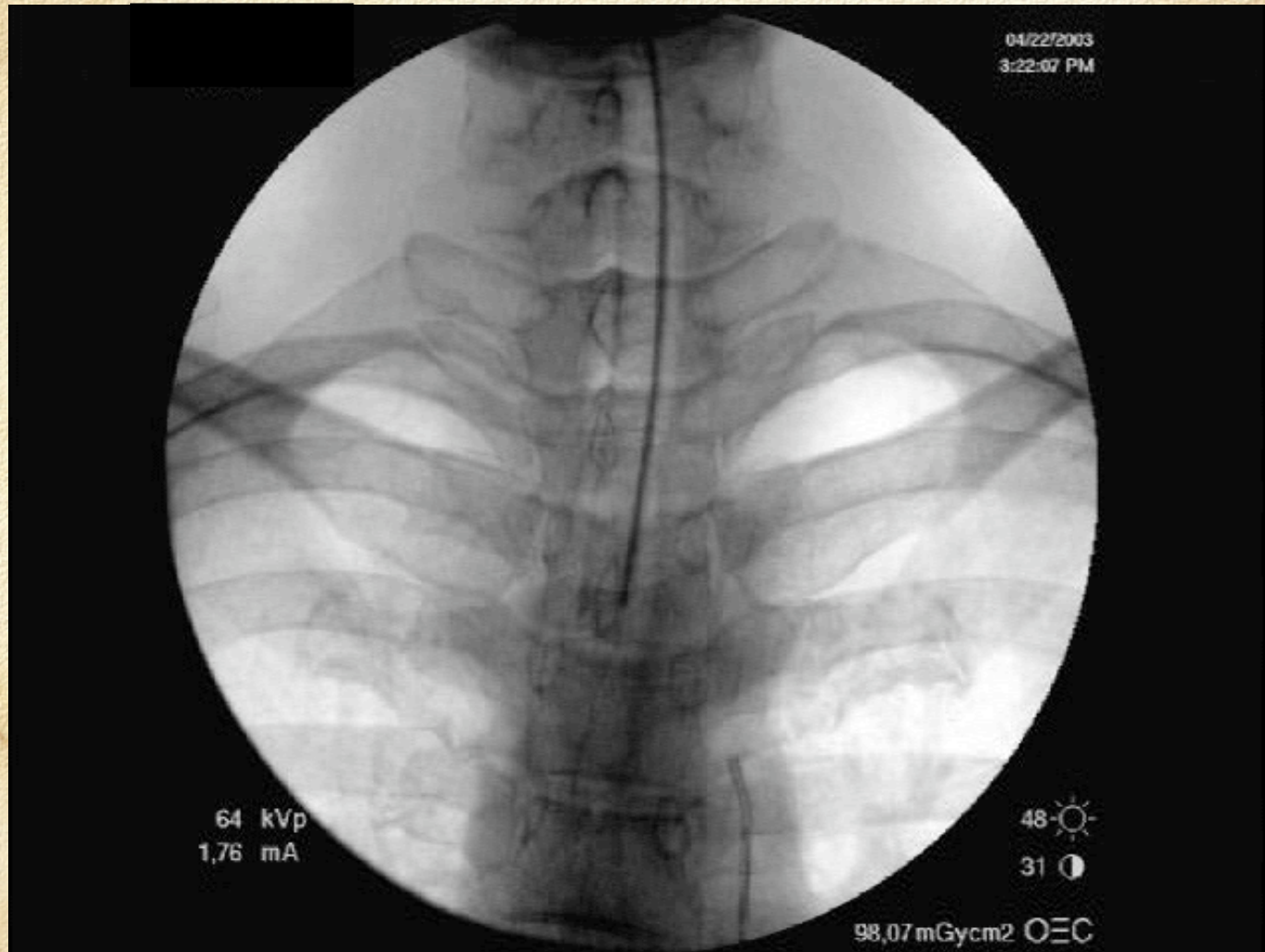
# Coil Embolization for Aneurysms

---

- General Anesthesia
- Setting Sheath
- Placing Guiding Catheter
- Navigating Microcatheter
  - Fluoroscopy and Road Mapping
  - 3D DSA
- Coil Deposition and Detach
- Removing All Catheters
- Hemostasis

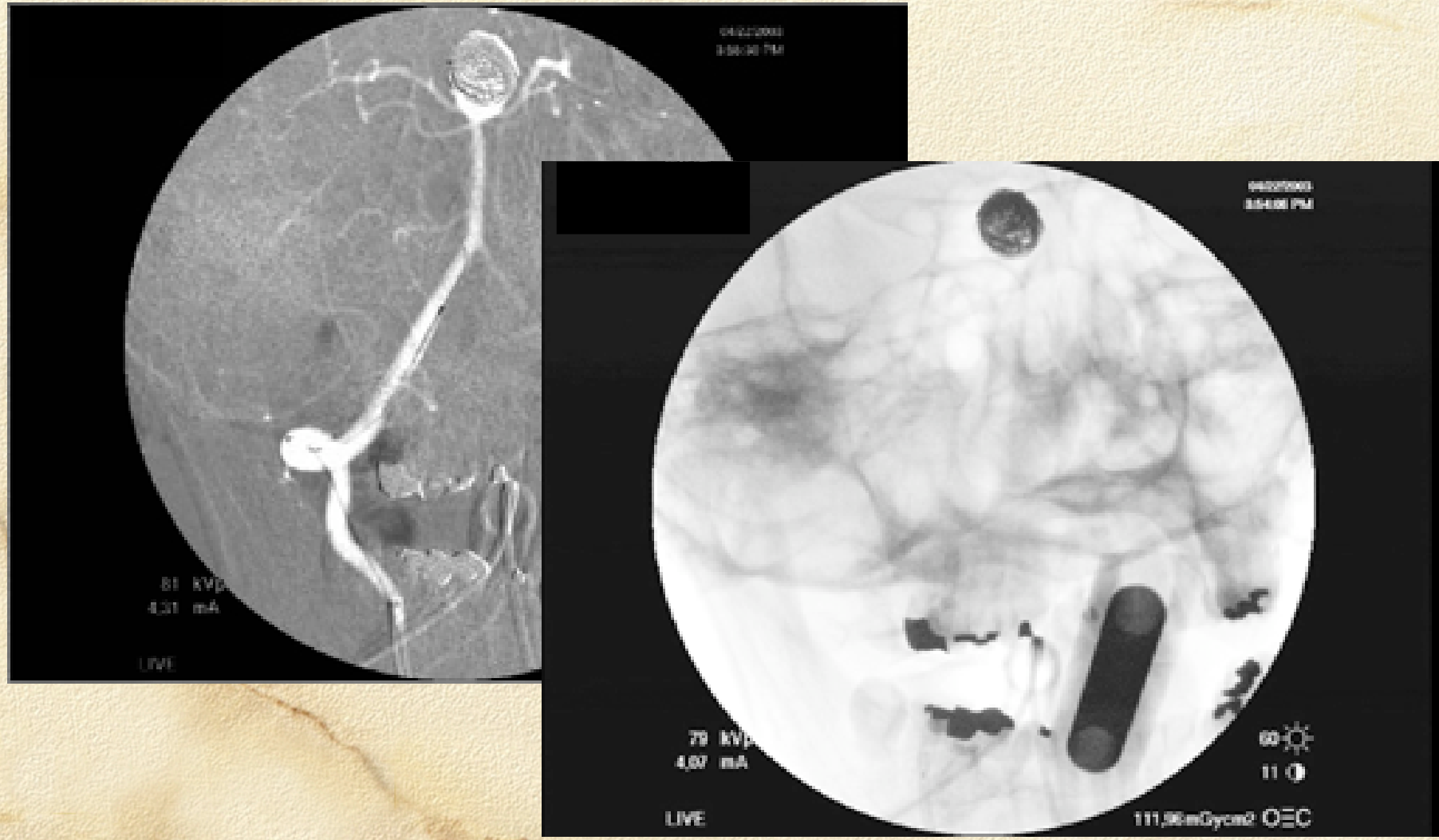
# Coil Embolization for Aneurysms

- Set Guiding Catheter



# Coil Embolization for Aneurysm

## □ Roadmap Technique



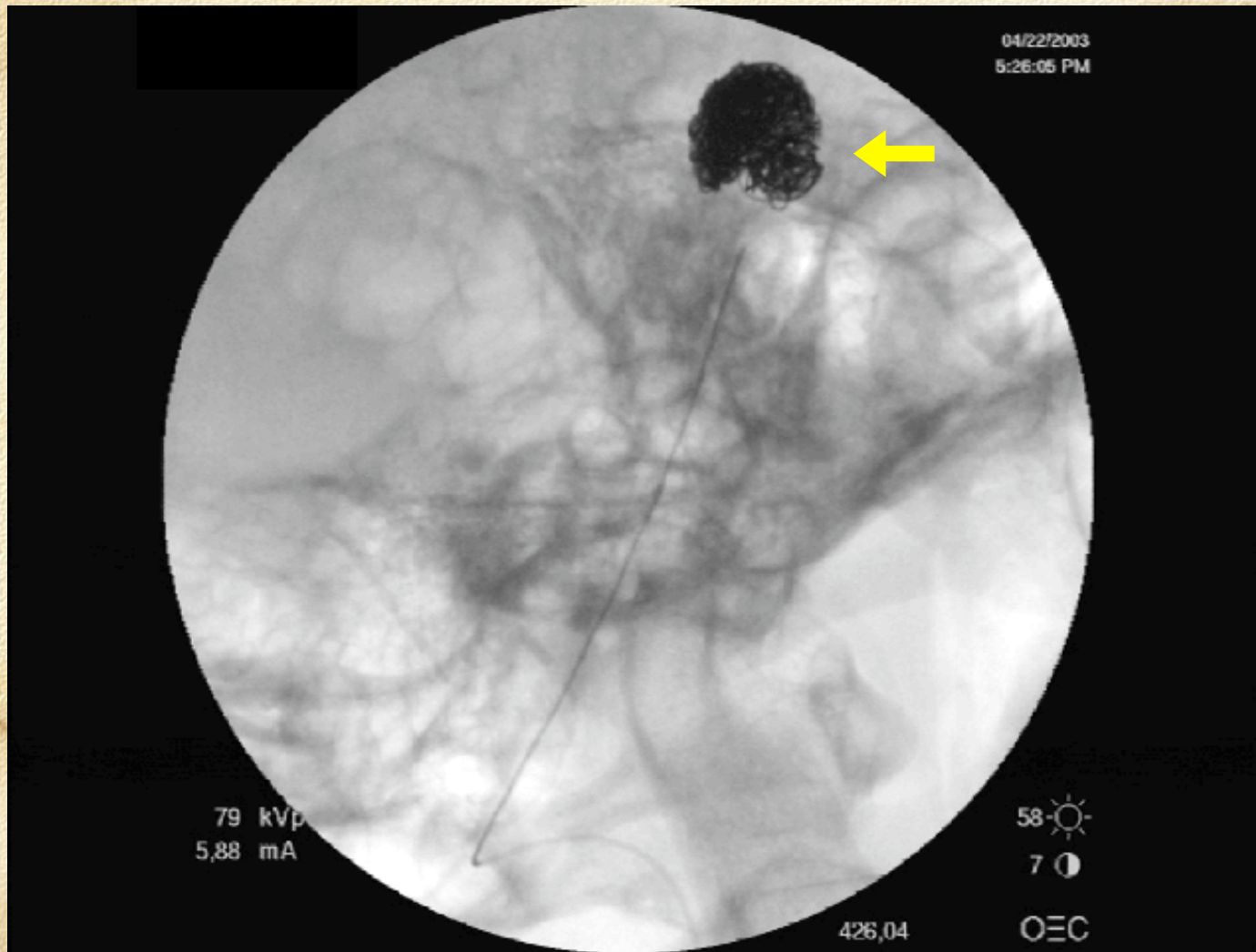
# Coil Embolization for Aneurysms

- Navigation of Microcatheter



# Coil Embolization for Aneurysms

- Deliver of Coil(s)





# Coil Embolization for Aneurysms

- Control DSA after Embolization



# Problems of Coil Embolisation

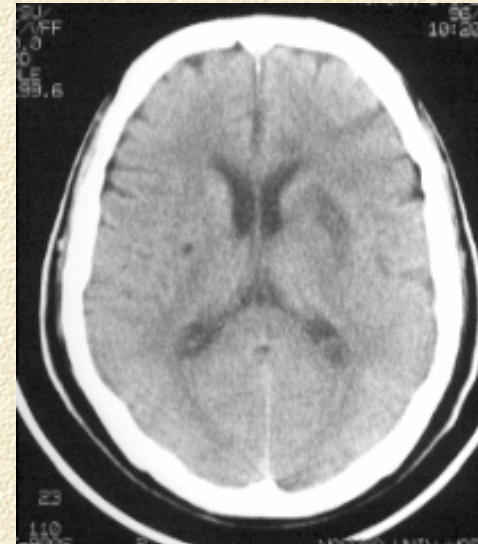
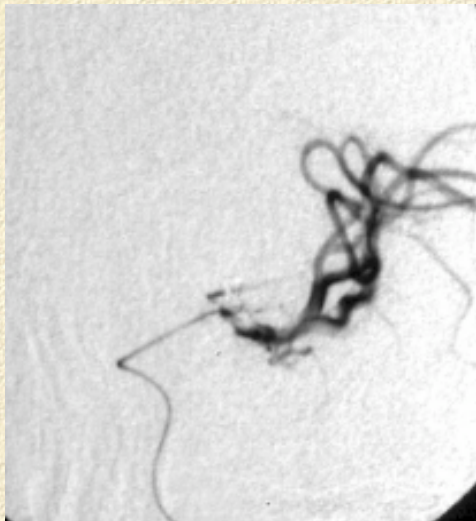
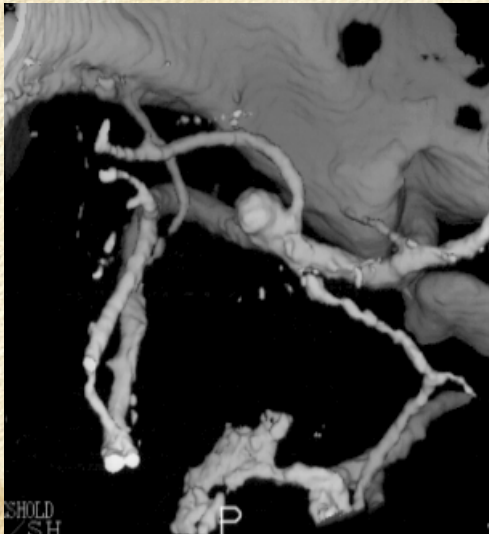
---

- Procedure Related
- Long Term Result

# Coil Embolization - Ischemia

---

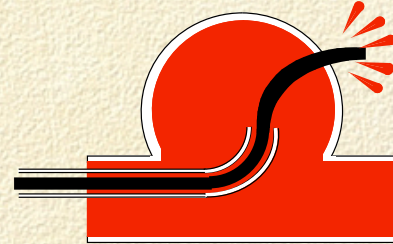
- Immediate Complication, Ischemia



# Problems of Coil Embolisation

---

- Procedure Related



- Rupture (Coil, Guide Wire, Microcath.)

- Ischemia

- Others

- Puncture site, Radiation

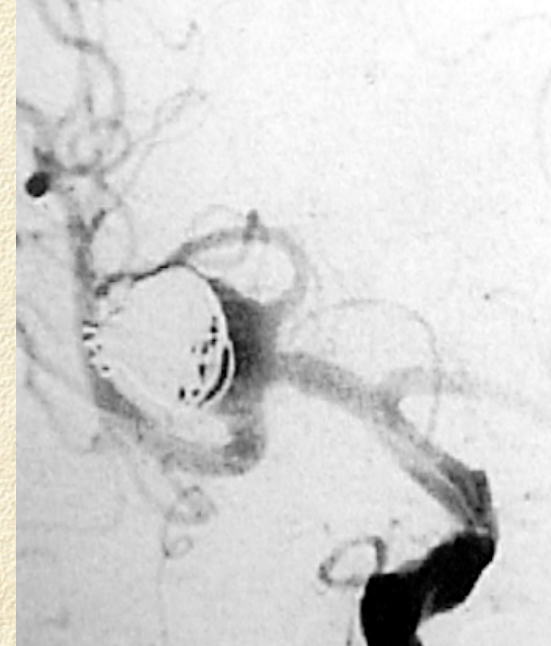
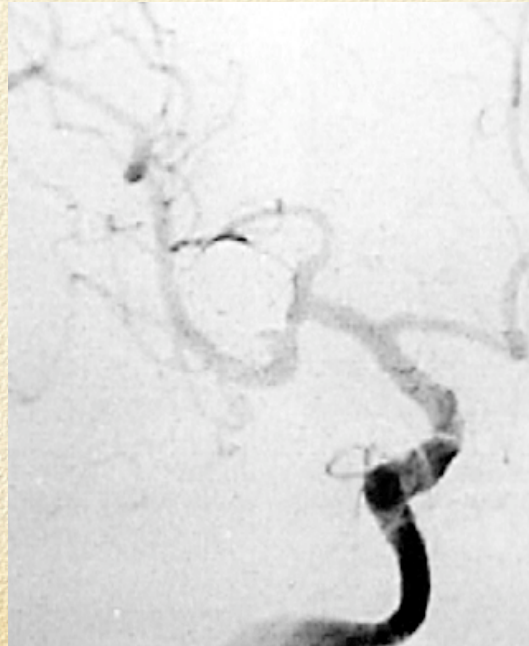
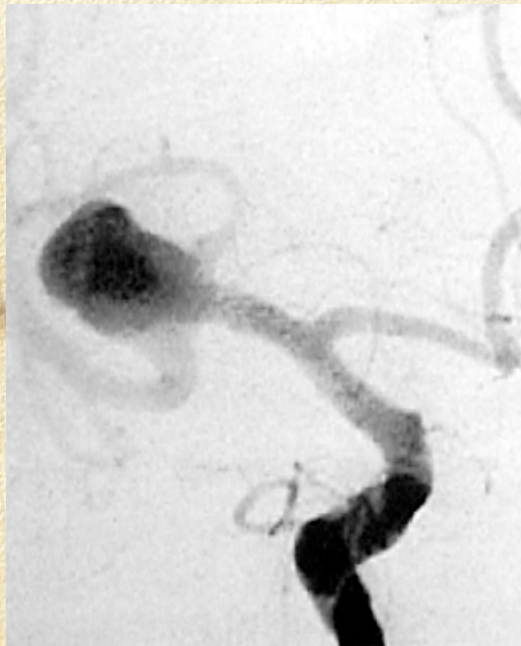
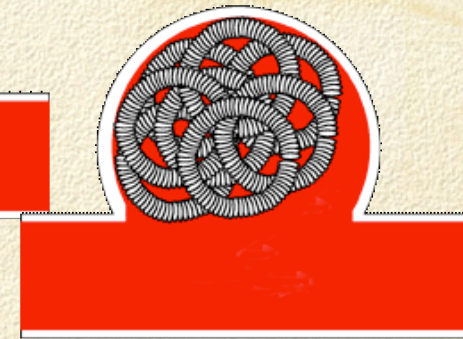
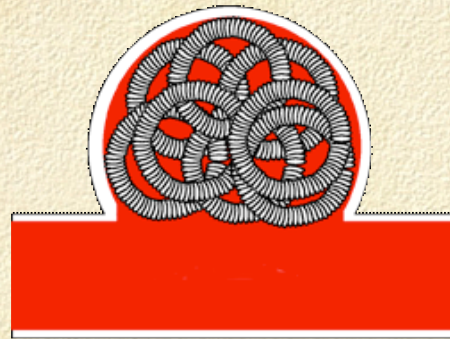
- Long Term Result

# Problems of Coil Embolisation

---

- Procedure Related
- Long Term Result
  - Compaction
  - Regrowth
  - Sink into Mural Thrombus
  - Others
    - Infection, Allergy for Metallic Materials, Exposure to X Ray

# Coil Embolization for Aneurysms



# Coil Variation

GDC® UltraSoft



GDC® Soft 2D SR



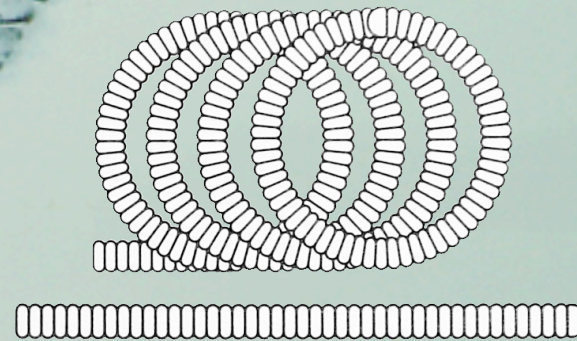
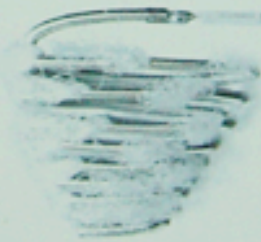
GDC® Soft



GDC® 3D Shape



GDC® Fibered VortX® Shape



# Coil Variation & Rigidity

- Rigidity

- GDC 18; Large, 3D(6 x 15), 3D (8 x 25), Standard & 3D (Others), Soft

- GDC 10; Standard & 3D, Soft, Ultra Soft

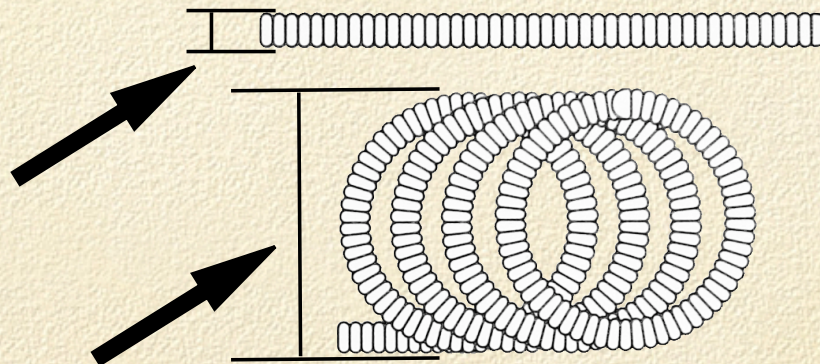
- Diameter

- 10 or 18

- Size

- 2 mm to 20 mm in diameter

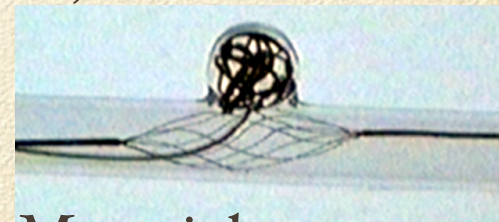
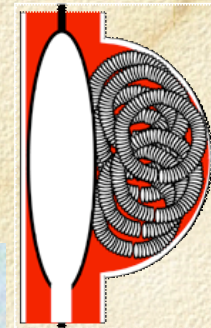
- **Proper Rigidity for Each Size**





# Prevention for Compaction

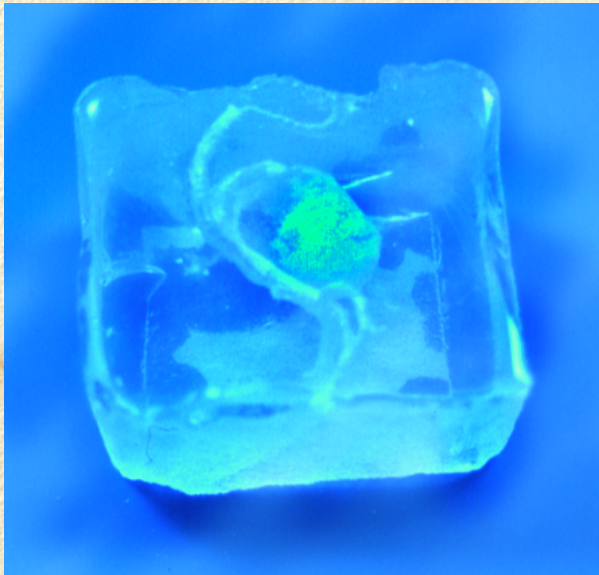
- Using Coil
  - Increase VER (Volume Embolization Ratio)
    - Hydrogel Coil
    - “Ultra Soft” Coil
    - Variable Detachable System
    - Neck Remodeling
      - Non Detachable Balloon, MicroBasket
  - Bioactive Coil
    - Surface Coating
    - Core Rod with Bioactive Material
- Liquid Material
- Stent/Covered Stent



# Prevention for Compaction

---

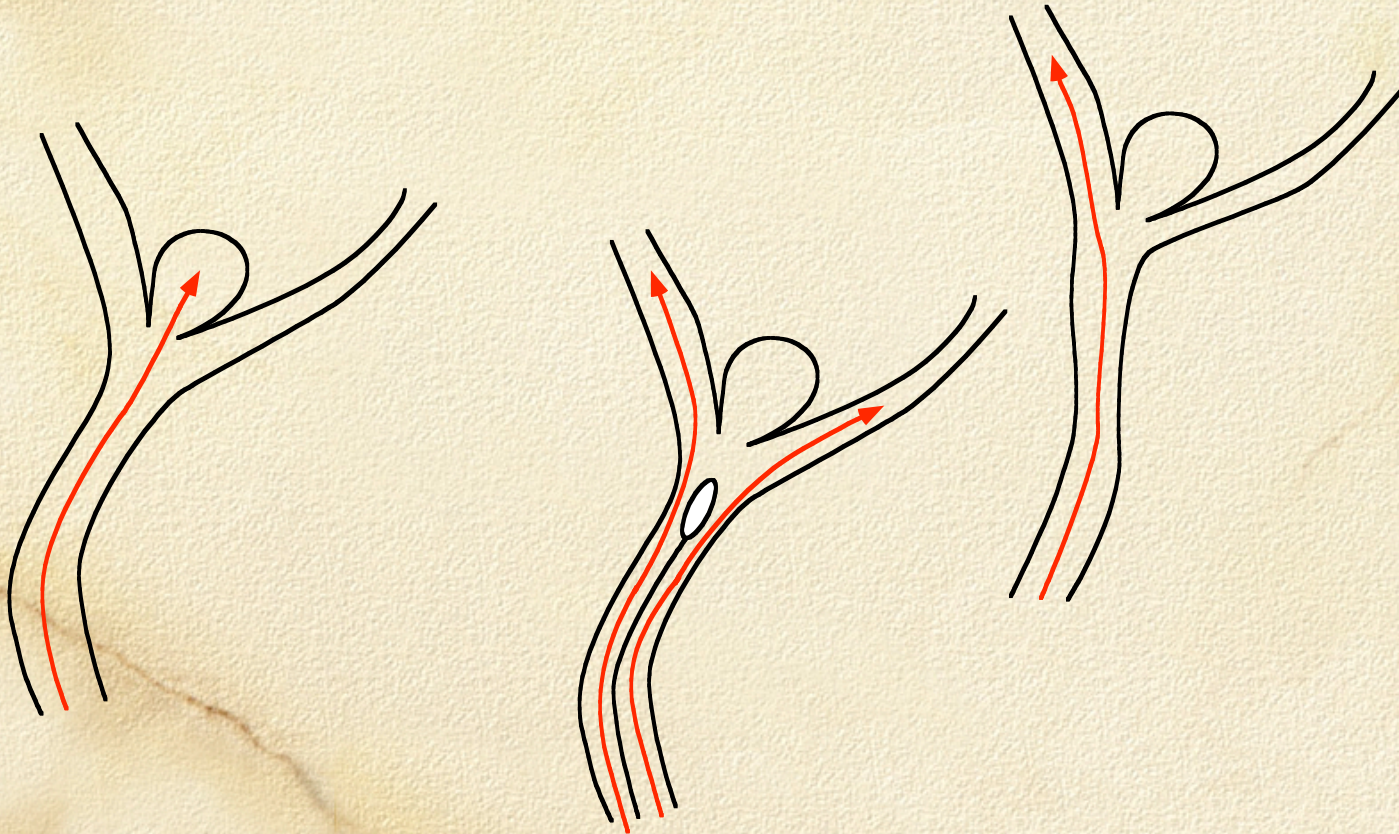
- Tailor Made Coil for Each Patient's Each Aneurysm Using Shape Memory Alloy?



# Flow Pattern Modification?

---

- Modification of Proximal Artery
  - “Spontaneous” Thrombosis?



# Catheter Manipulation

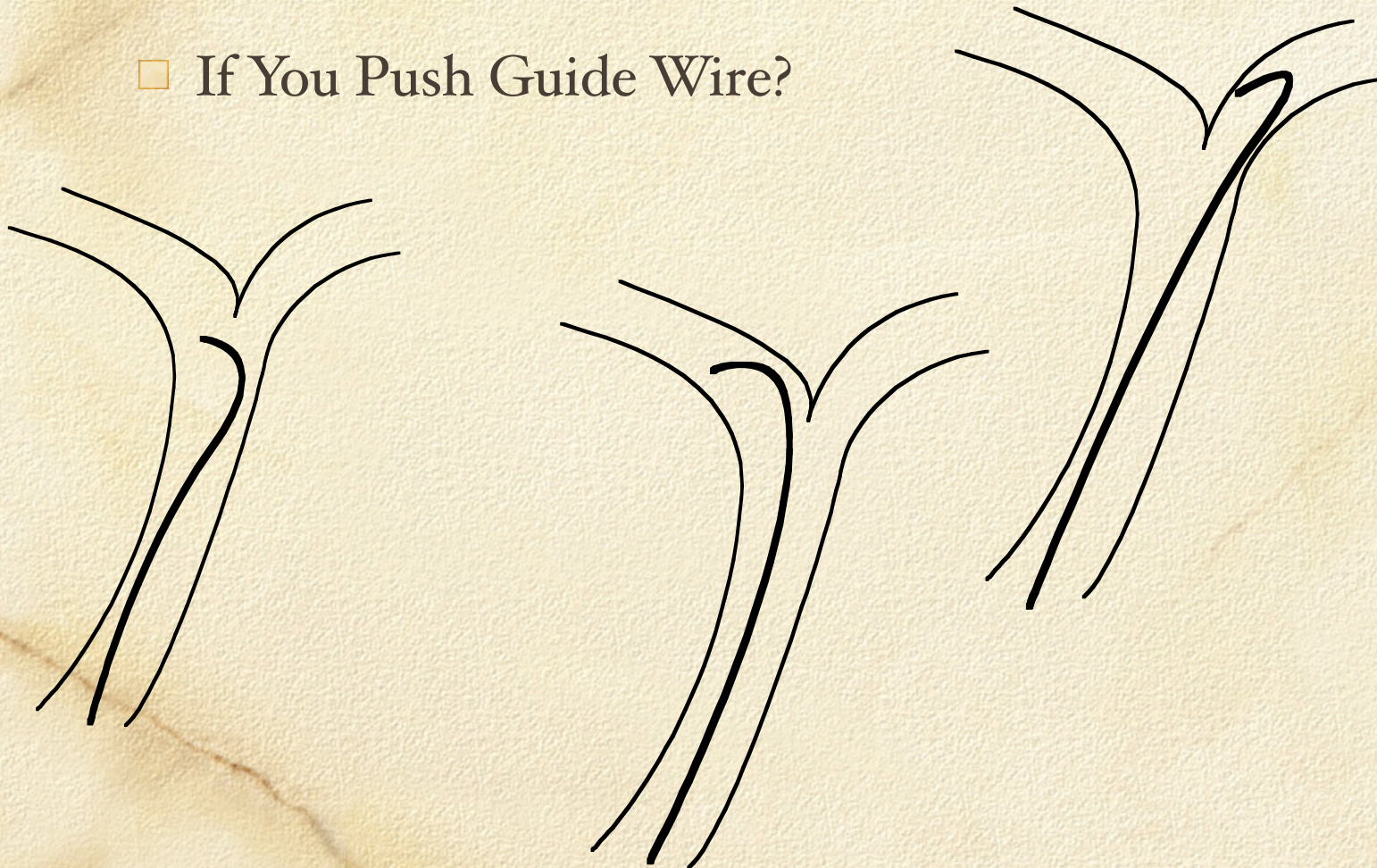
---

- Movement of Catheter and Guide Wire
  - Manipulation by the Operator
  - Rigidity of the Materials
  - Blood Flow
  - Friction between Vessel Wall
  - Shape of the Tip (Especially Gap Cath/Wire)
  - Shortening/Compression of Catheter
  - Shape of Vessels

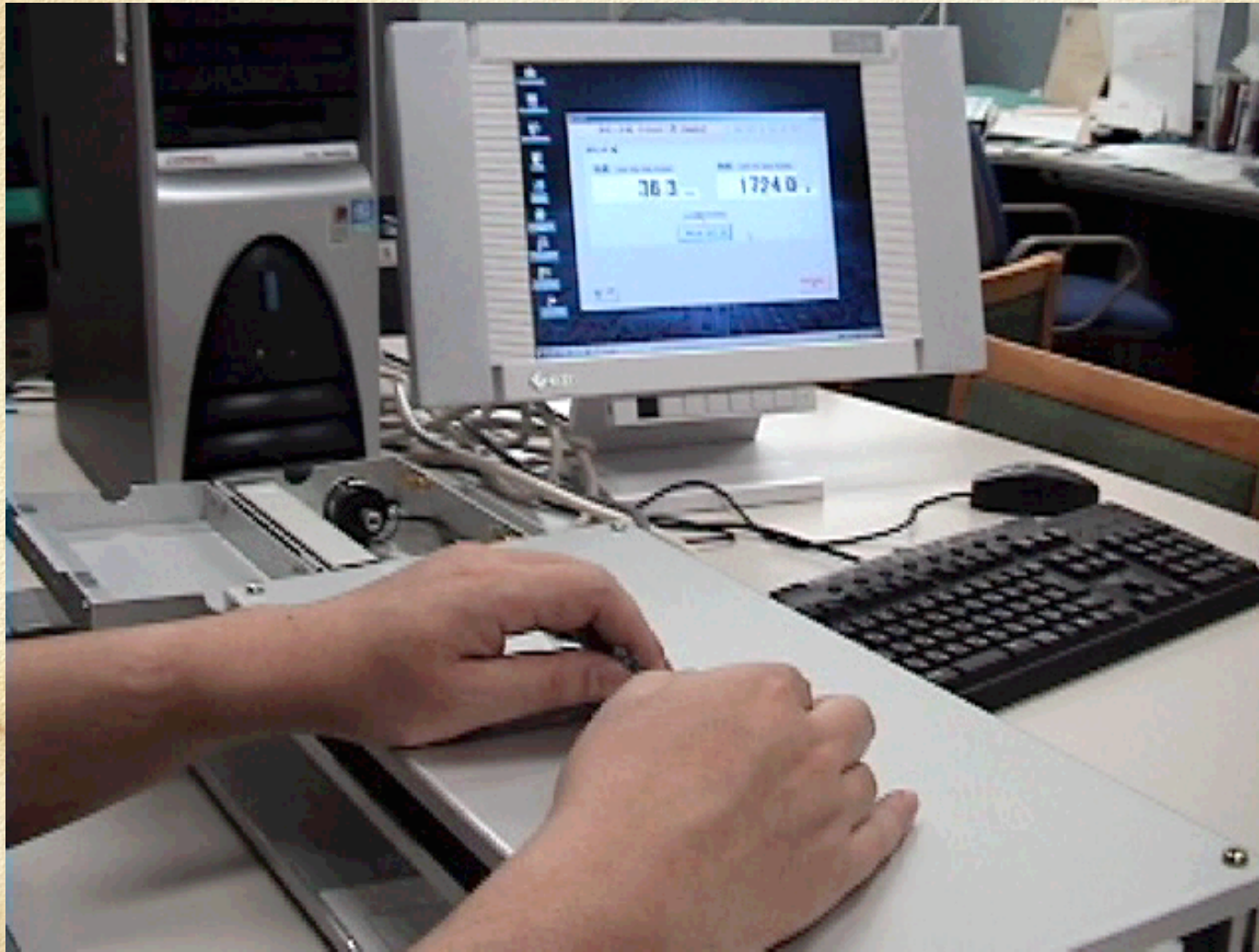
# Catheter Manipulation

---

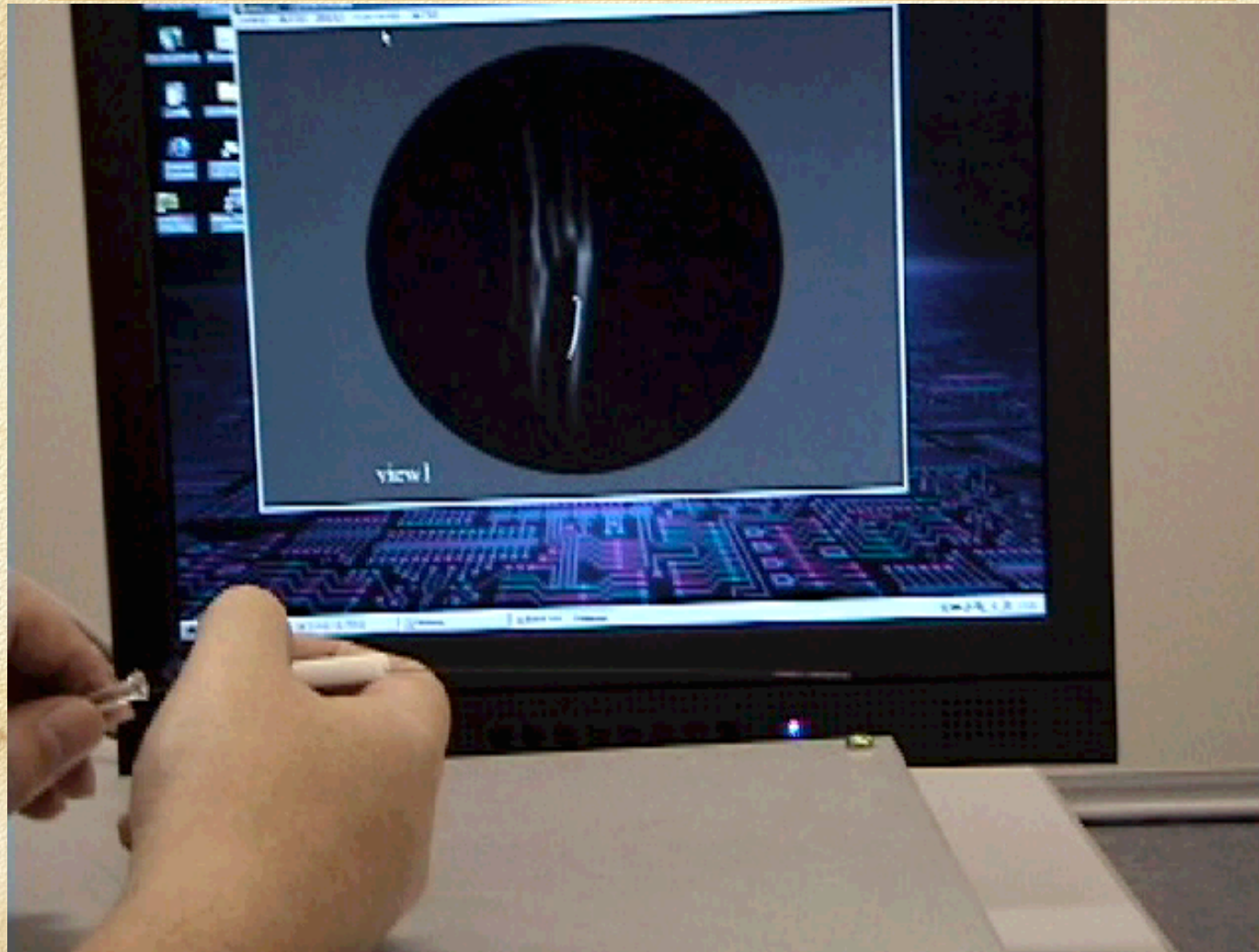
- If You Push Guide Wire?



# Catheter Manipulation



# Catheter Manipulation



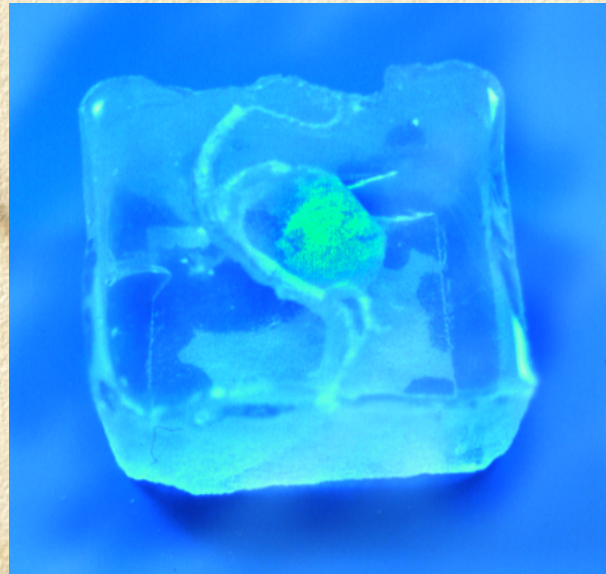
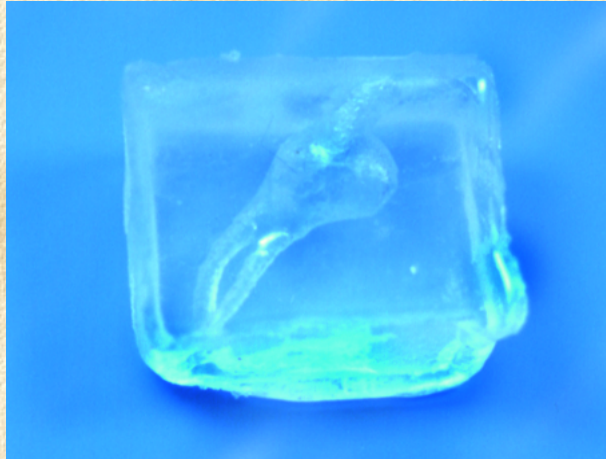
# Manipulator & Actuator





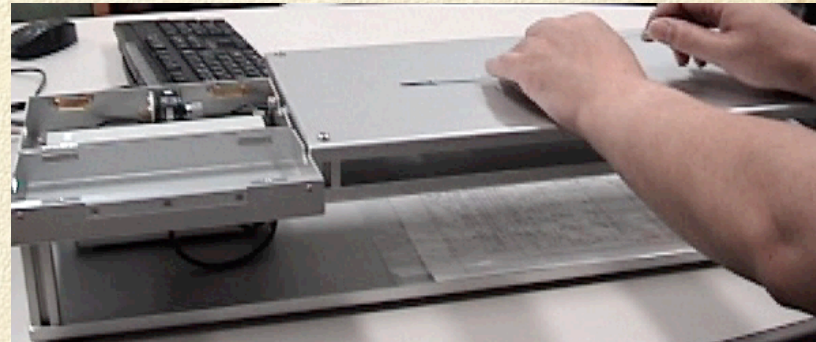
# Catheter Manipulator/ Tubular Model of Vessels

---



# Catheter Manipulation

- Simulator for Air Pilot, Why NOT for Surgeons?



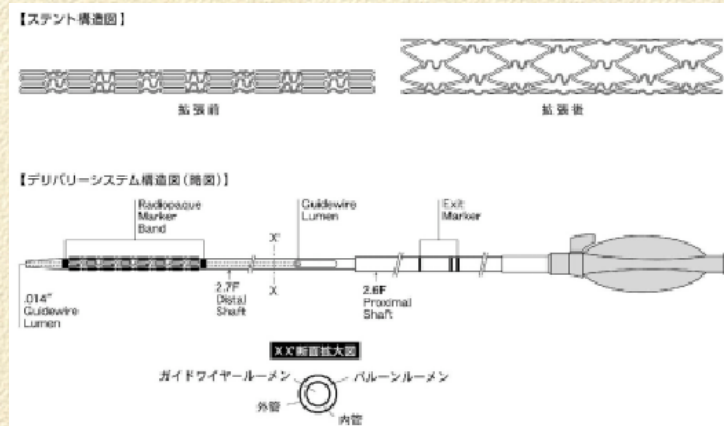
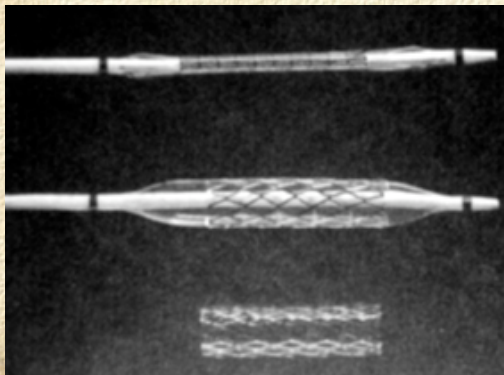
# Ischemia

---

- Cause of Ischemia
  - Thrombotic
  - Embolic
    - Cardiogenic
    - Artery to Artery
- Cardiogenic
- Embolic occlusion
- Hemodynamic

# Stenting

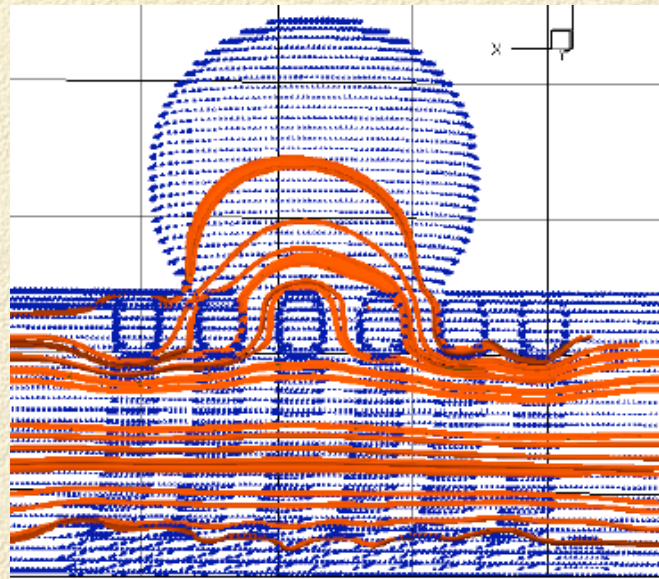
## □ Coil Stent and Tubular Stent



## □ Prevention of In-Stent Thrombosis

# Stenting

## □ Flow Pattern Around Stent?



Coil Stent

In Stent Thrombosis

Same Anti-Plt

Tube Stent

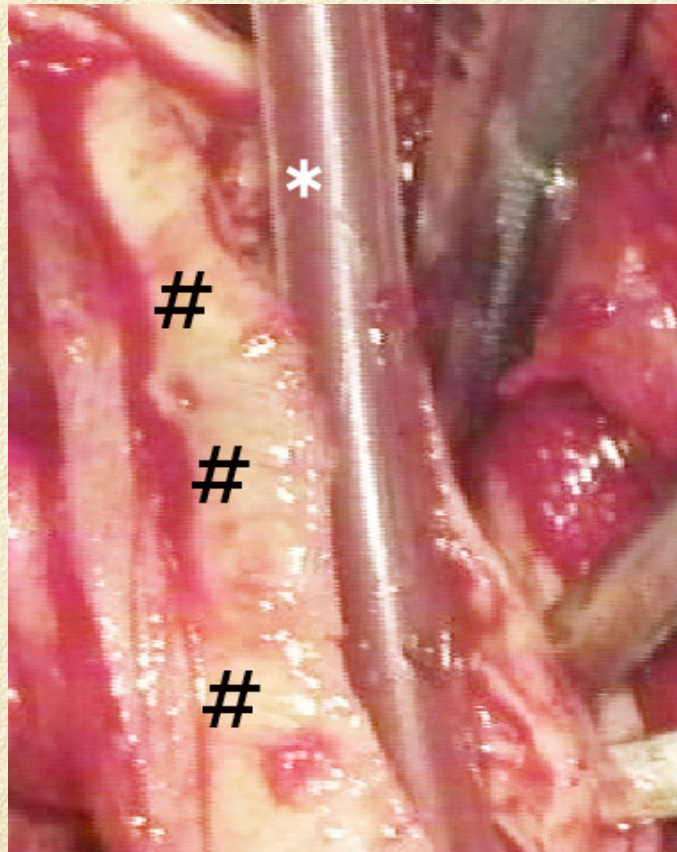
No Thrombosis

# Carotid Endarterectomy

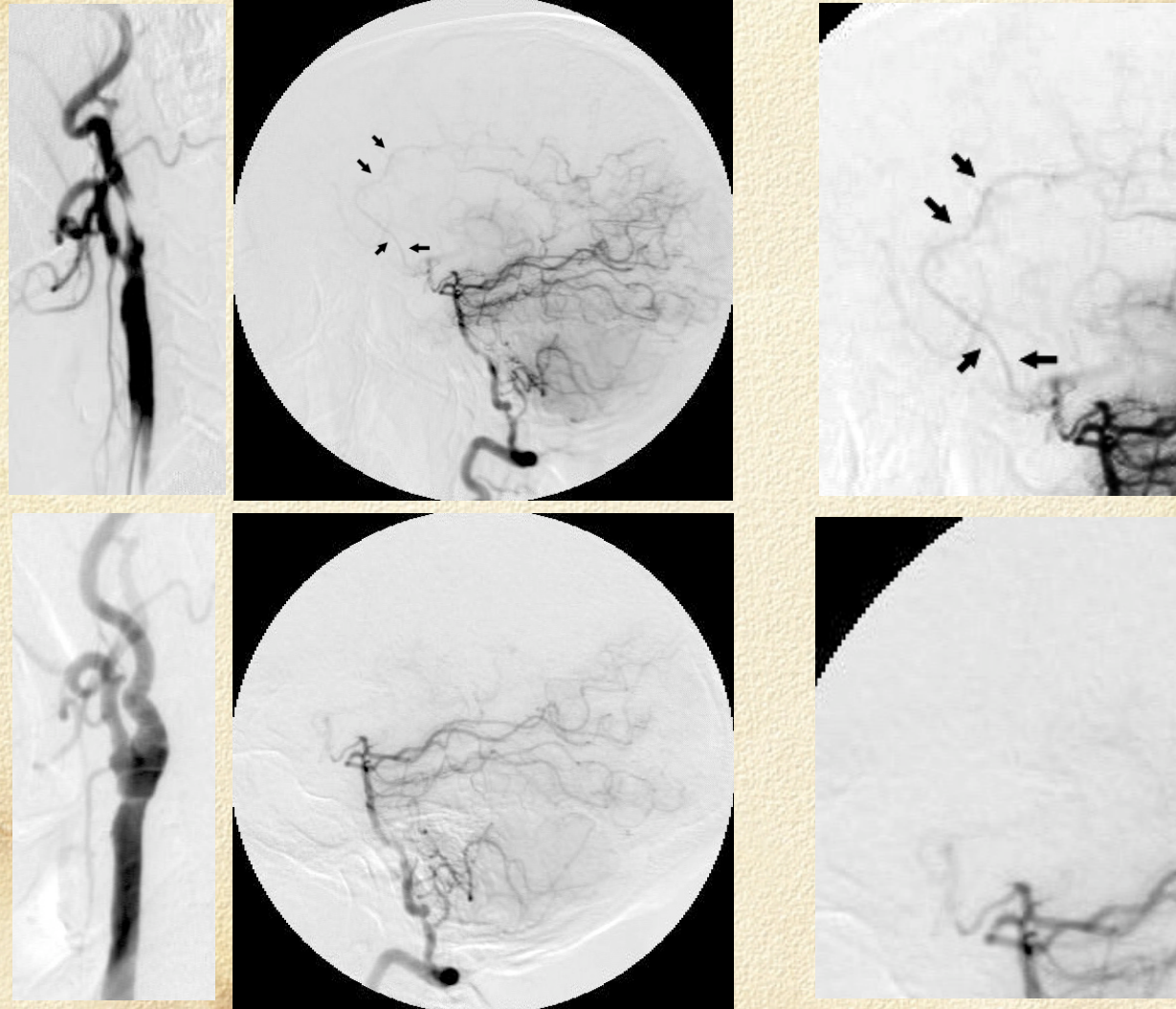
---

- ❑ Surgery for Carotid Stenosis, Brain Ischemia
- ❑ Removing Atheromatous Plaque Surgically
- ❑ Indication
  - ❑ Hemodynamic Compromise
  - ❑ Embolic Source

# Carotid Endoarterectomy



# Carotid Endoarterectomy





# Carotid Endoarterectomy

---

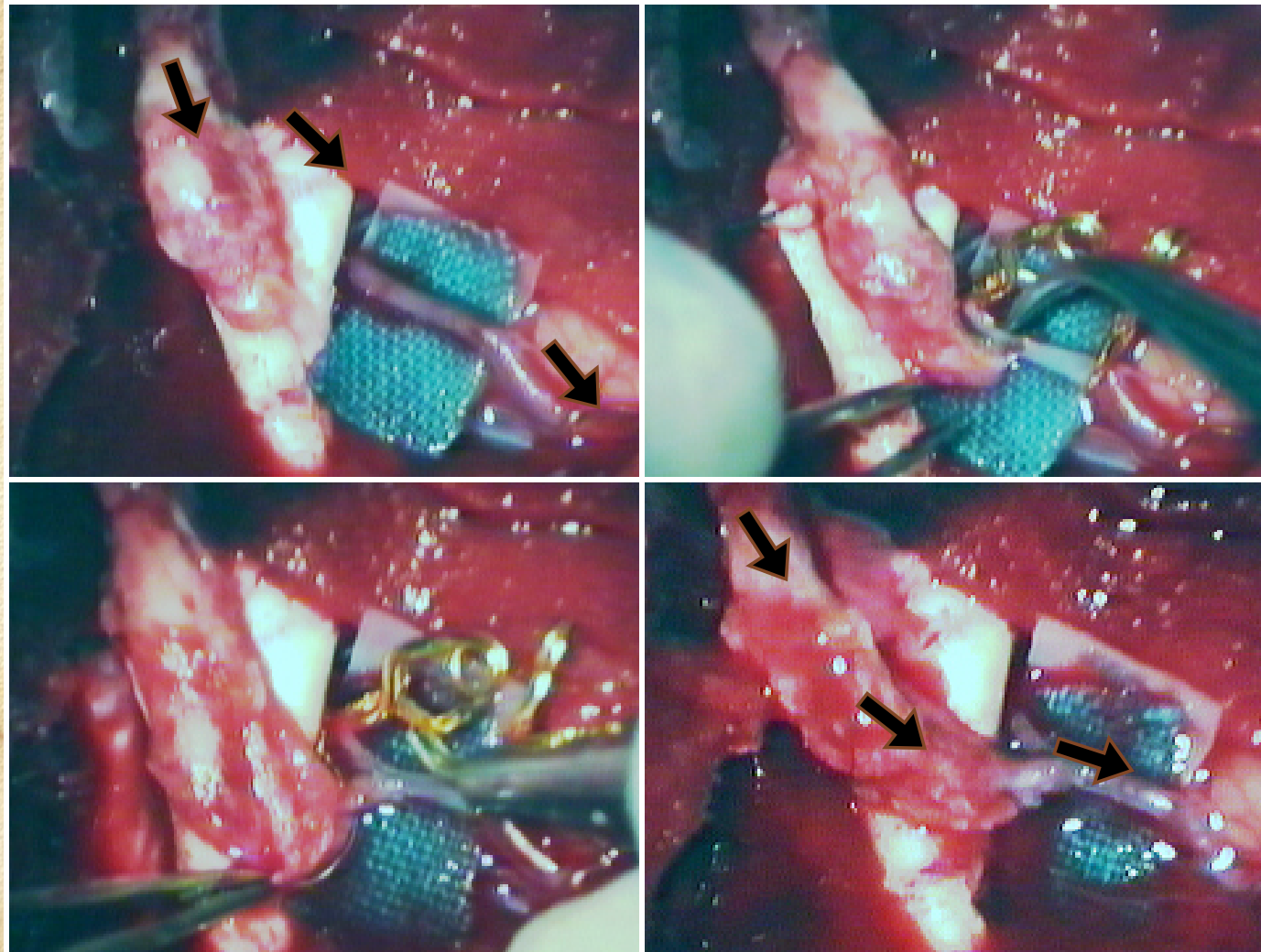
- Indication
  - Hemodynamic Compromise
  - Source of (Micro?) Emboli
    - At Ulcer? At Severe Turbulance?
- Hyperperfusion after Surgery?
- Stent or CEA

# STA MCA Anastomosis

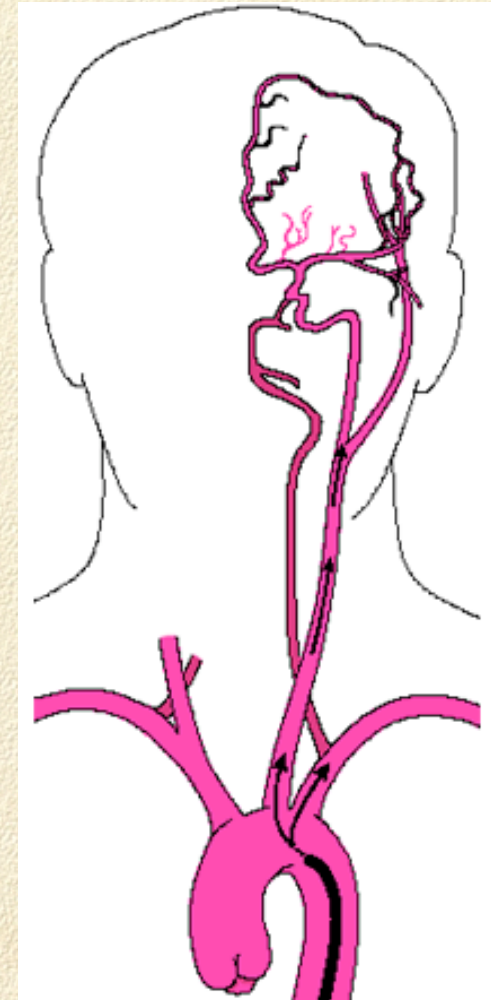
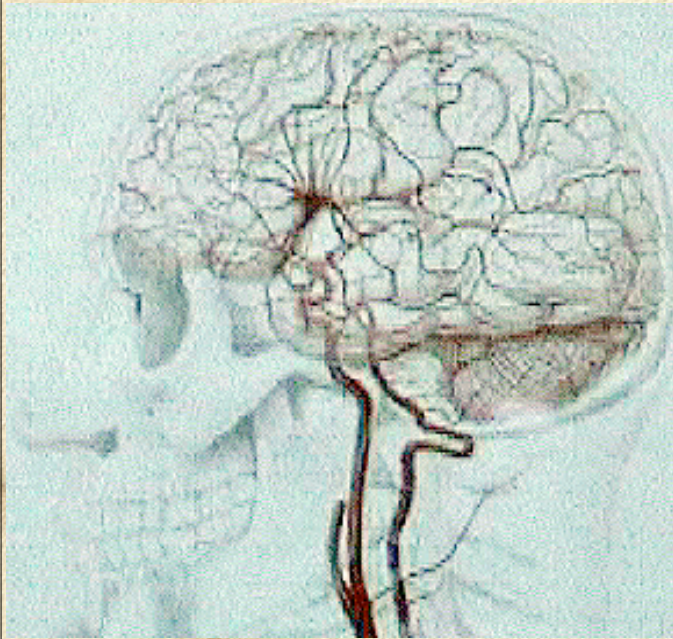
---

- Bypass Surgery for Brain Ischemia
- Connect Scalp (Extracranial) Artery to INTRACranial Artery
  
- Mass Clinical Study.....
  - Biased Data? (Maybe)

# STA MCA Anastomosis



# STA MCA Anastomosis



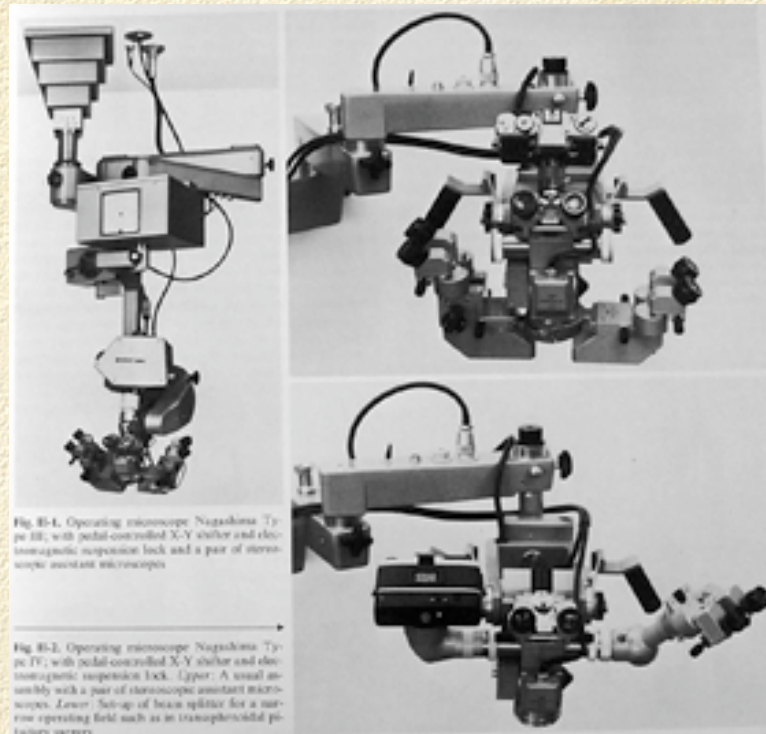
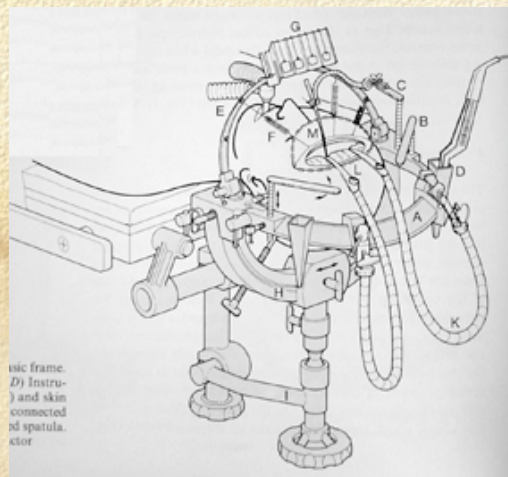
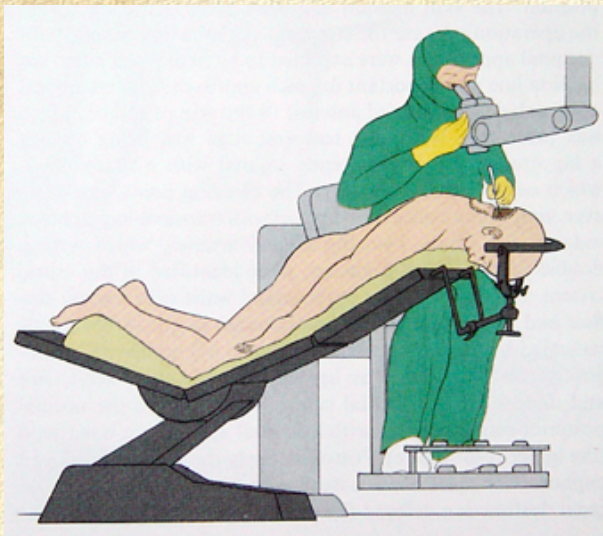
# STA MCA Anastomosis

---

- ❑ Really Effective?
  - ❑ Mass Clinical Trial?
- ❑ Stenotic Lesion??



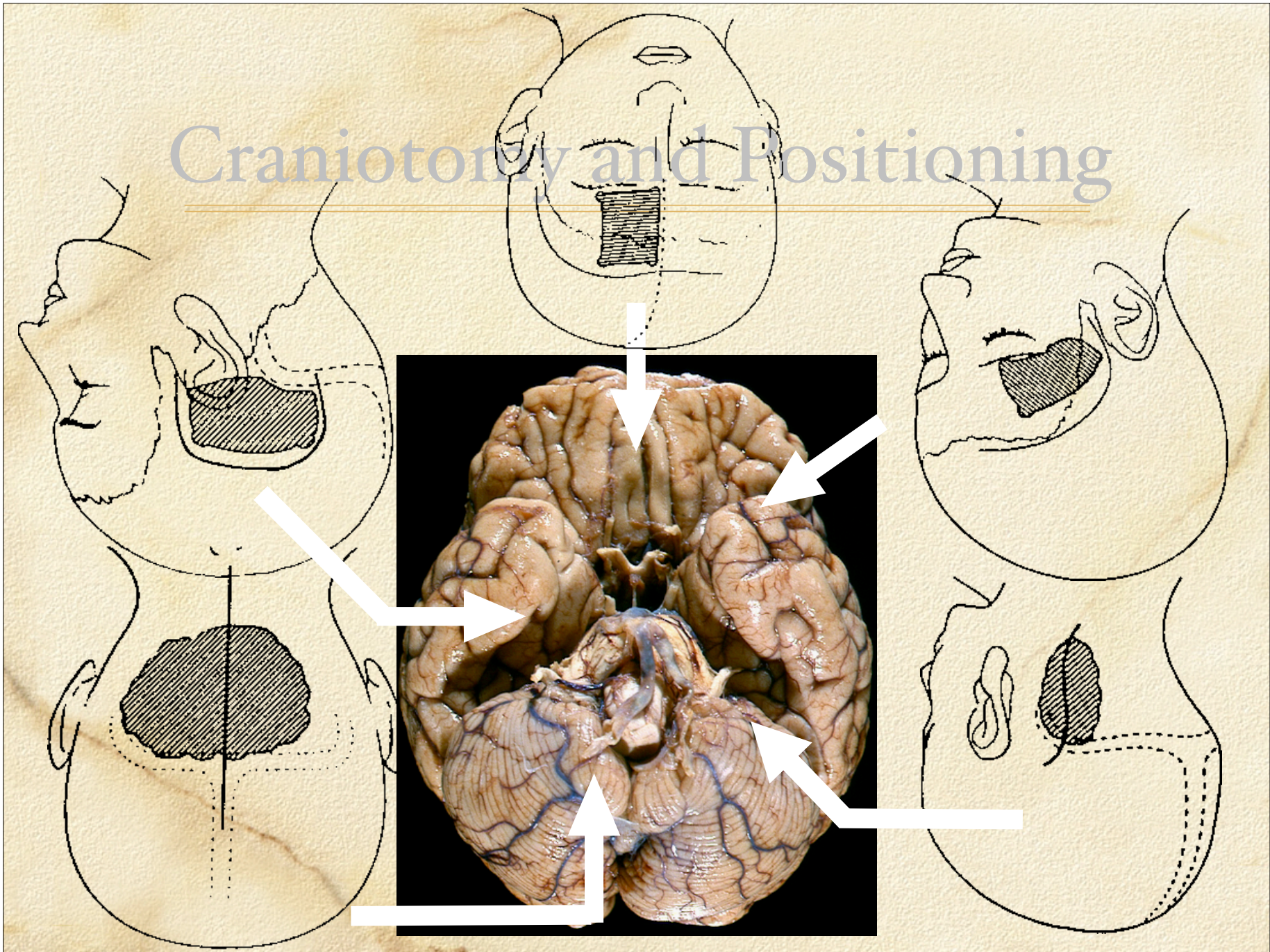
# Craniotomy and Positioning



# Craniotomy and Positioning

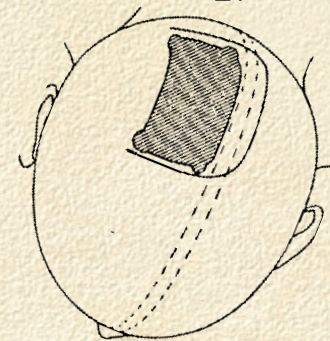
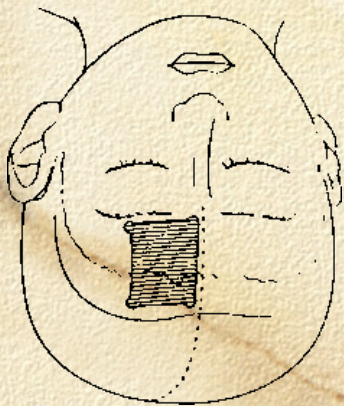
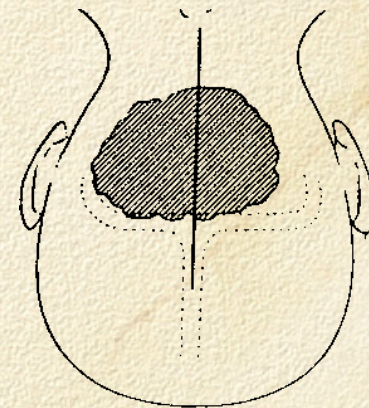
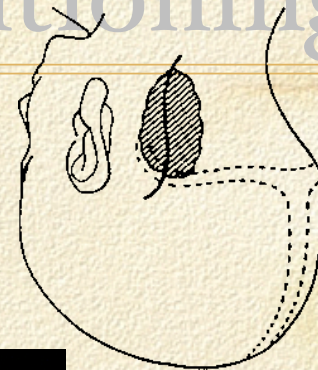
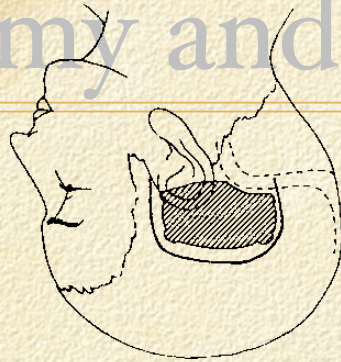
- Craniotomy
  - Minimal Brain Retraction
    - “Skull Base Technique”
    - Gravity and Retraction
- Positioning
  - Limitation for Approach
  - Bed Sore
  - Nerve Root Injury

# Craniotomy and Positioning

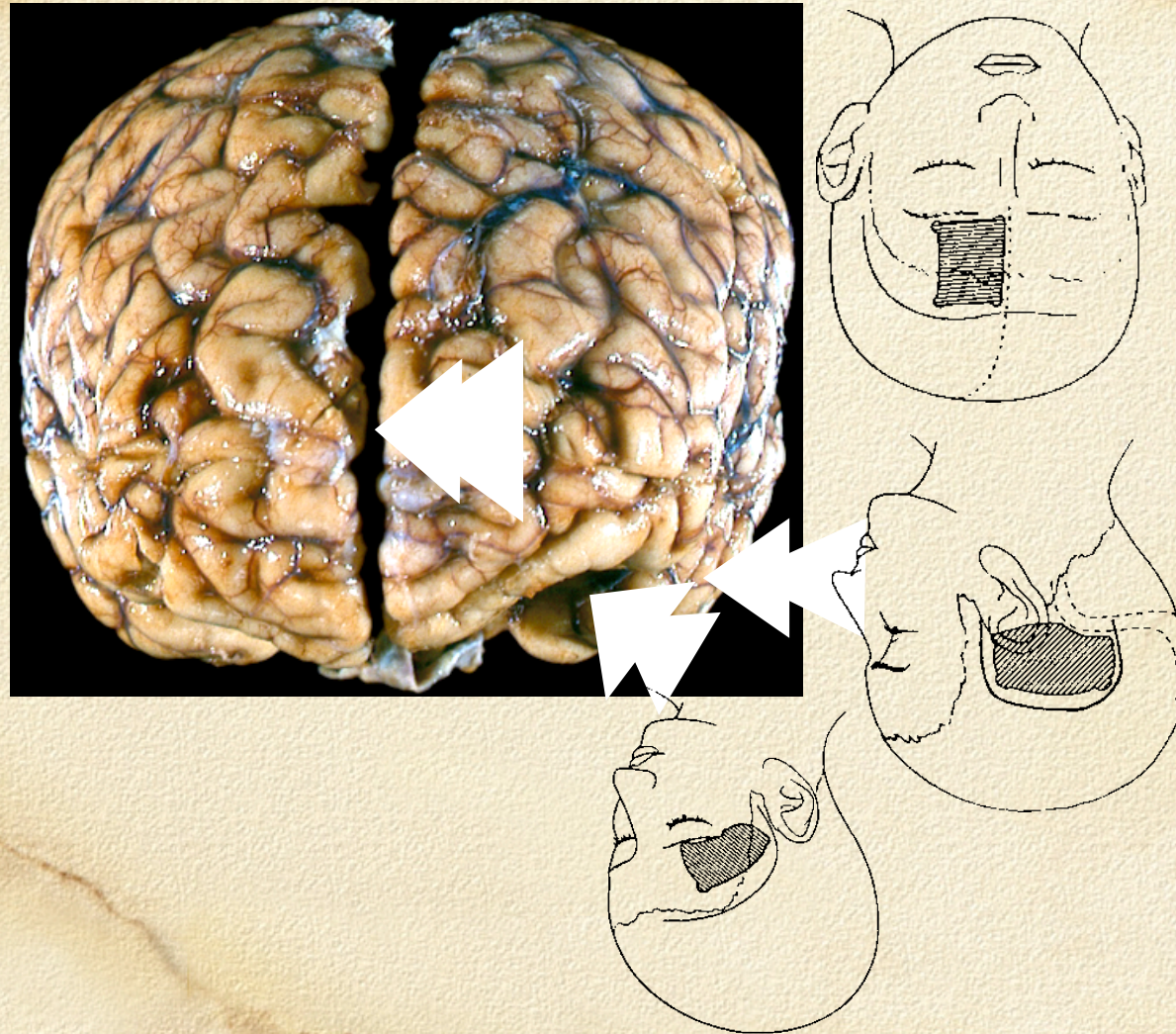




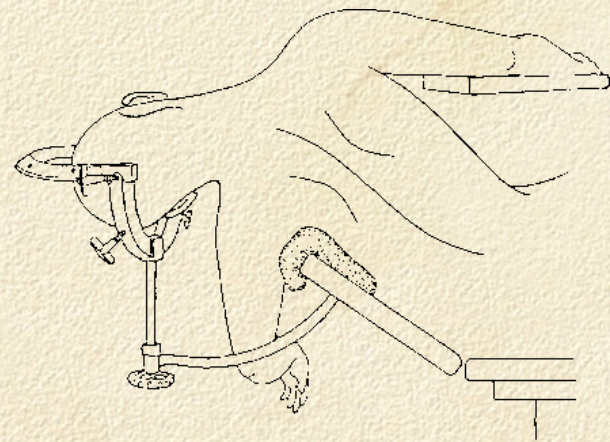
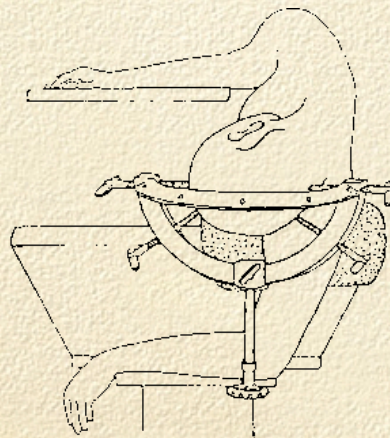
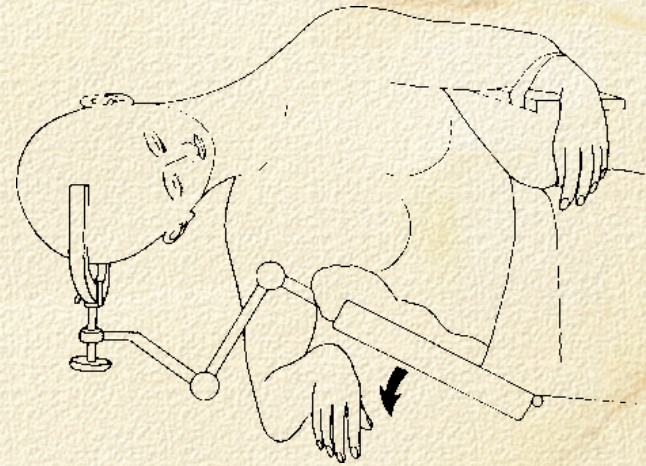
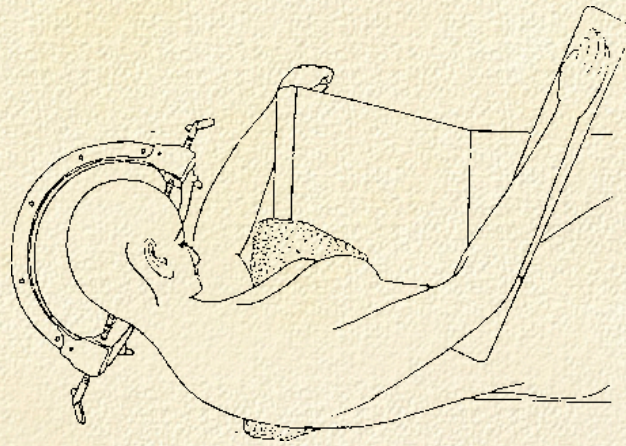
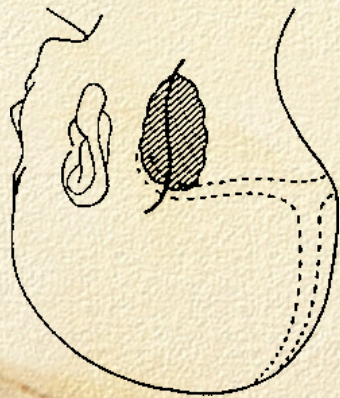
# Craniotomy and Positioning



# Craniotomy and Positioning

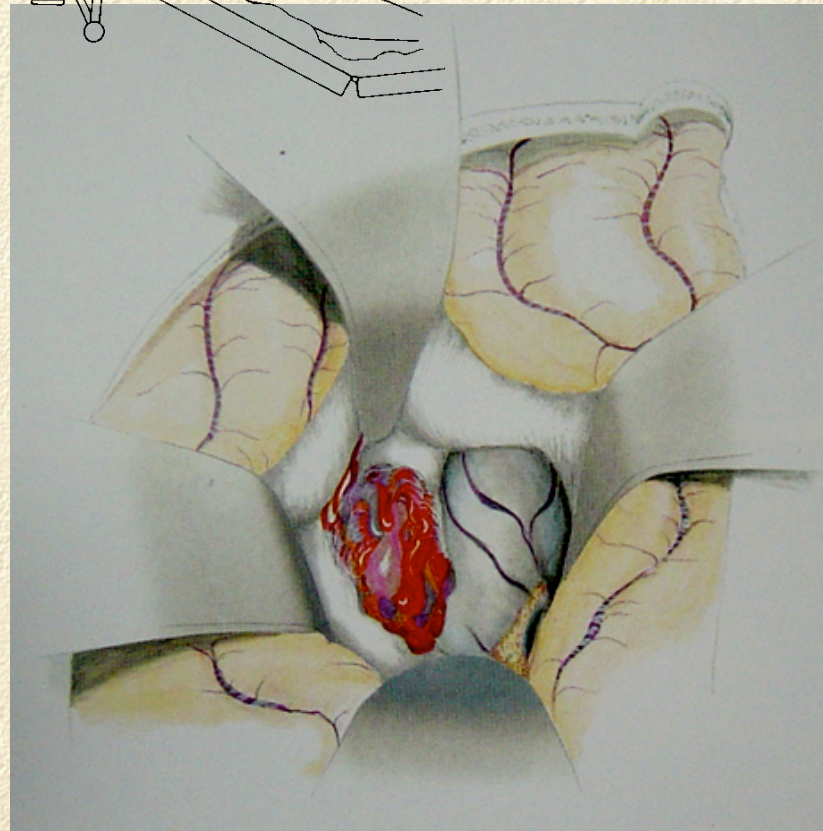
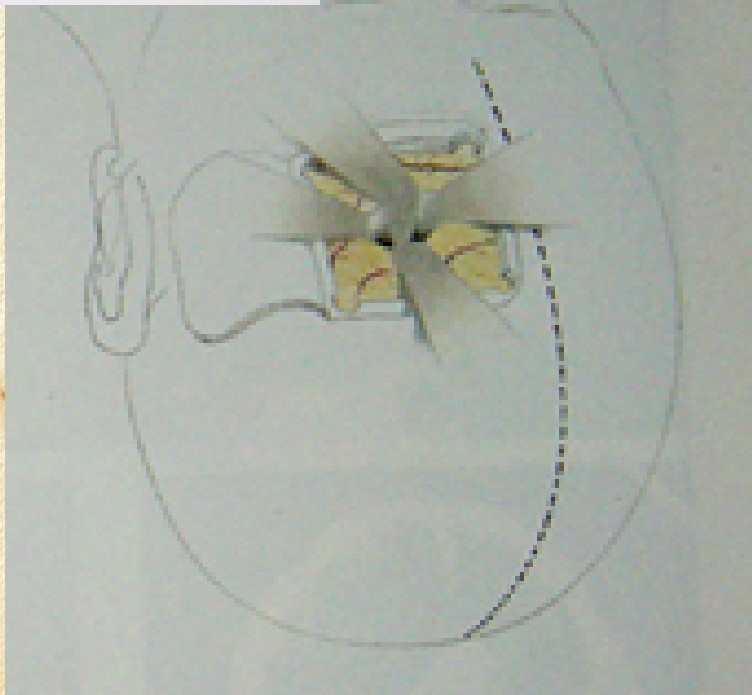
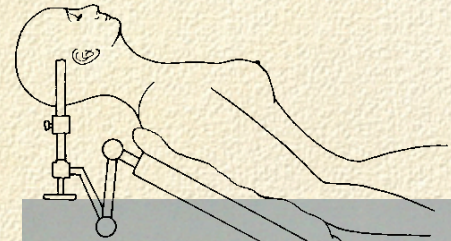
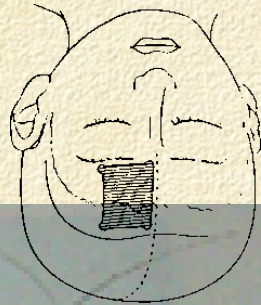
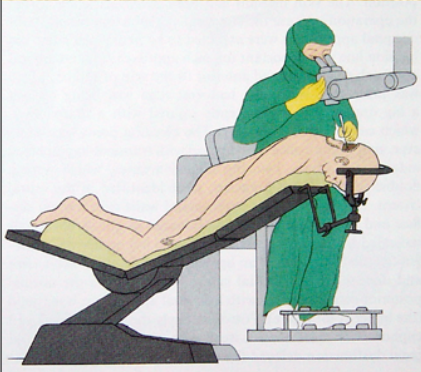


# Craniotomy and Positioning



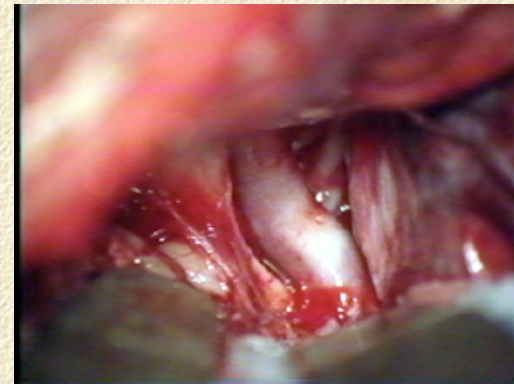
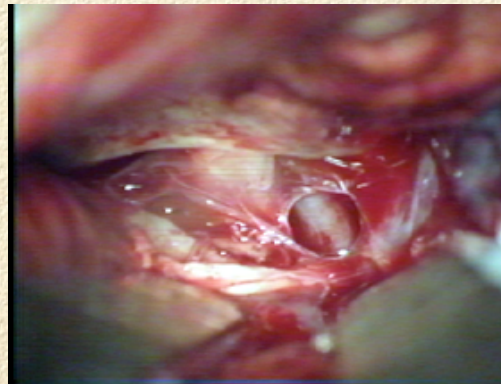
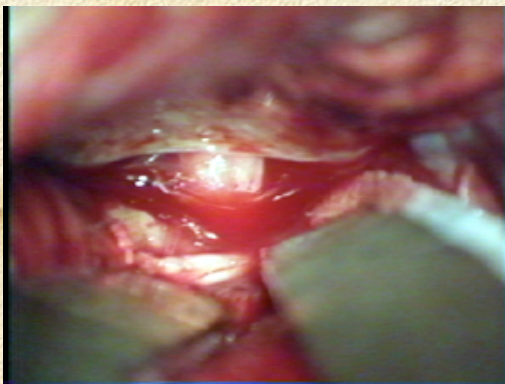
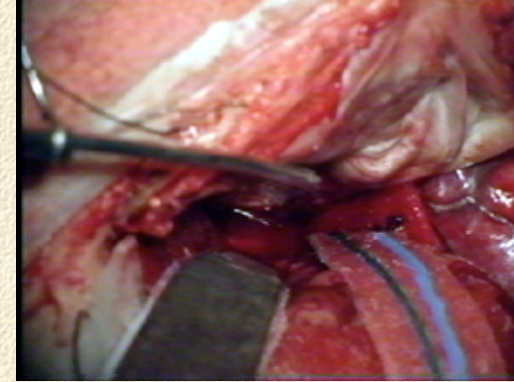
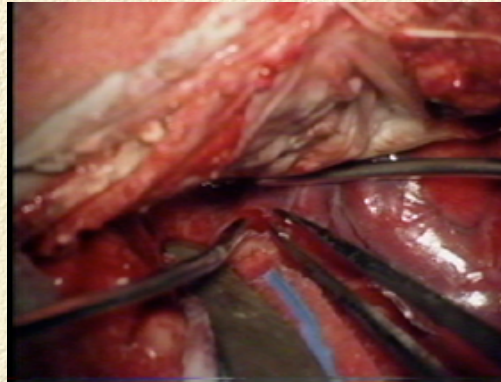
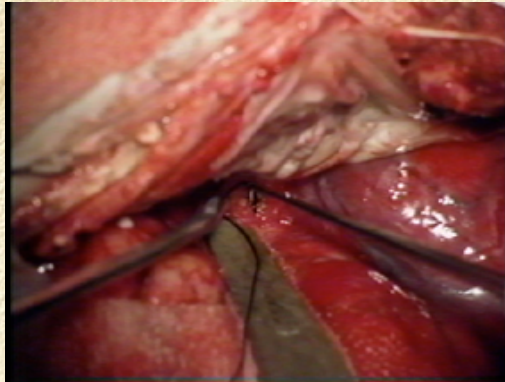
possible nerve root injury

# Craniotomy and Positioning



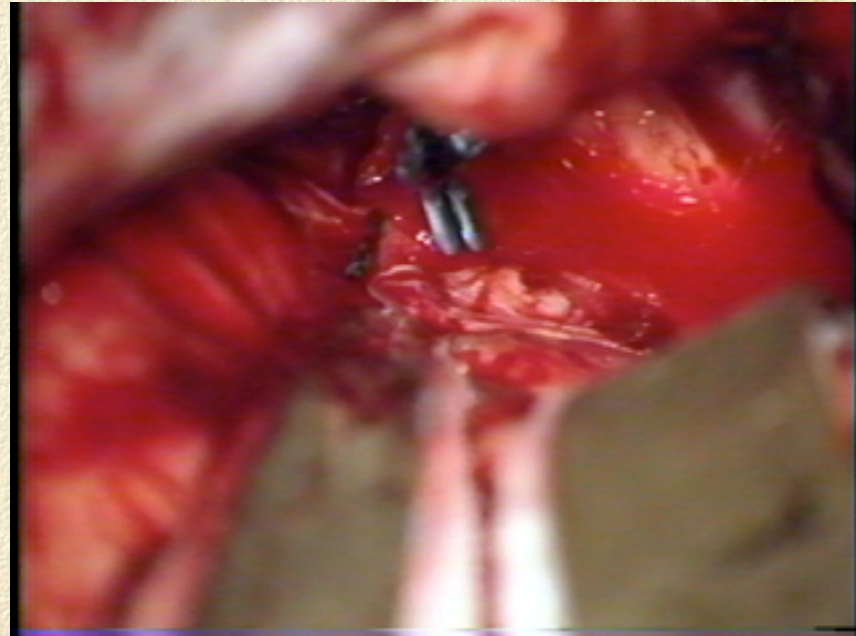
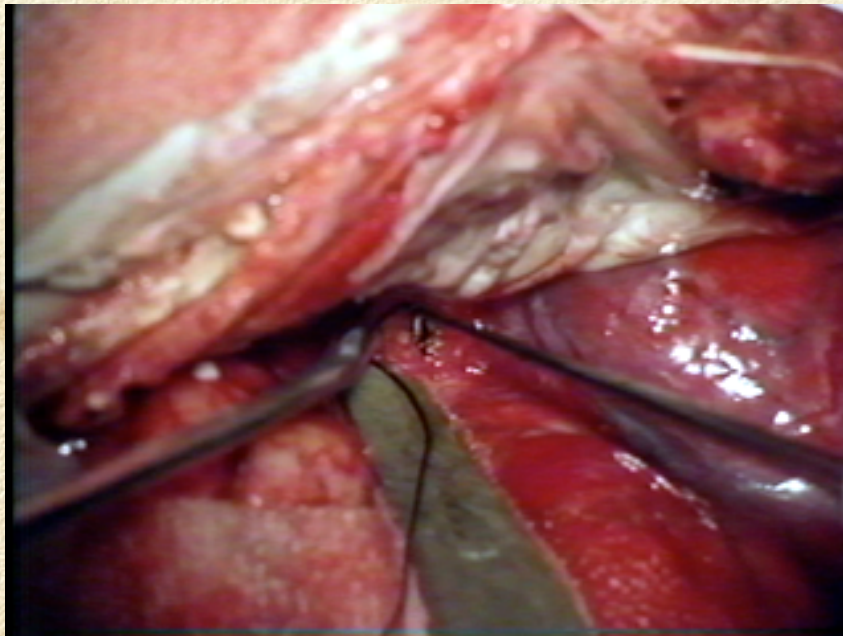
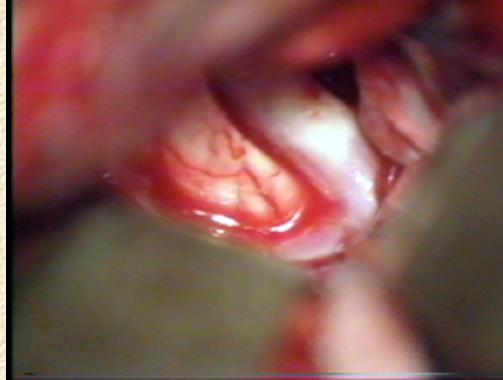
# Brain Retraction

---



# Brain Retraction

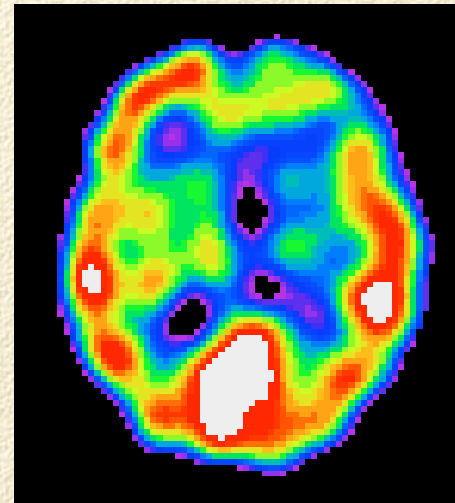
---



# Brain Retraction

---

- ❑ Possible Damage to the Brain
- ❑ Decreased Cerebral Blood Flow after Surgery
- ❑ Minimal Brain Retraction?
  - ❑ Approach
  - ❑ Maximam Safe Retraction?



# Conclusion

---

- BioMechanics/Human Simulator
- **Tailor Made Medicine**
  - Not Only Medicine Based on Mass Study
    - Operate or Not for Incidental Lesions
  - Indication
  - Tailor Made Materials, Approach
    - Increase Safety of Craniotomy
    - Make Safer Embolization
    - Design of Materials
- Robotic Surgery





*Thank You for Your Attention*

# Hemiparesis

