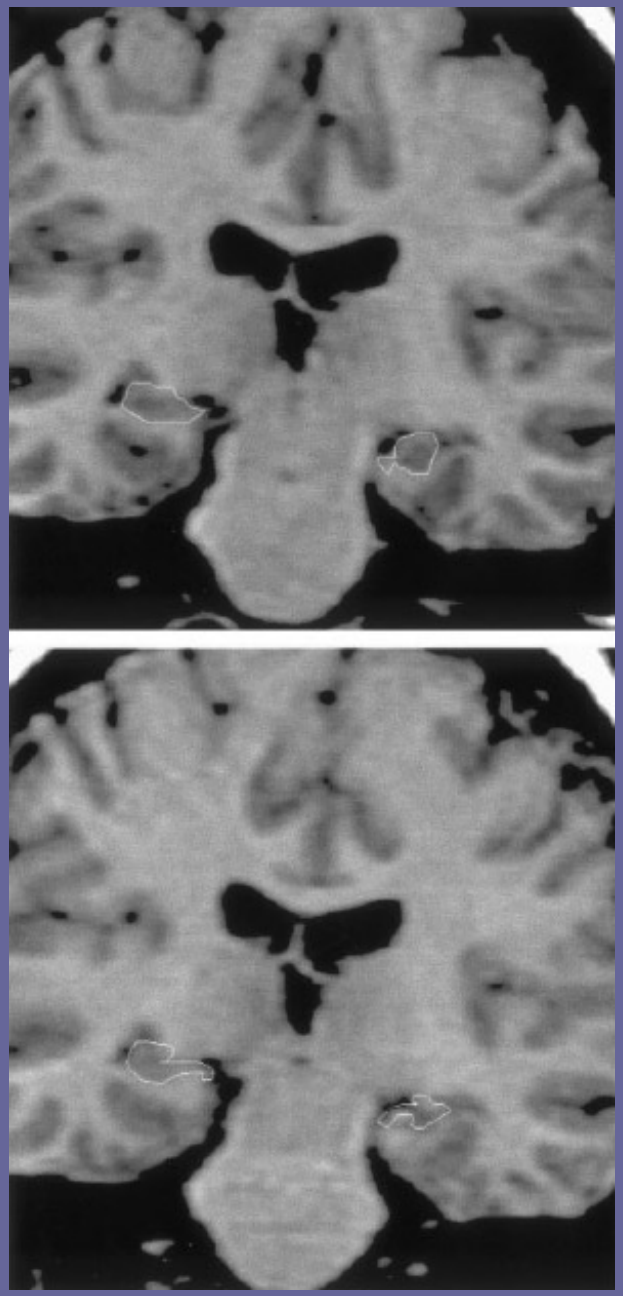
Volumetric and morphometric imaging

Quantitative and Functional Imaging

BME 4420/7450

Fall 2022

These images were acquired 3 years apart. What changed?



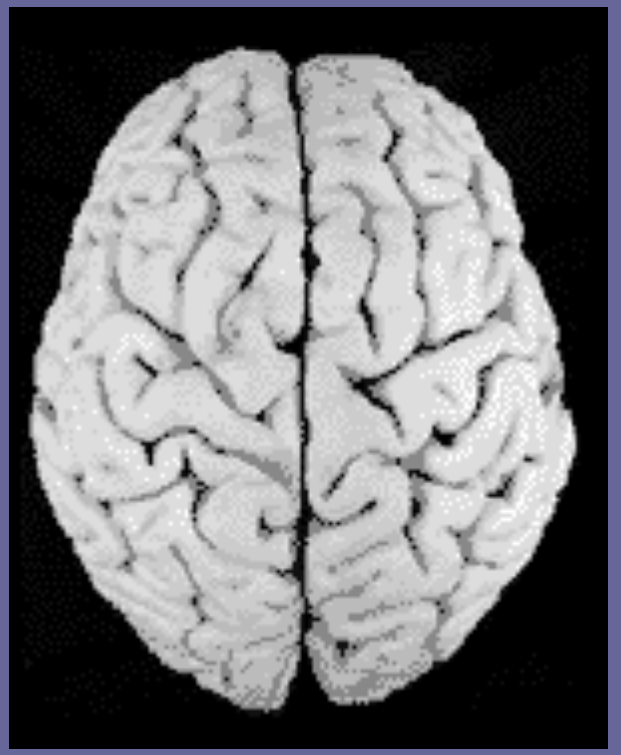
Fuerst, Ann. Neurol (2003)

Outline

- Overview of brain anatomy
- Why measure tissue volume?
- Methods of measuring volume from images
- Why measure structure shape?
- Methods of characterizing shape
- Examples

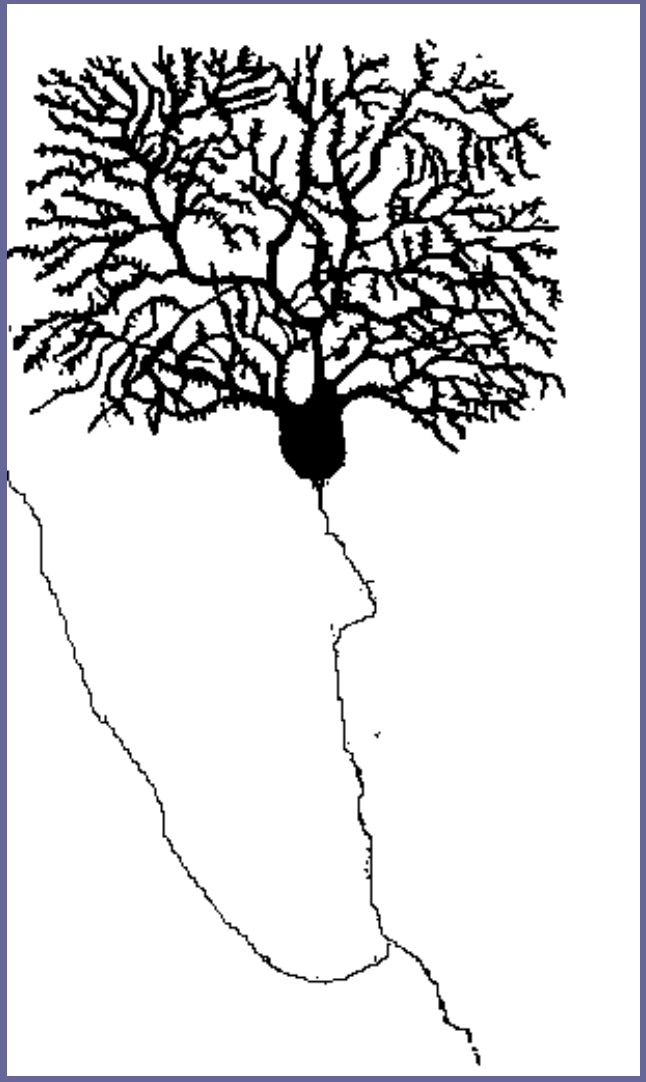
Overview of brain anatomy

- Total volume ~1400cc
- Two hemispheres
- Surrounded by fluid (cerebral spinal fluid)
- Cell types
  - Neurons
  - Glia



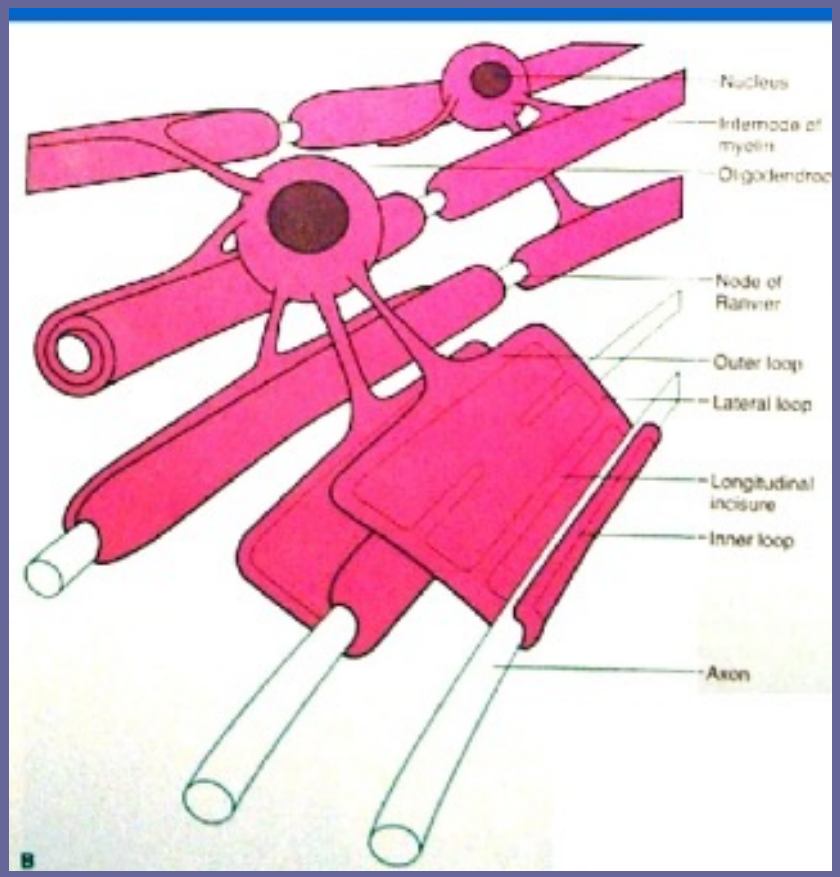
Neurons

- ~100 billion in brain
- Input from dendrites
- Output along axon
- Axon carries action potential to dendrites of other neurons



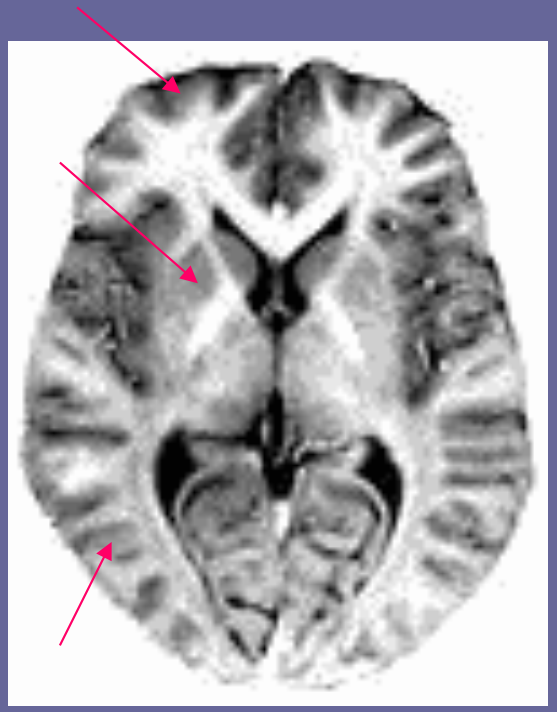
Glia

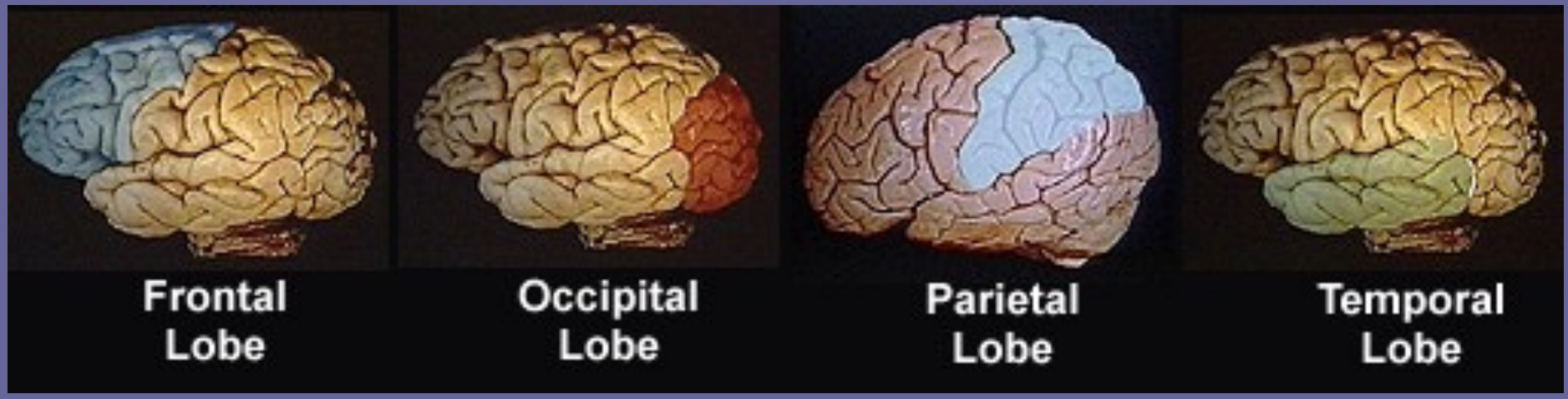
- Supporting cells
- Outnumber neurons 10:1
- Types
  - Oligodendrocytes make myelin
  - Astrocytes buffer and support neurons



Gray matter

- Neuronal cell bodies
- Glial cell bodies
- Neuropil (cell processes)
  - Dendrites
  - Proximal (mostly unmyelinated) axons





- Frontal lobe
  - Reasoning
  - Problem solving
  - Movement
  - Emotions
- Occipital lobe
  - Vision
- Parietal lobe
  - Spatial reasoning
  - Touch
  - Temperature & pressure
  - Pain
- Temporal lobe
  - Auditory processing
  - Memory

White matter

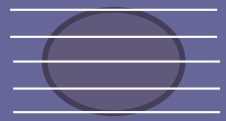
- Many myelinated axons
- Long range connections between neurons
  - Between hemispheres
  - Between cortical and subcortical
  - Within hemisphere cortical to cortical

Why measure tissue volume?

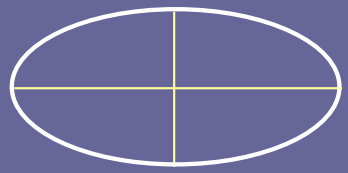
- Volume is related to function
- Blood volume
  - Vessel resistance depends on diameter ($R \sim 1/d^4$)
  - Cardiac output = left ventricle volume change
- Tissue volume changes as
  - Cells grow in size
  - Cells divide (i.e., grow in number)
  - Cells die
  - Cell populations change
  - Extracellular fluid expands (edema)
- Tissue volume reflects cell composition
  - Cell composition influences tissue function

Volumetry from images

- Calculate tissue volume
  - Find number of voxels in tissue, multiply by voxel volume
  - Find area on each slice, then multiply total area by slice thickness



- Assume a particular shape and measure parameters of the shape
  - e.g., an ellipsoid (measure major & minor axes)



- Accuracy is limited by
  - Resolution
  - Image distortions
  - Ability to determine location of tissue boundaries

Interpreting associations found with imaging

- Association does not imply causation
- If *A* and *B* are associated conditions, any of the following is possible
  - *A* causes *B*
  - *B* causes *A*
  - *C* causes *A* and *B*
- How can the cause be determined?

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- How can the cause be determined?
  - Find which condition comes first
  - Find the mechanism
  - Controlled experiments can help

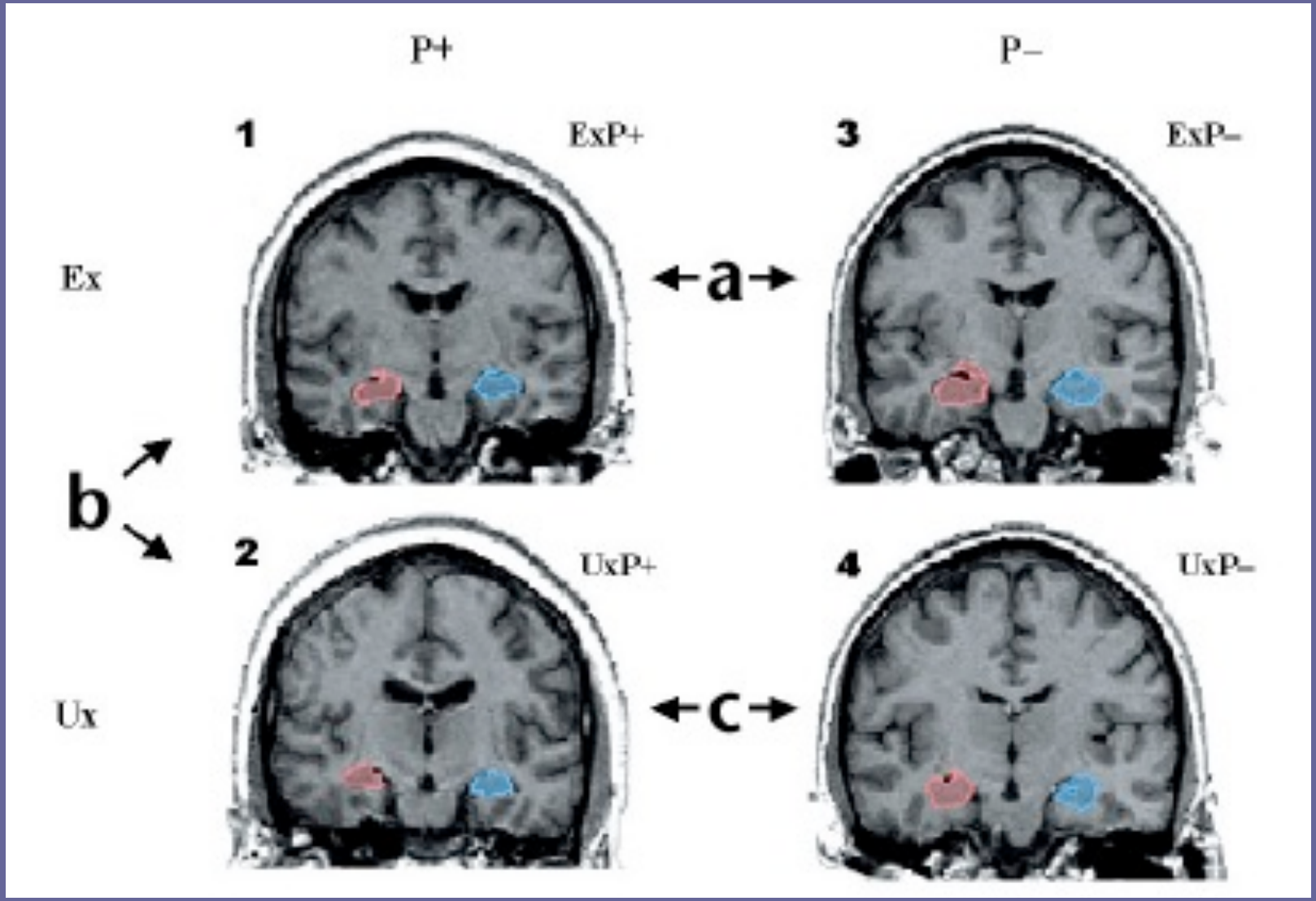
An example: risk factors for Post-Traumatic Stress Disorder (PTSD)

- Symptoms:
  - Flashbacks to traumatic event(s)
  - Sleep problems/nightmares
  - Emotional numbness or outbursts
  - Inappropriate startle reflex
  - Memory and concentration deficits
- PTSD is associated with atrophy of the hippocampus (memory)
  - Combat trauma
  - Prolonged childhood abuse
  - Is atrophied hippocampus cause or effect?
    - How could we determine this?
- Stress hormones (e.g., cortisol) may be the link

What is the causal relation between hippocampal volume and PTSD?

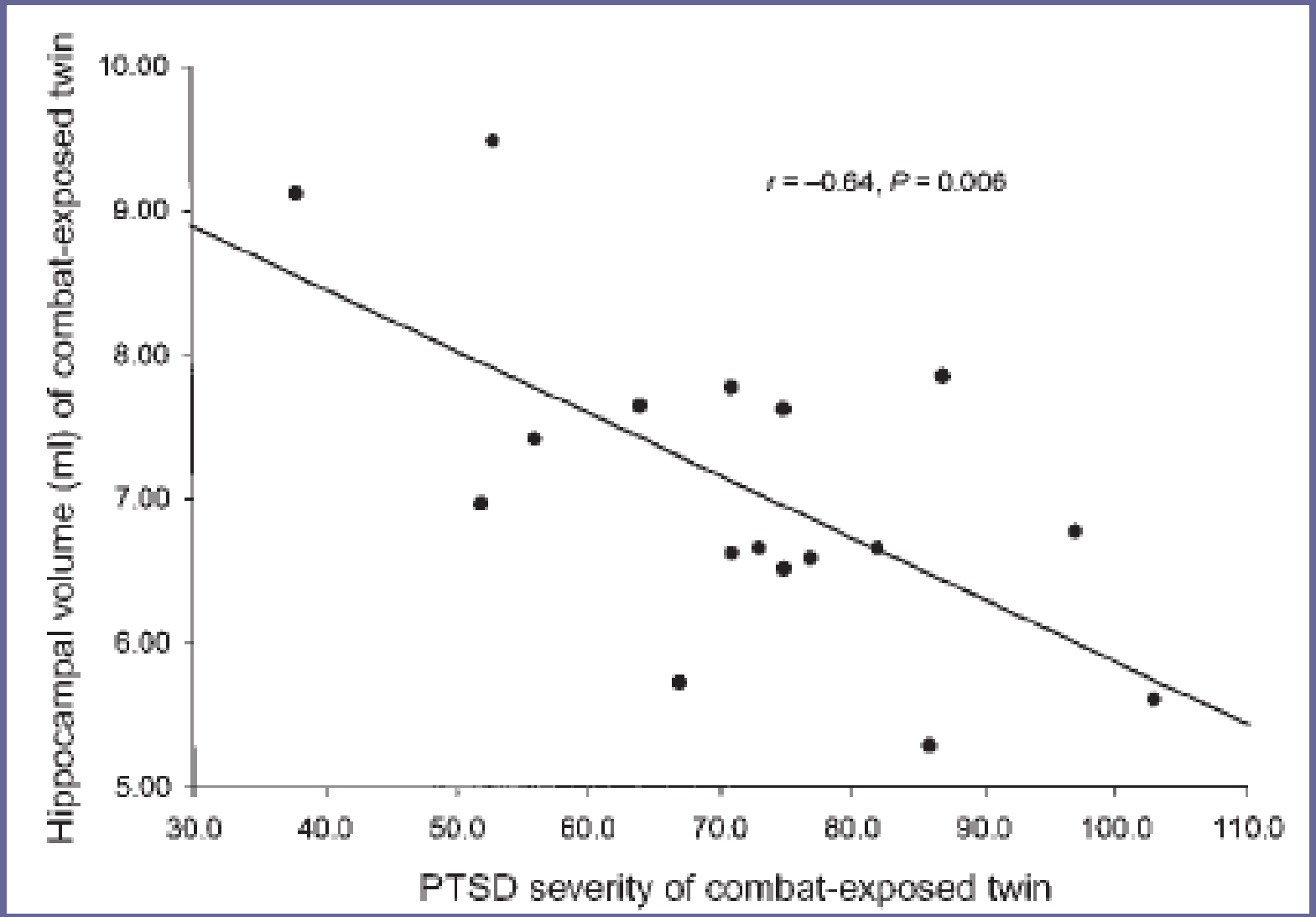
- Monozygotic (genetically identical) twins
  - Differences are due to environment
- In each pair
  - One twin is a (Vietnam) combat veteran (Ex)
    - PTSD positive (P+) or negative (P-)
  - One twin is not a veteran (Ux)
    - Exposed twin is PTSD positive (P+) or negative (P-)

Measure hippocampal volume in both twins



Gilbertson, Nature Neurosci (2002)

Correlation between hippocampal volume and PTSD severity



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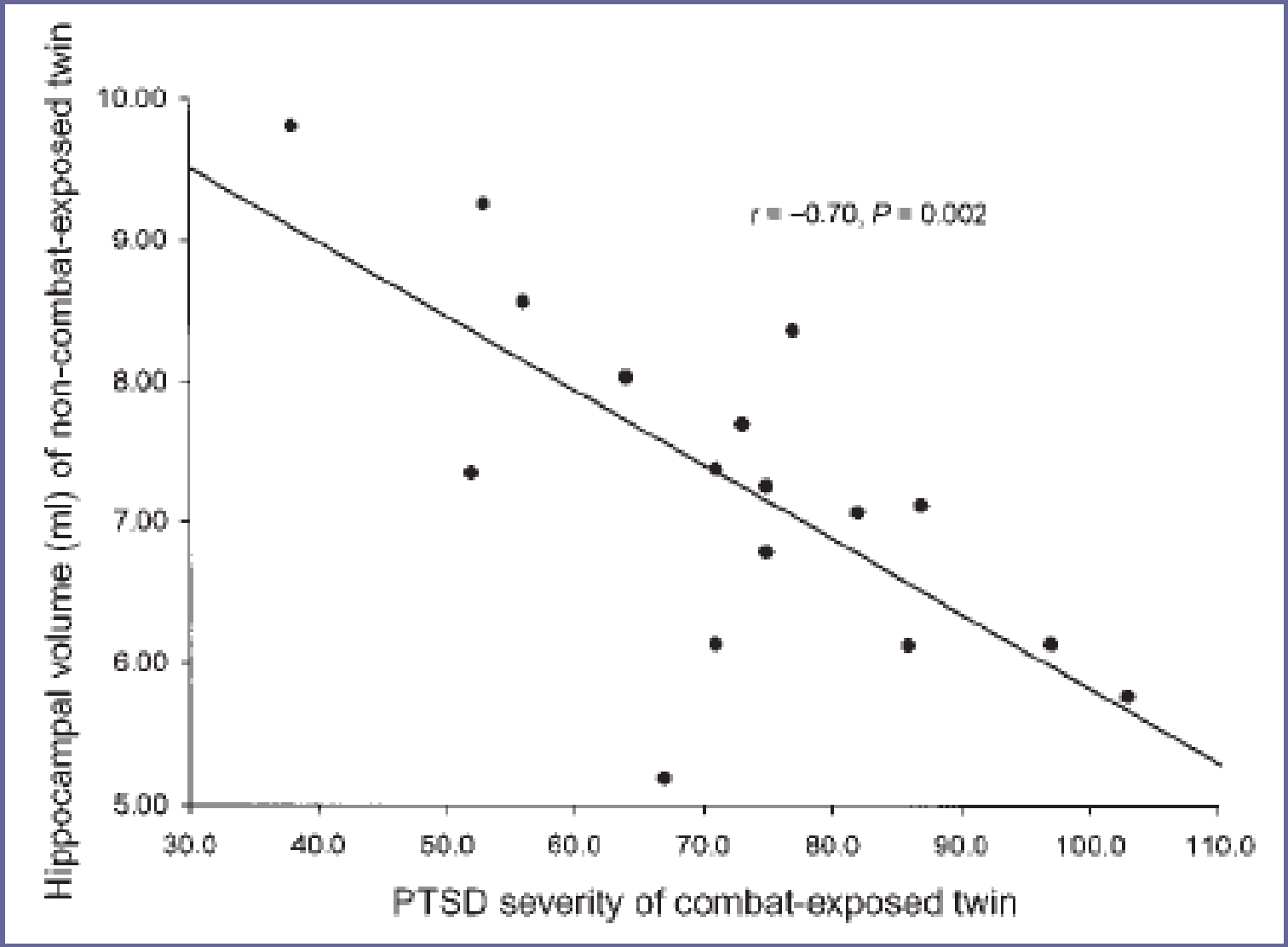

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Summary of PTSD study

- Smaller hippocampus is associated with higher risk for PTSD
  - Stress is bad for the hippocampus
  - Larger hippocampus -> greater ‘reserve’
- Studying twins distinguishes two cases:
  - PTSD increases risk of smaller hippocampus
  - Small hippocampus increases risk of PTSD
- Controlled experiments can reveal causal links

Why measure shape?

- Shape can reflect function
  - Relationship between a tissue and its input/output (e.g., vessel lumen)
  - Biomechanics (e.g., muscle insertion angles)
- Changes in shape reflect
  - Strain (cardiac muscle)
  - Uniform/non-uniform growth (bone growth)
  - Cell death
  - Tissue injury

Morphometry

- Measurement of tissue shape
- Shape descriptions:
  - Curvature (line, surface model)
  - Eccentricity (ellipsoids)
  - Branching structure (vascular, respiratory systems)
  - Folding patterns (cortex of brain)
- Relies on fitting pixel data to a geometric model
- Limited by
  - Resolution
  - Image distortions
  - Ability to determine tissue boundary locations

In-class exercise: Choose an application

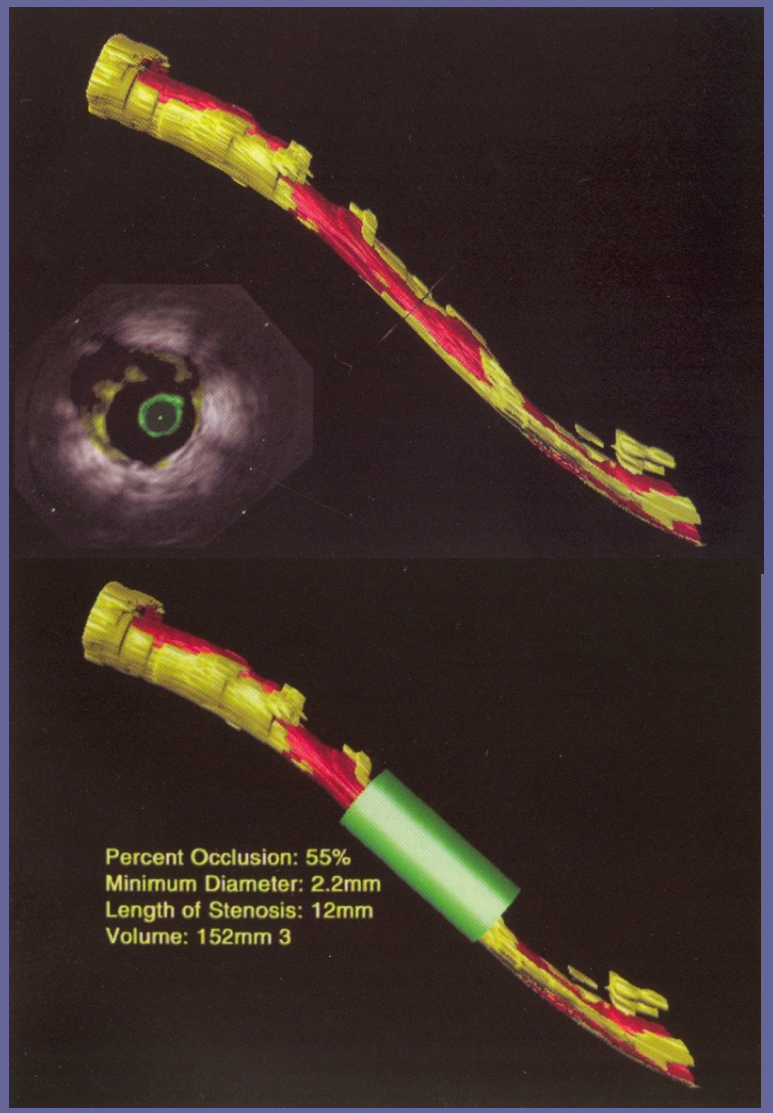
Coronary artery disease	Cardiac function
Cause of seizures	Loading of the spine
Tumor growth	Airway resistance

Define

- Quantity of interest
  - Volume or shape?
- Imaging method
- How to analyze images
- Likely limitations of measurements

Evaluation of coronary artery disease using intravascular ultrasound

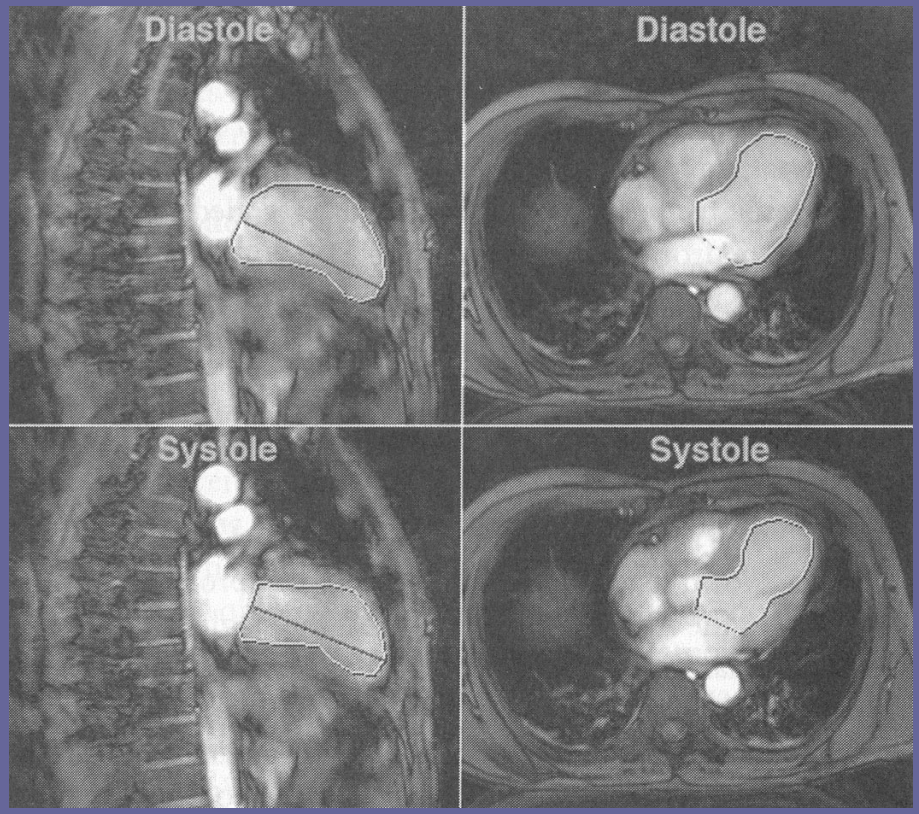
- Ultrasound contrast between
  - Plaque
  - Healthy vessel wall
  - Blood
- Where is stenosis most severe?
  - Guide for stent placement
- Classify pixels (plaque, blood, etc)
- Measure sizes, volumes
- Plot vessel lumen diameter and plaque thickness along vessel



Robb (1999)

Measuring cardiac ejection fraction with MRI

- Cardiac function is related to volume of blood pumped per sec
- Maximum change in volume of left ventricle (LV)
- Model LV as ellipsoid
- Volume is determined by length and area

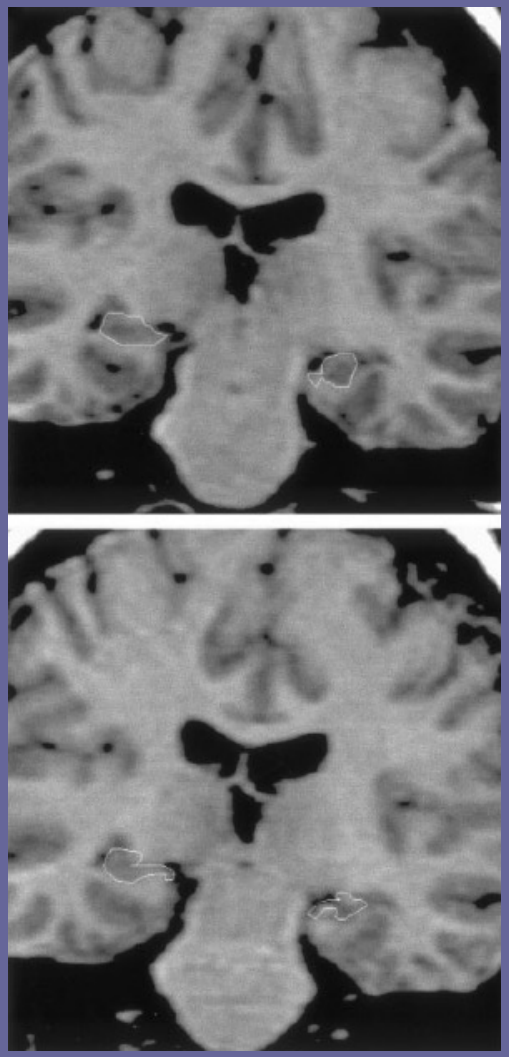


Bankman (2000)

Temporal lobe epilepsy

- Hippocampal formation is sensitive to damage
- Neurons die, glia proliferate
- Hippocampus becomes hyperexcitable
  - Positive feedback loop increases seizure frequency
- Volume loss is correlated with seizure frequency
- Volumetrics for diagnosis and surgical planning

Volume loss over 3 years



Fuerst, Ann. Neurol (2003)

Summary

- Volume and shape of structures reflect their composition and function
- Imaging provides the starting point for analysis
- Measurements depend on
  - Image contrast-to-noise ratio
  - Resolution
  - Spatial distortion
  - Artifacts

Sources

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