Open Source Software for Image Guided Therapy: 3D Slicer

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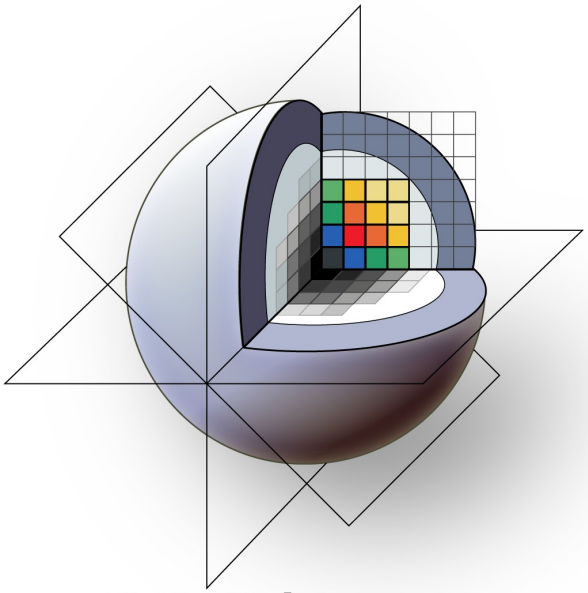
Brigham and Women's Hospital
Harvard Medical School

Guest Lecture: MIT HST 582/6.555

May 5, 2015

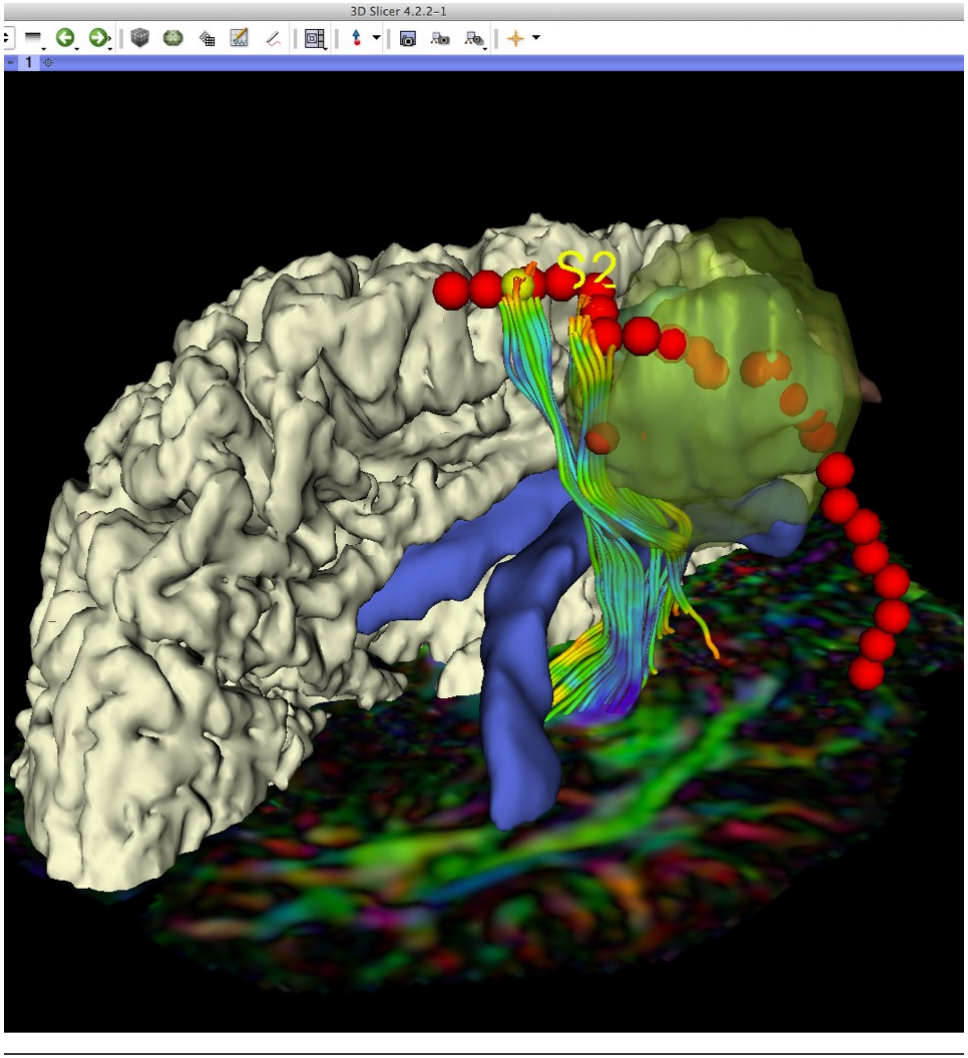
Two technologies
and
a community
developing open science
to accelerate important
discoveries
that improve health and save
lives.



AM

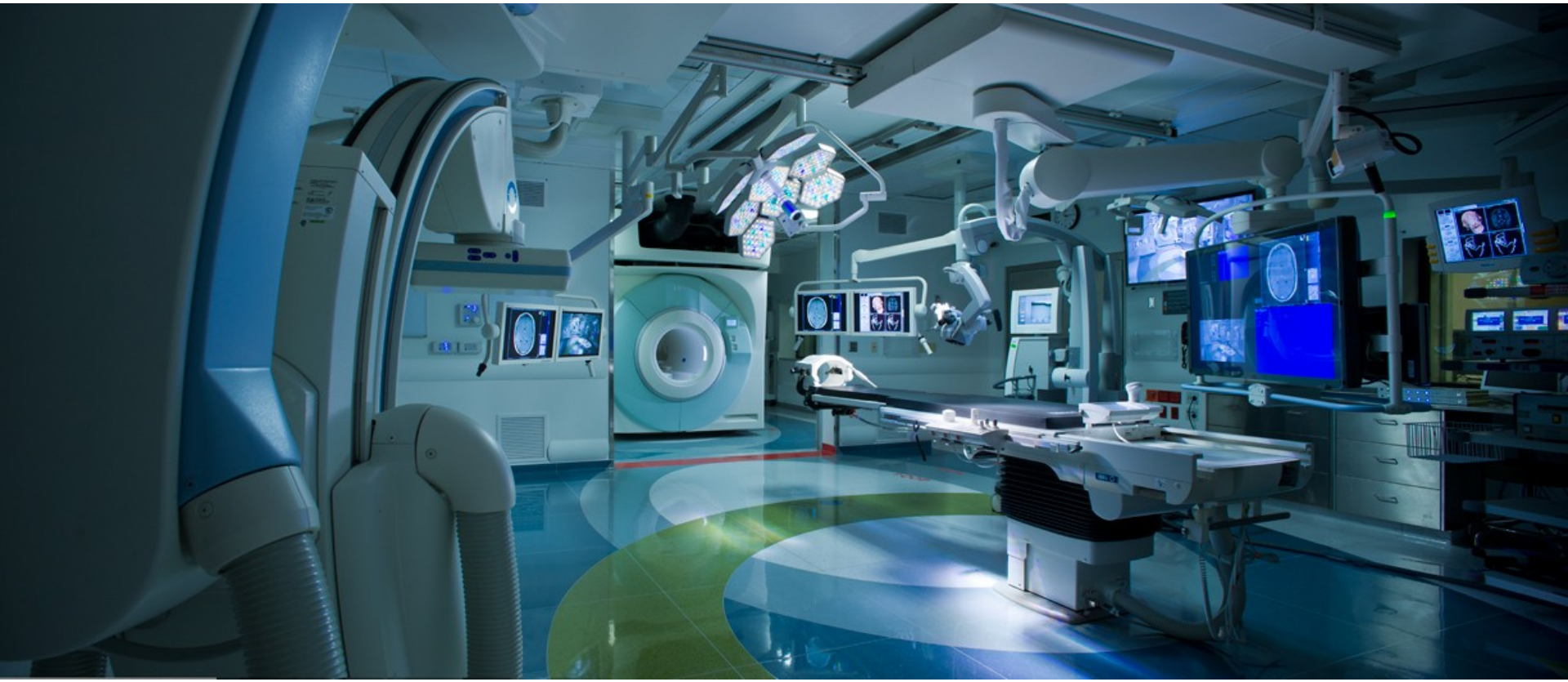
3D Slicer: http://slicer.org

- Medical Image Visualization and Analysis
  - -Multi-Modal: CT, MR, fMRI, dMRI+
  - -Integrated View: Images, Surfaces, Annotations, Devices...
- Multi-OS End-User Application (Windows, Linux, Mac)
- Extensible Architecture
  - -Dozens of Custom Modules
  - -Application Specific Functionality
- Fully Open and Non-Restrictive License
  - -All Source Code Available
  - -Can Be Used in Commercial or Proprietary Projects
- 100+ person-years of effort
- PI Ron Kikinis, MD



Courtesy Pieper, Kikinis, S. Pujol, A. Golby

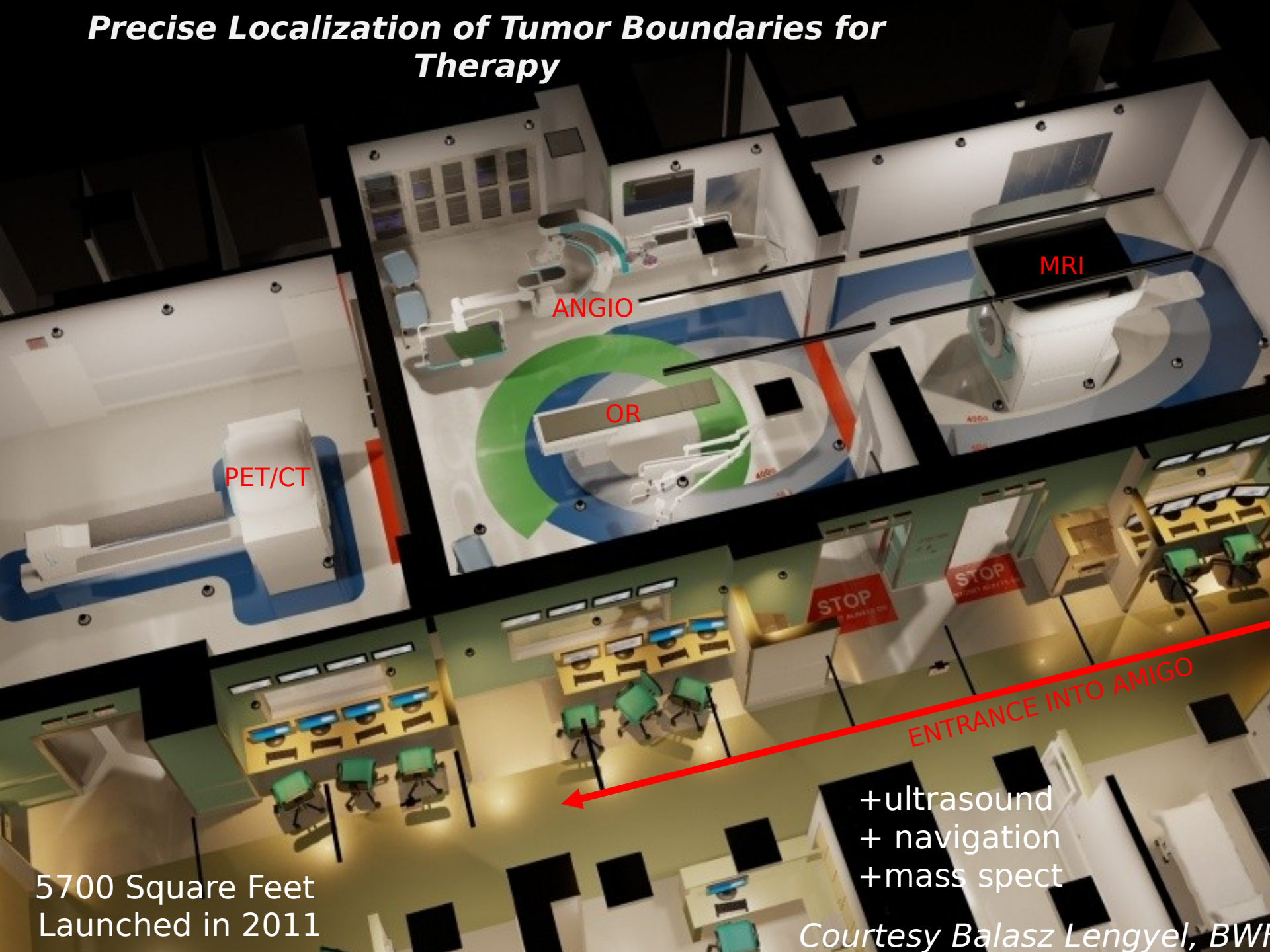
Advanced Multimodality Image Guided Operating Suite (AMIGO)



Precise Localization of Tumor Boundaries for Therapy

P41EB015898 (PI Clare Tempany, MD)

Precise Localization of Tumor Boundaries for Therapy



Courtesy Balasz Lengyel, BWH

794 Procedures in AMIGO
08/31/2011-04/10/2015

Neurosurgery

- 94 MR and Ultrasound Guided Brain Tumor Resections
- 22 MR Guided Transsphenoidal Resections for Pituitary Tumors
- 16 MR Guided Deep Brain Stimulation Electrodes Placements
- 9 MR Guided Laser Brain Tumor Ablations

Thoracic Surgery, Biopsy,

- 28 Video Assisted Thoracoscopic surgeries (iVats)
- 15 Breast Lumpectomies
- 9 PET/CT Guided Lung Biopsies
- 7 Cardiac EP Ablations
- 7 PET/CT Guided Microwave Ablations of Lung Tumors
- 3 PET/CT Guided Cryoablations of Lung or Rib Tumors
- 1 MR Guided Cryoablation of Metastatic Paraspinal

Head & Neck Surgery

- 5 Parathyroidectomies/Hemithyroidecotmies
- 3 PET/CT Guided Biopsy of Tongue/Mouth/Neck
- 2 MR Guided Biopsy of Tongue/Mouth/Neck
- 2 MR-guided Cryotherapy of Neck Tumors

Skeletal Biopsy & Ablation

- 3 MR Guided Cryoablation of Spinal Tumor
- 3 PET/CT Guided Biopsy of Spine Tumor
- 1 MR Guided Biopsy of Femoral Tumor

Pelvic Biopsy, Ablation,

- 214 MR Guided Prostate Biopsies
- 86 MR and Ultrasound Guided Gynecologic Cancer Brachytherapy
- 8 MR and Ultrasound Guided Prostate Brachytherapy
- 7 MR Guided Cryoablations of Prostate Tumors
- 1 MR Guided Biopsy of Penile Tumor
- 1 PET/CT Guided Penile Biopsy
- 1 PET/CT Guided Cryoablation of Pelvic Tumor

Abdominal Tumor Ablation &

- 154 MRI Guided Cryoablations of Liver or Kidney Tumors
- 32 MR Guided Biopsies of Liver or Kidney Tumors
- 31 PET/CT Guided Microwave Ablations of Liver or Kidney Tumors
- 24 PET/CT Guided Cryoablations of Liver or Kidney Tumors

- http://ncigt.org/pages/AMIGO
- http://brighamandwomens.org/research/amigo/default.aspx

520 Procedures in AMIGO (08/31/2011-04/18/2014)

Neuro 108

- 70 Craniotomies/Biopsies
- 22 Transsphenoidals
- 7 Laser Ablations
- 7 Deep Brain Stimulation electrodes placement
- 1 Epilepsy Electrode Placement

Head and Neck 5

- 5 Parathyroidectomies/Hemithyroidecotmies

Spine 1

- 1 MR Cryoablation/Biopsy (Spinal Tumor Mass)

Thorax 51

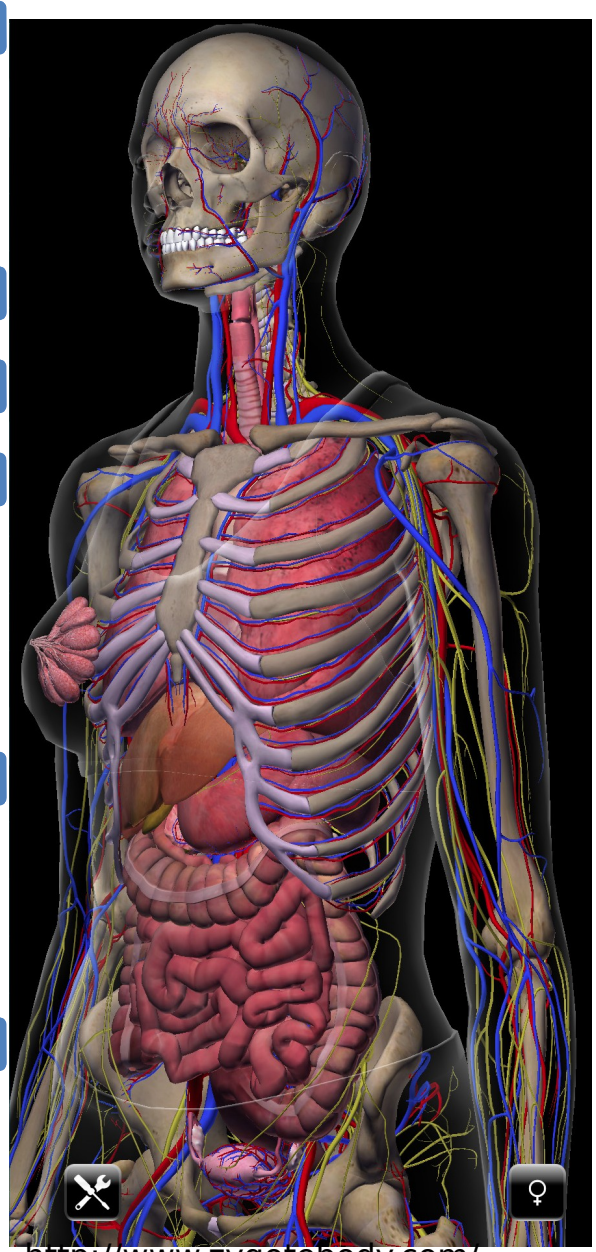
- 19 Video Assisted Thoracoscopic surgeries (iVats)
- 8 Breast Lumpectomies
- 7 EP Cardiac Ablations
- 7 Microwave ablations PET/CT guided (lung)
- 6 Biopsy PET/CT guided (lung)
- 3 Cryoablations PET/CT guided (lung, rib)

Abdomen 159

- 98 Cryoablations MRI guided (liver, kidney)
- 24 Biopsies MR guided (liver, kidney)
- 14 Cryoablations PET/CT guided (liver, kidney)
- 13 Microwave Ablations PET/CT guided (liver, kidney)
- 9 Cryoablations & Biopsies MR guided (liver, kidney)

Pelvis 196

- 115 Prostate Biopsies
- 67 Gynecologic Cancer Brachytherapy
- 7 Prostate Brachytherapy
- 5 Cryoablations MR guided (iliac, prostate)
- 1 Biopsy MR guided (penile)



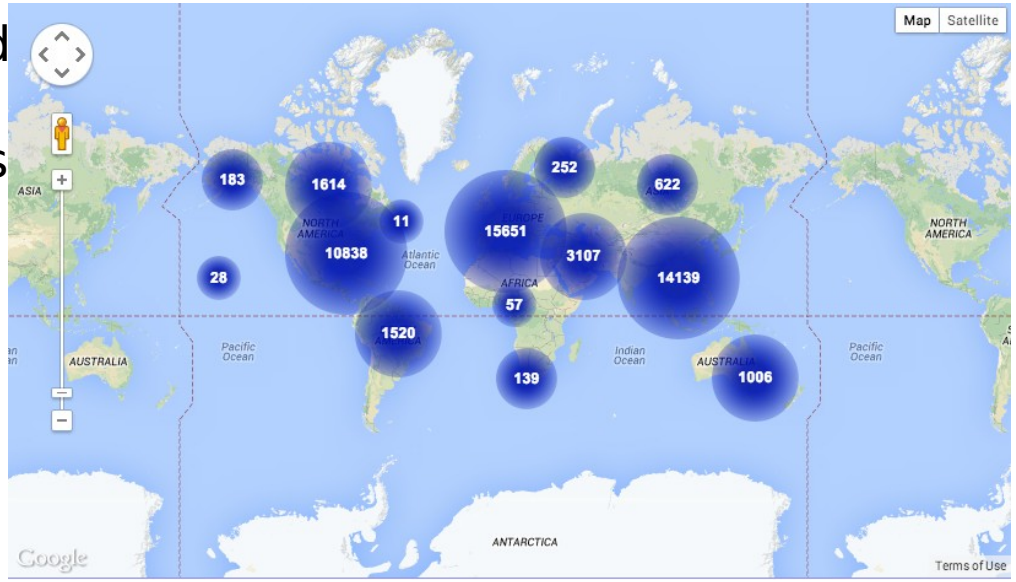
http://www.zygotebody.com/

3D Slicer Community

,000 Downloads in 12 months/168 a d

00 messages per year on mailing lists

mi-annual hackathon “Project Weeks”
th 100+ open source developers and
entists



3D Slicer Enabled Research In…

- Huntington’s Disease (HD)
- Gynecologic Cancer Brachytherapy
- Image Guided Parathyroid Tumor Resection

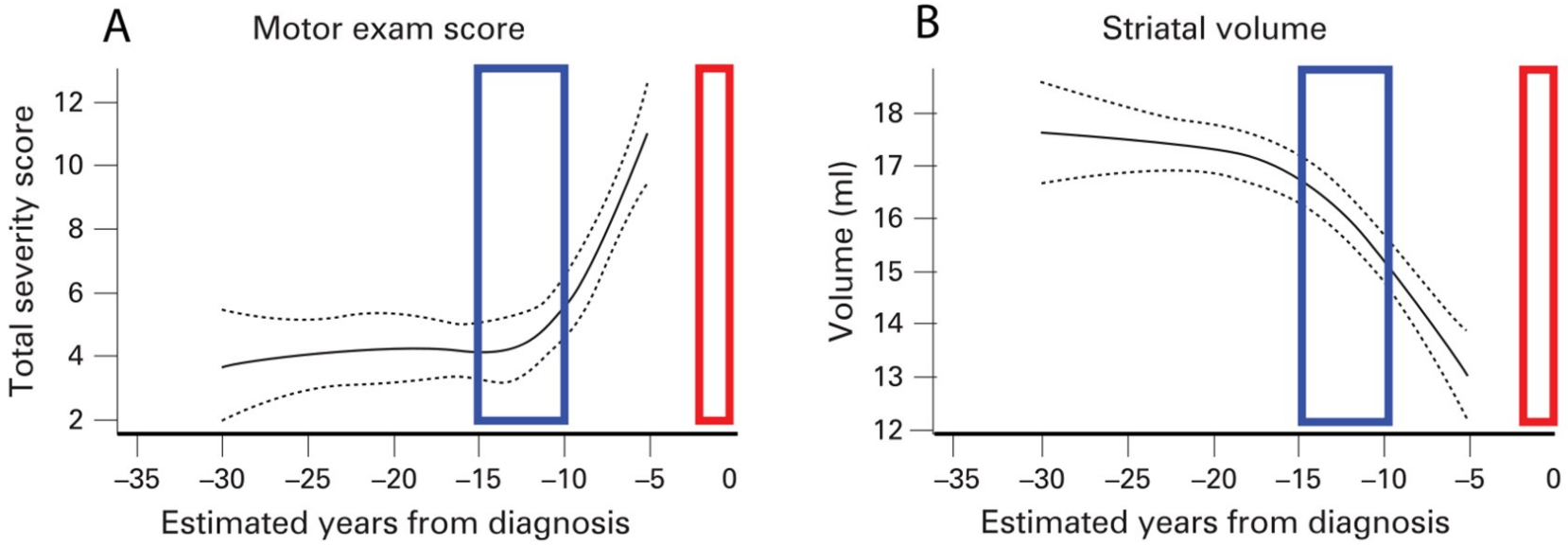
Huntington's Disease (HD)

- HD is a Neurodegenerative Disease
  - Affects Muscle Coordination, Behavior, and Cognitive Function
  - Causes Debilitating Symptoms by Middle Age
- Caused by mutation of Huntingtin gene, HTT, on chromosome 4
- If CAG repeats on HTT > 40, individual is almost always affected
- The more CAG repeats on HTT, the lower the HD onset age is **likely** to be.
- No cure today
- Disease modifying interventions; timing matters
- Readable: http://ghr.nlm.nih.gov/gene/HTT

Langbehn DR et al. Clin Genet. 2004;65(4):267-77

Clinical Symptoms vs. MR Imaging

Clinical symptoms are used to estimate most likely time of neurological diagnosis
and to propose window for starting disease-modifying intervention.



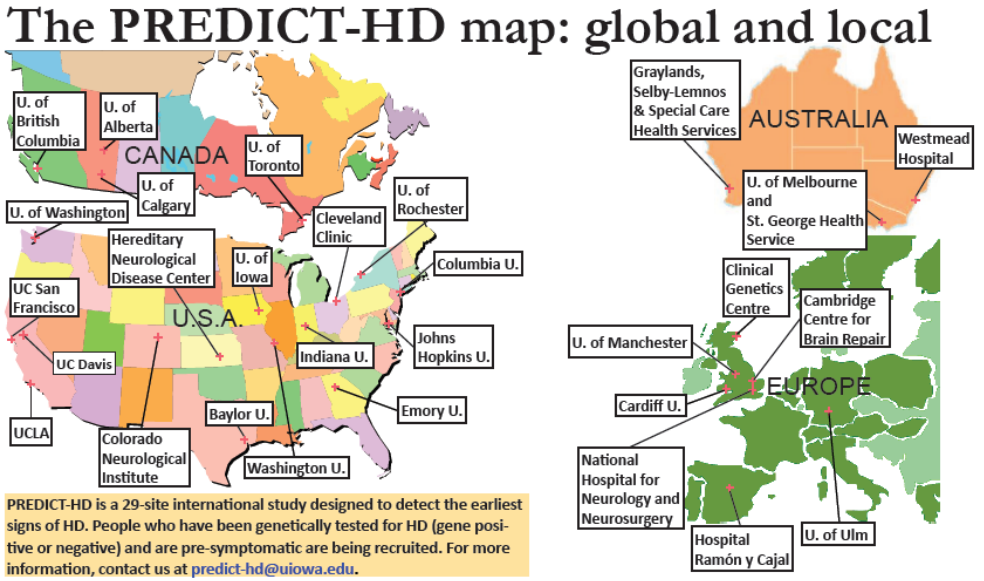
Regional brain volume and white matter integrity changes may even precede clinical symptoms, and improve timing for intervention.

Paulsen JS et al. J Neurol Neurosurg Psychiatry. 2008;79:874-80.

PredictHD

- Genetic and Imaging Study at 29 sites
  - Detect Earliest Signs of Huntington's Disease
- PI: Jane Paulsen, PhD, University of Iowa
- **3D Slicer Scientists: Hans Johnson** and Colleagues, University of Iowa

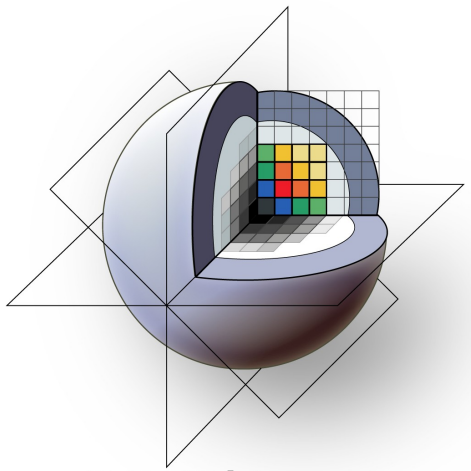
THE UNIVERSITY OF IOWA



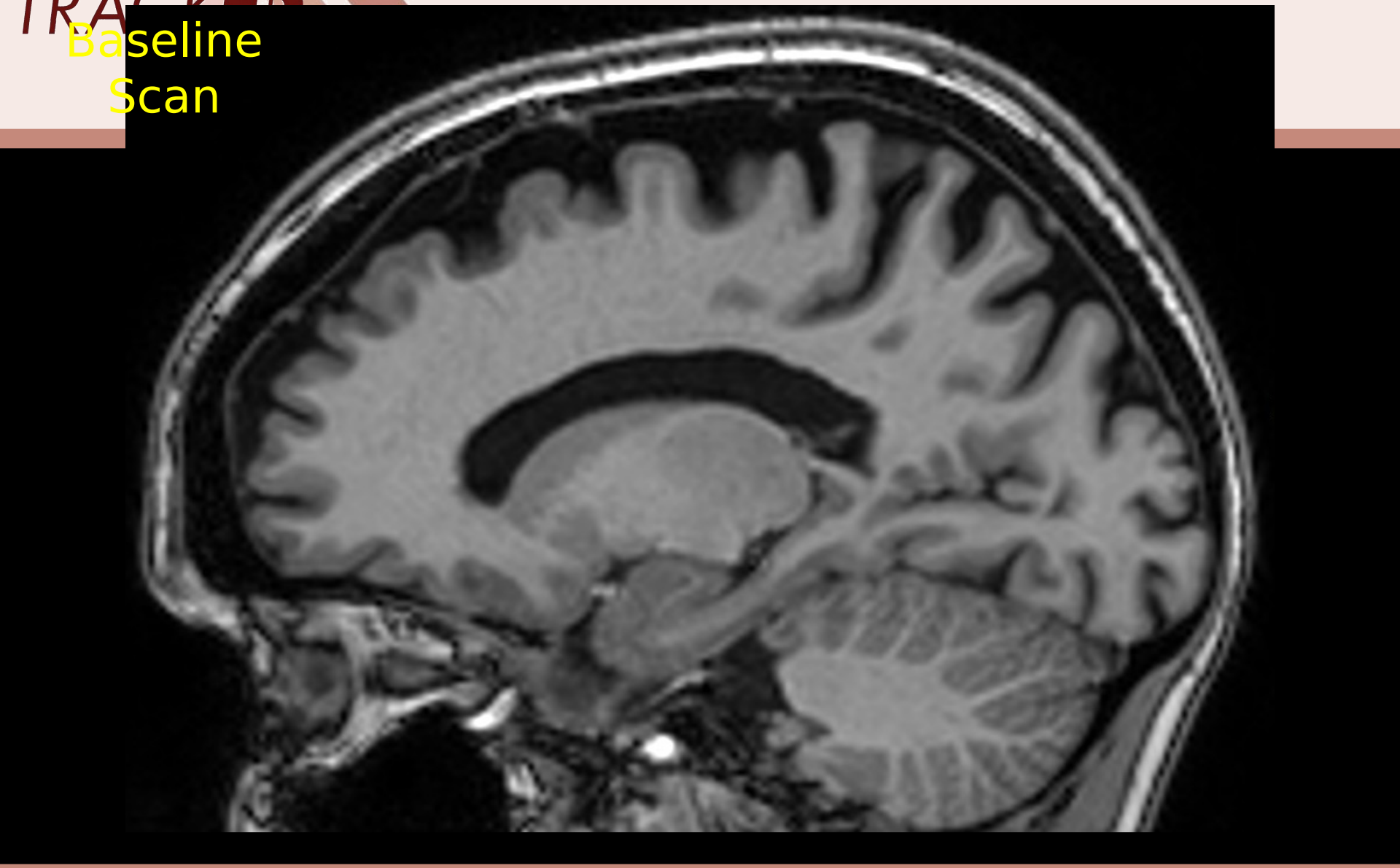
http://www.predict-hd.net/

Accurate Detection of Brain Volume and White Matter Integrity Changes Requires:

- Well Calibrated Acquisitions
- Robust Analysis Pipelines
  - Registration
  - Segmentation
  - Diffusion Analysis



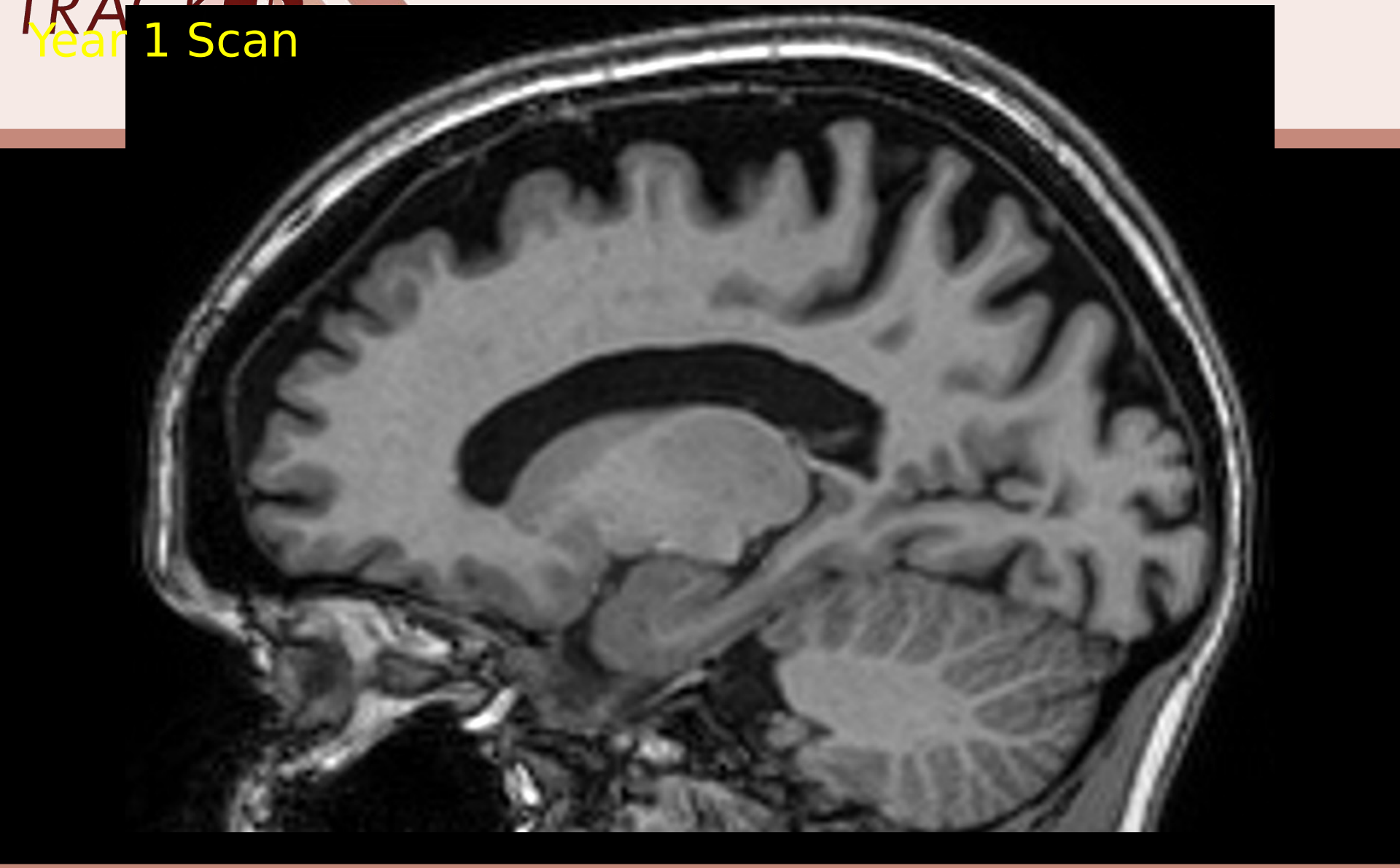
TRACK-HD Stage 1 HD Subject



Sarah J Tabrizi et al. Lancet Neurol. 2009 September; 8(9): 791–801.
Slide courtesy Hans Johnson, UIowa

http://www.track-hd.net

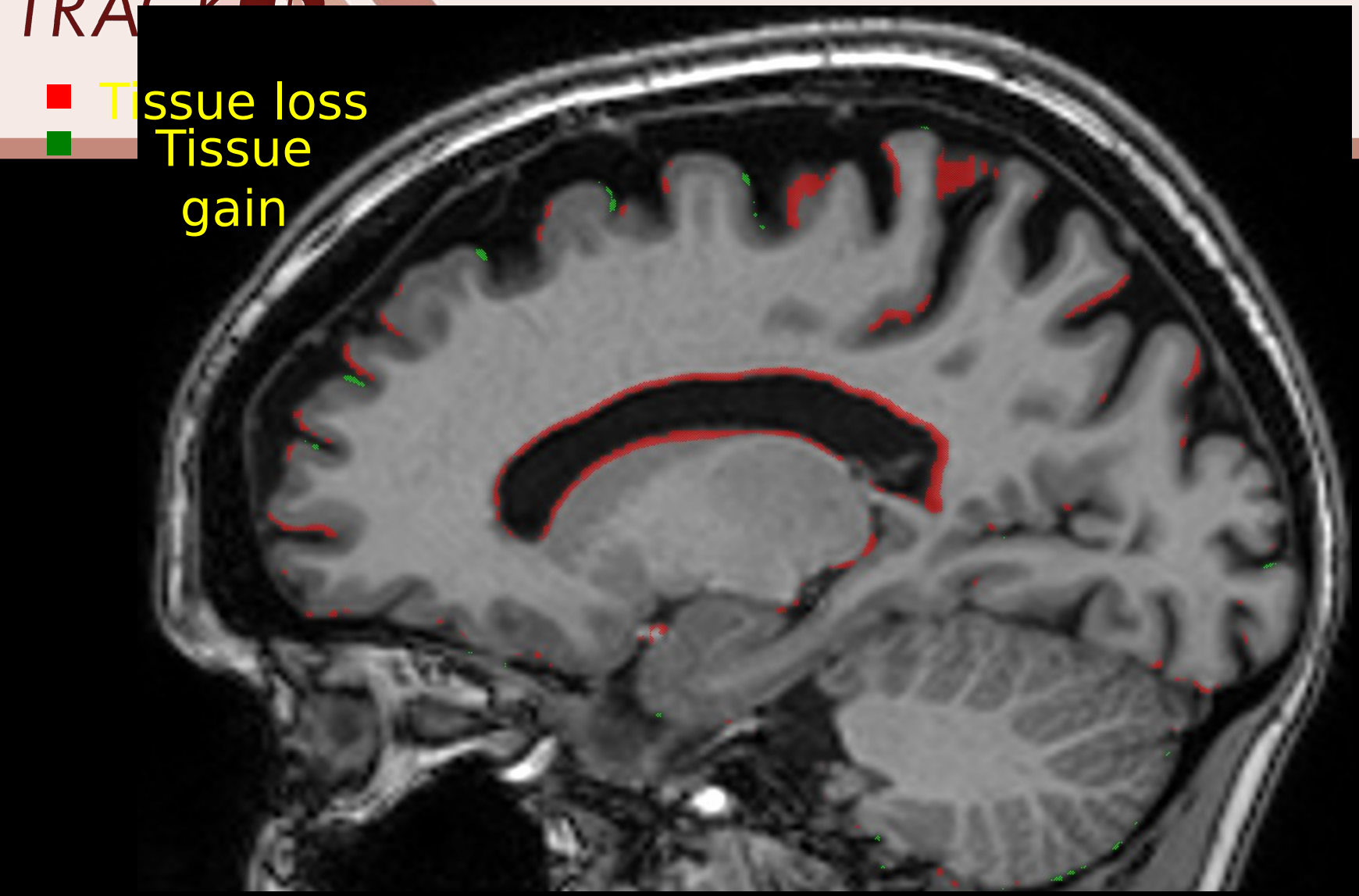
TRACK-HD Stage 1 HD Subject



Slide courtesy Hans Johnson, UIowa

http://www.track-hd.net

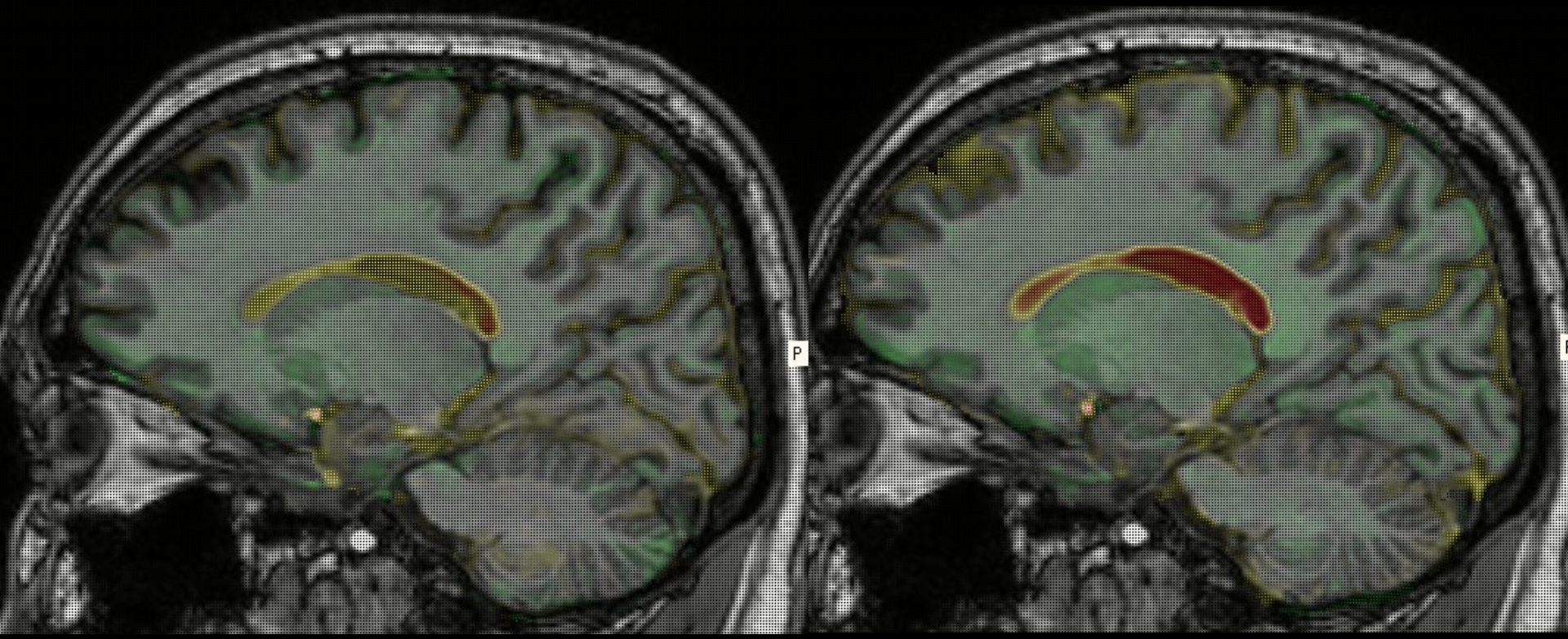
TRACK-HD Stage 1 HD Subject



Atrophy Rate: 1.9% Premanifest Rate: 0.7% Control

http://www.track-hd.net

TRACK-HD Premanifest A Subject: voxel-compression mapping



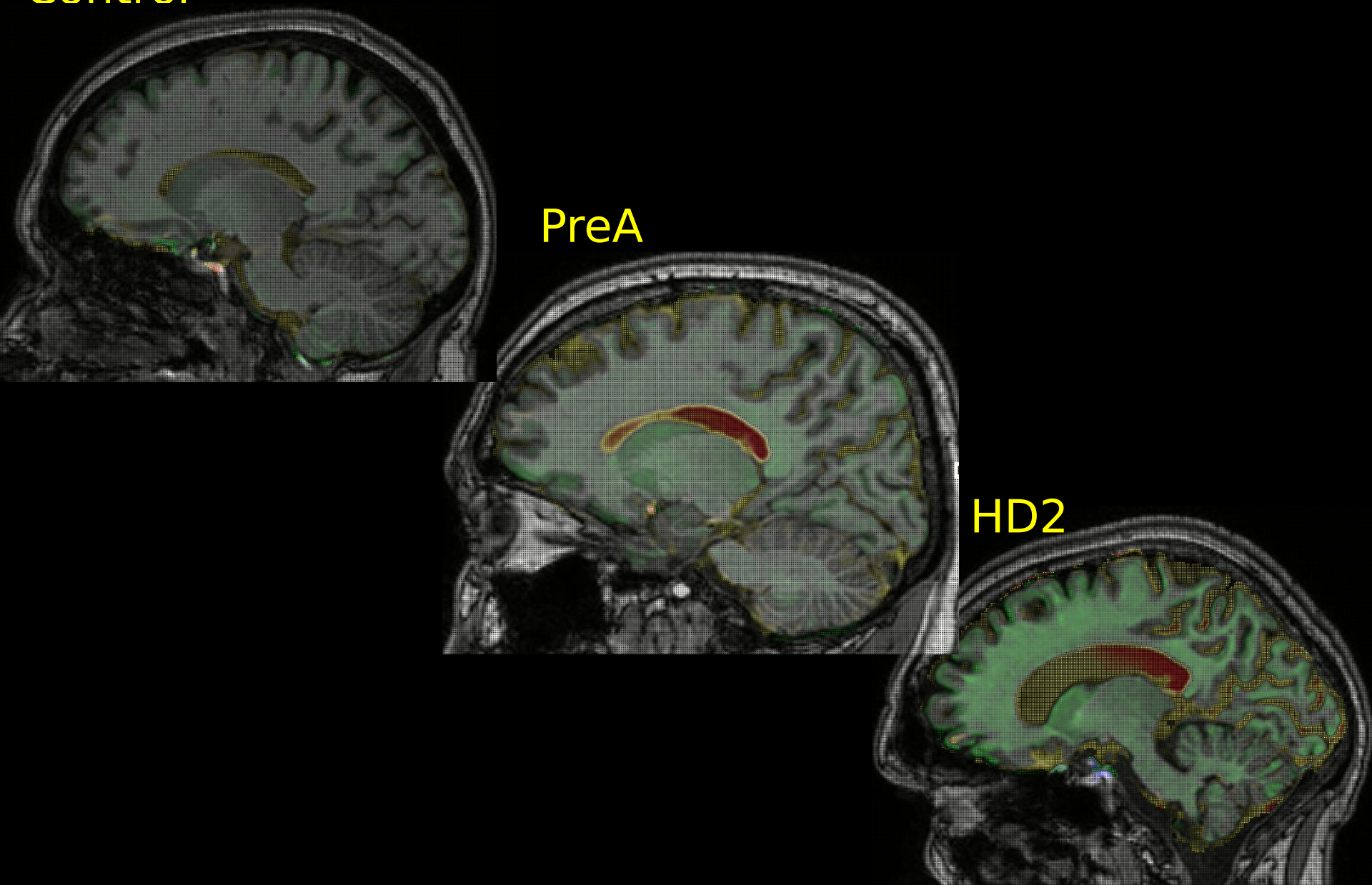
12-month atrophy

24-month atrophy

Contraction ≤ 20%

Expansion ≥ 20%

24-month voxel-compression mapping



Additional Information

- **Hans Johnson** and Colleagues at University of Iowa
- http://www.predict-hd.net/

3D Slicer Enabled Research In…

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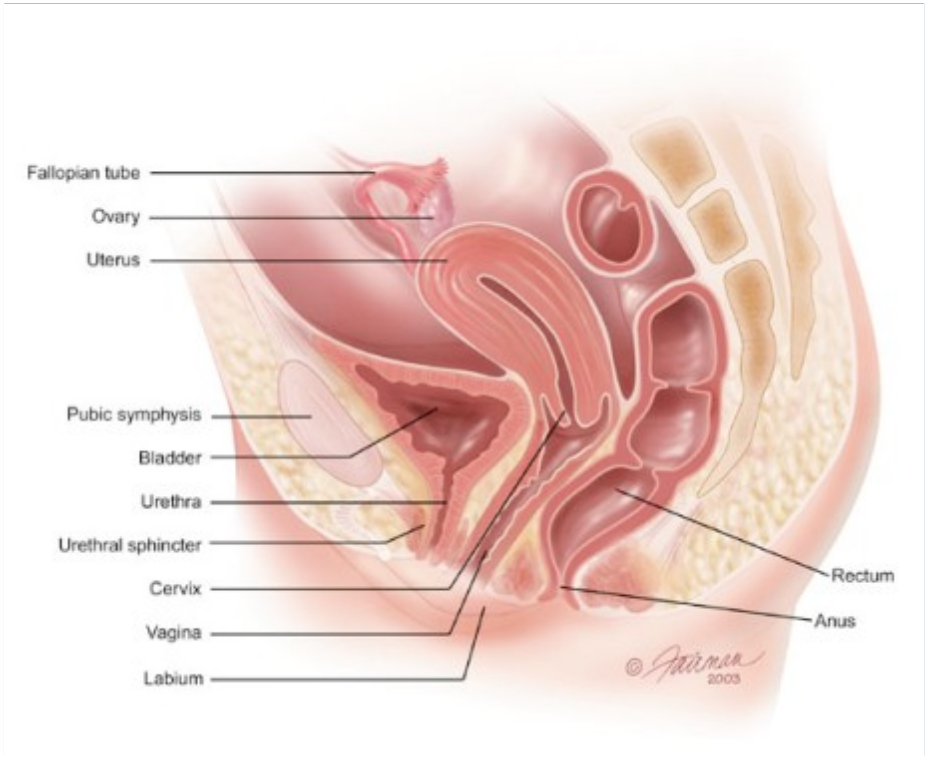
Gynecologic Cancers



- 500,000 cases per year worldwide: Cervical, Uterine, Vaginal, Vulvar, Ovarian
- 4th leading cause of death in women in the US

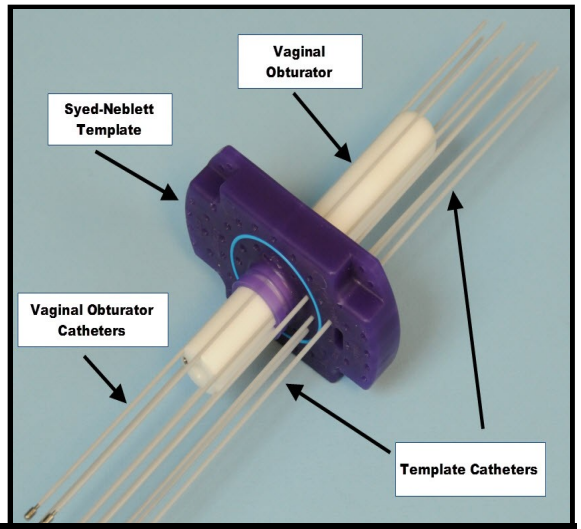
MR-guided Gynecologic Cancer Brachytherapy In AMIGO

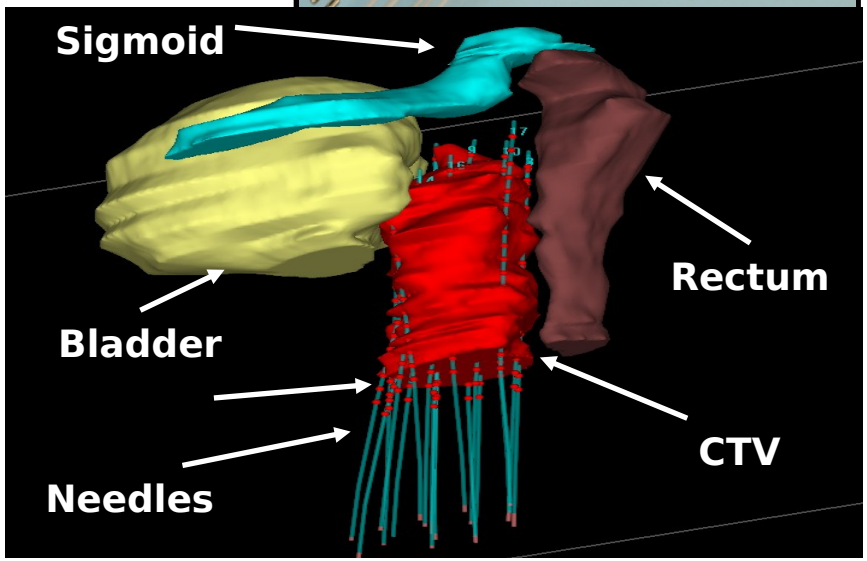
MR is the preferred imaging modality for visualization of gynecologic cancers

Needle artifacts in MR are ambiguous compared to x-ray or CT

10-50 needles are inserted in a case

Need for applicator identification/verification





3DSlicer

Iterative Catheter Detection

Idea: find n control points on the needle path to fit a Bézier curve accurately approximating the catheter shape

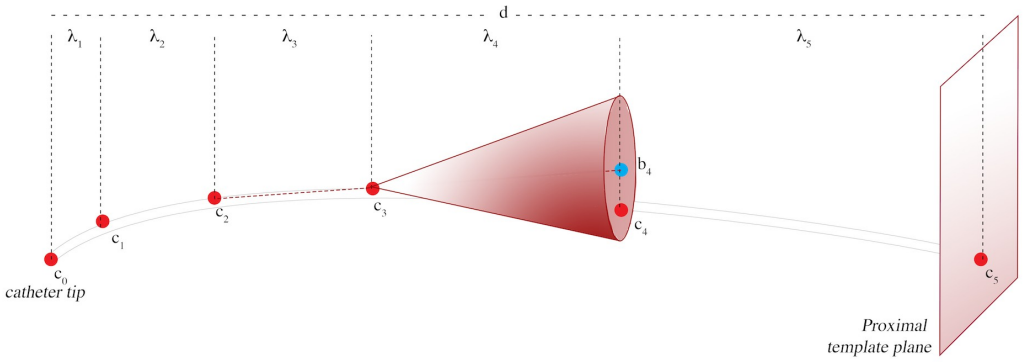
Algorithm structure

(0) **Interactively** provided needle-tip

(1) Algorithm searches the MR image for a segment that **maximizes the "needle likelihood"** in a conic volume. (needle tip = cone tip)

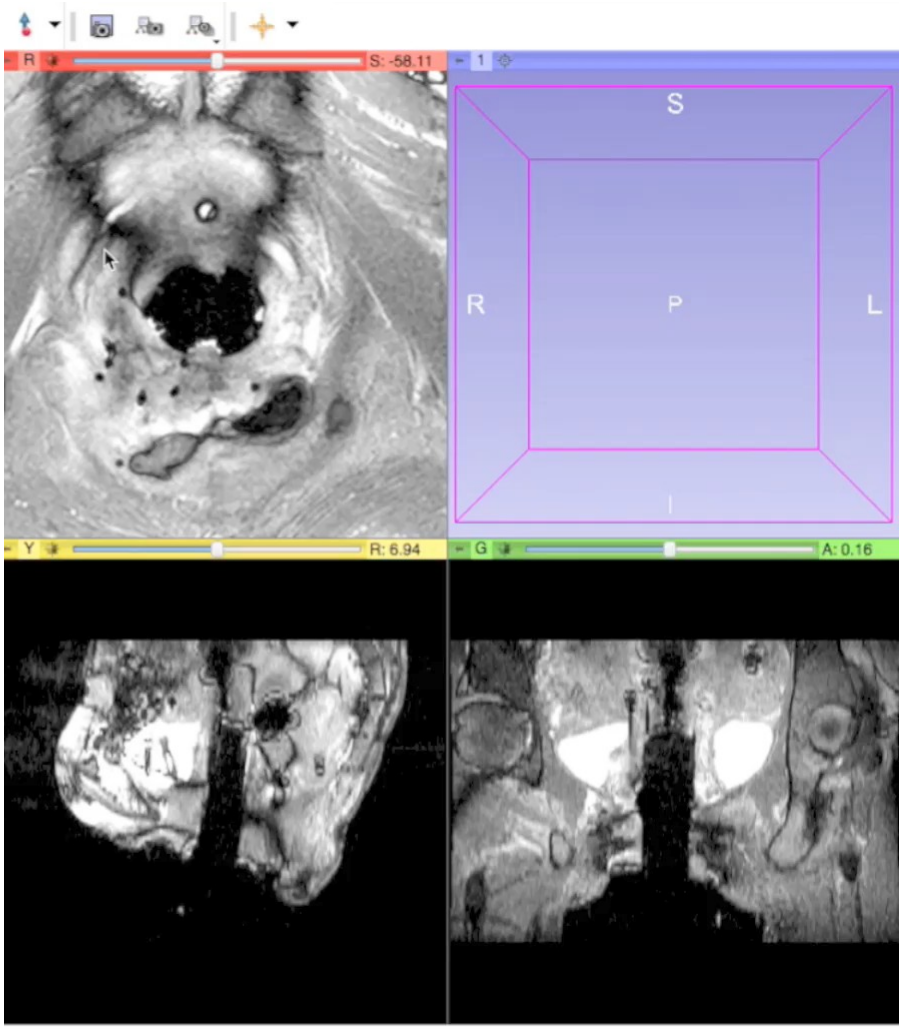
(2) **Reiterate** from the second extremity of the found segment.

(3) Extremities of the segments provide control points used to fit a Bézier curve.



Guillaume Pernelle et al. [MICCAI 2013], Andre Mastmeyer et al. [Submitted 2015]

Needle Detection in 3D Slicer



Guillaume Pernelle et al. [MICCAI 2013]

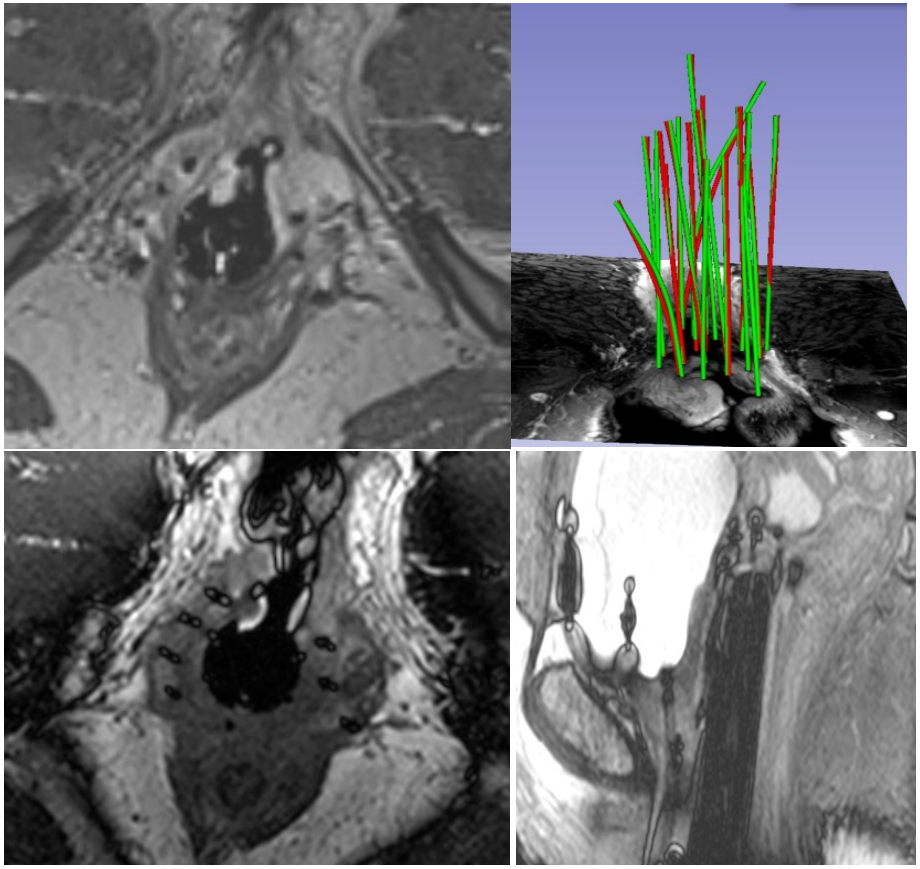
3DSlicer

10 brachytherapy patients, 101 catheters.

Hausdorff distance* manual and interactive segmentations.

93/101 HD error <2mm.

computation time < 1s/catheter.



interactive segmentation (red)
expert manual segmentation (green)

**HD is the distance of closest points of two surfaces that disagree the most*

Guillaume Pernelle et al.
[MICCAI 2013]

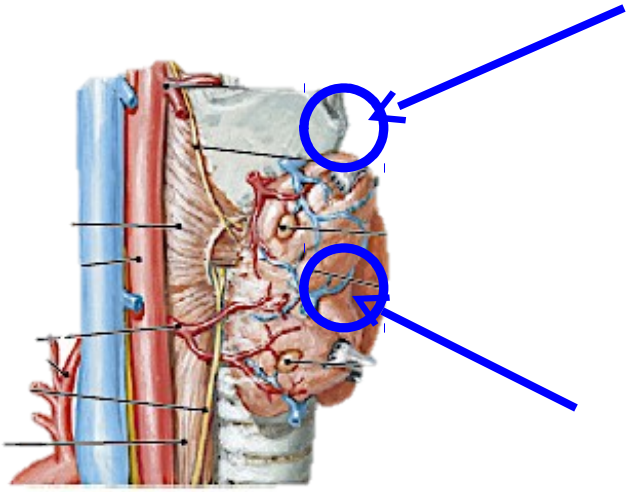
3D Slicer Enabled Research In…

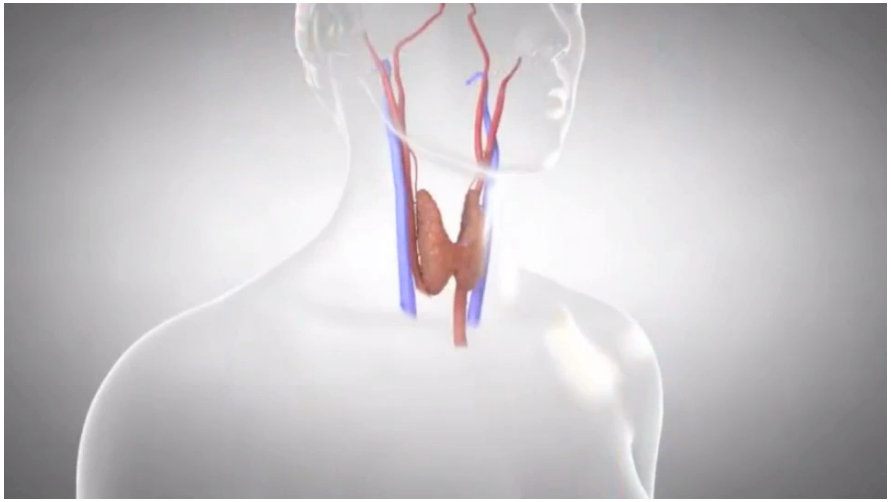
- Huntington’s Disease (HD)
- Gynecologic Cancer Brachytherapy
- Image-Guided Parathyroid Tumor Resection

Image-guided Parathyroidectomy in AMIGO

J. Jayender, T.C. Lee, D.T. Ruan
“Real-time localization of parathyroid adenoma during parathyroidectomy”, New England Journal of Medicine, 2015 (accepted)

Problems with Diagnosis and Surgical Resection



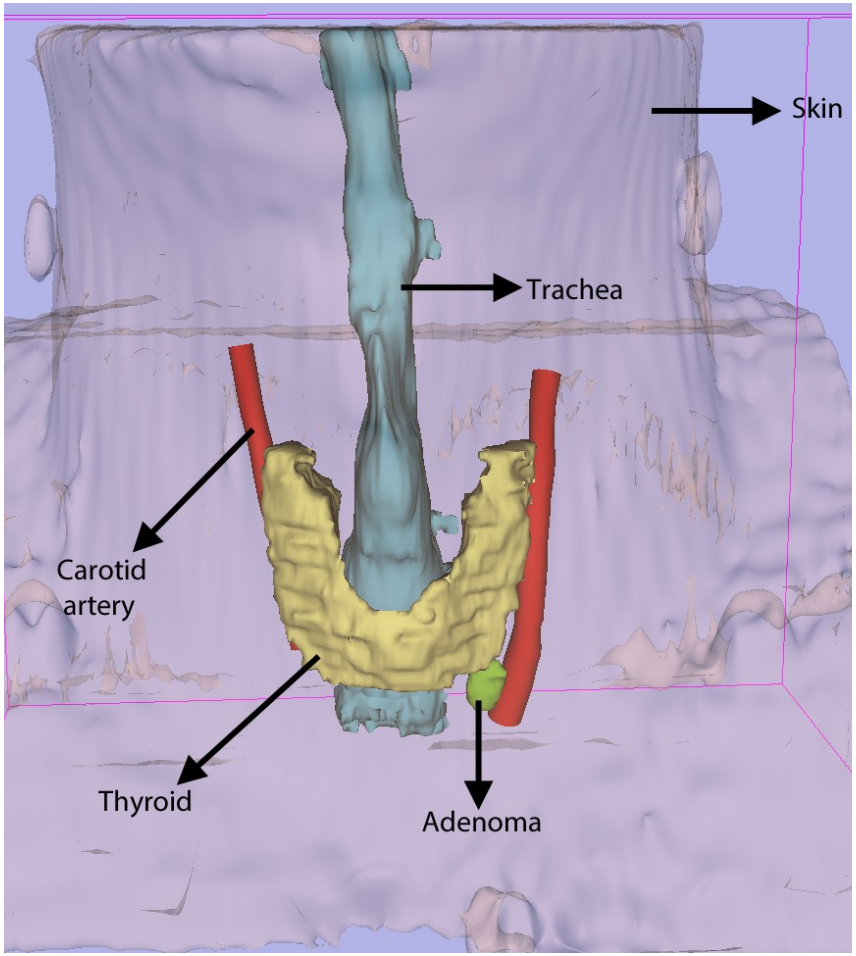


- Small glands hidden behind the thyroid gland
- As small as a rice grain
- Numerous sensitive structures around the parathyroid making surgical resection difficult
- Damage to laryngeal nerve could lead to hoarseness, inability to speak and difficulty in breathing

Slide courtesy of Jayender Jagadeesan Photo: Netter

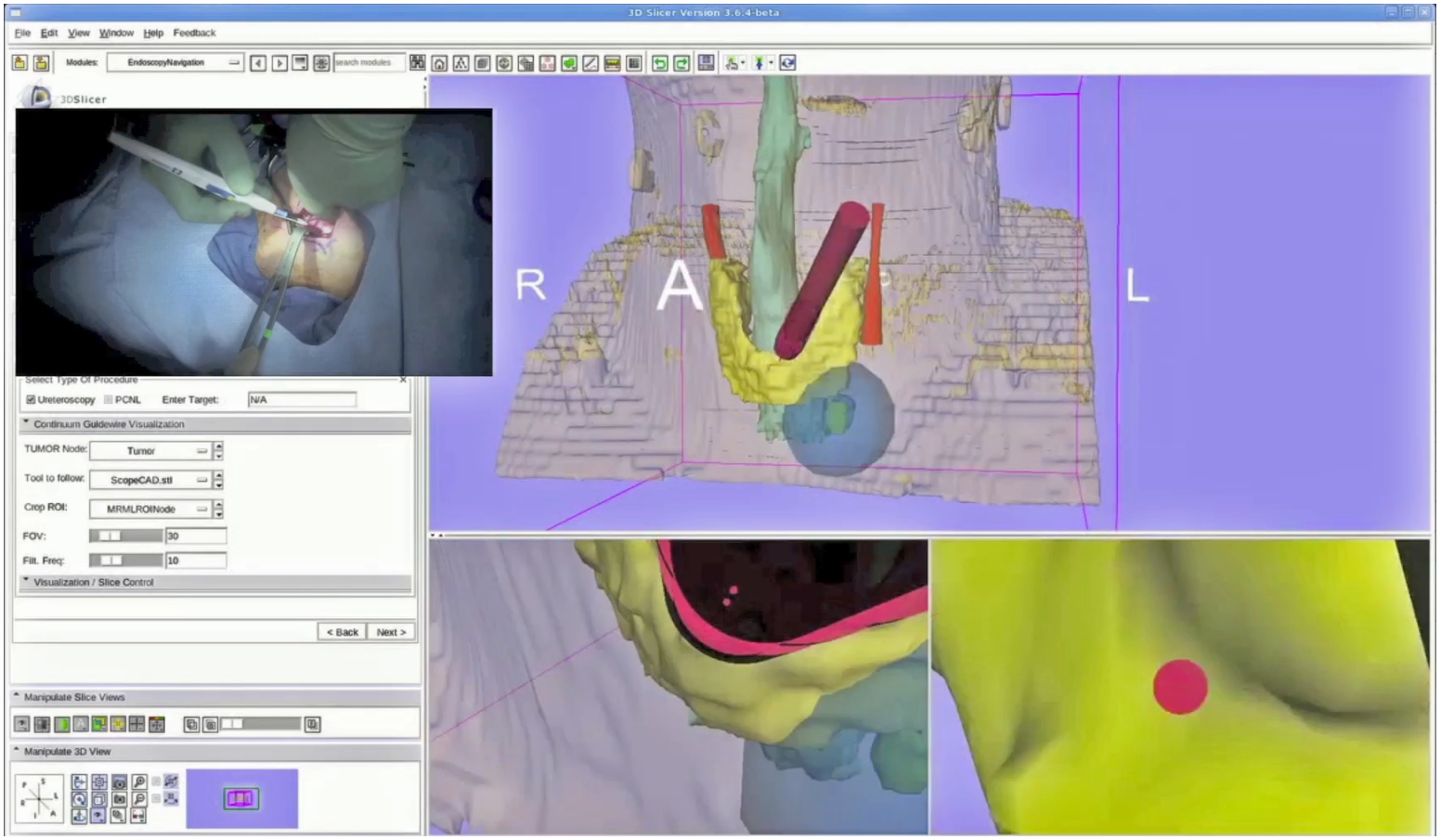
Creation of 3D models

- Relevant anatomical structures are rapidly segmented in 3D Slicer
- Segmentation done in parallel with imaging
- Fast vessel segmentation based on an interpolated cubic Hermitian polynomial
- Semi-automatic techniques to segment the tumor, skin, trachea, thyroid and parathyroid adenoma



Slide courtesy of Jayender Jagadeesan

Video



x 2 speed

Slide courtesy of Jayender Jagadeesan

Result of Navigation System

- Five patients completed to date
- Registration error = 3.1 mm

  (Rigid = 1.97mm)
- Minimum distance of the instrument to
  - Tumor = 0.31 mm
  - Trachea = 0.64 mm
  - Thyroid gland = 1.26 mm
- NASA TLX
  - Physical, Mental demand very low

J. Jayender, T.C. Lee, D.T. Ruan
"Real-time localization of parathyroid adenoma during parathyroidec
New England Journal of Medicine, 2015 (accepted)

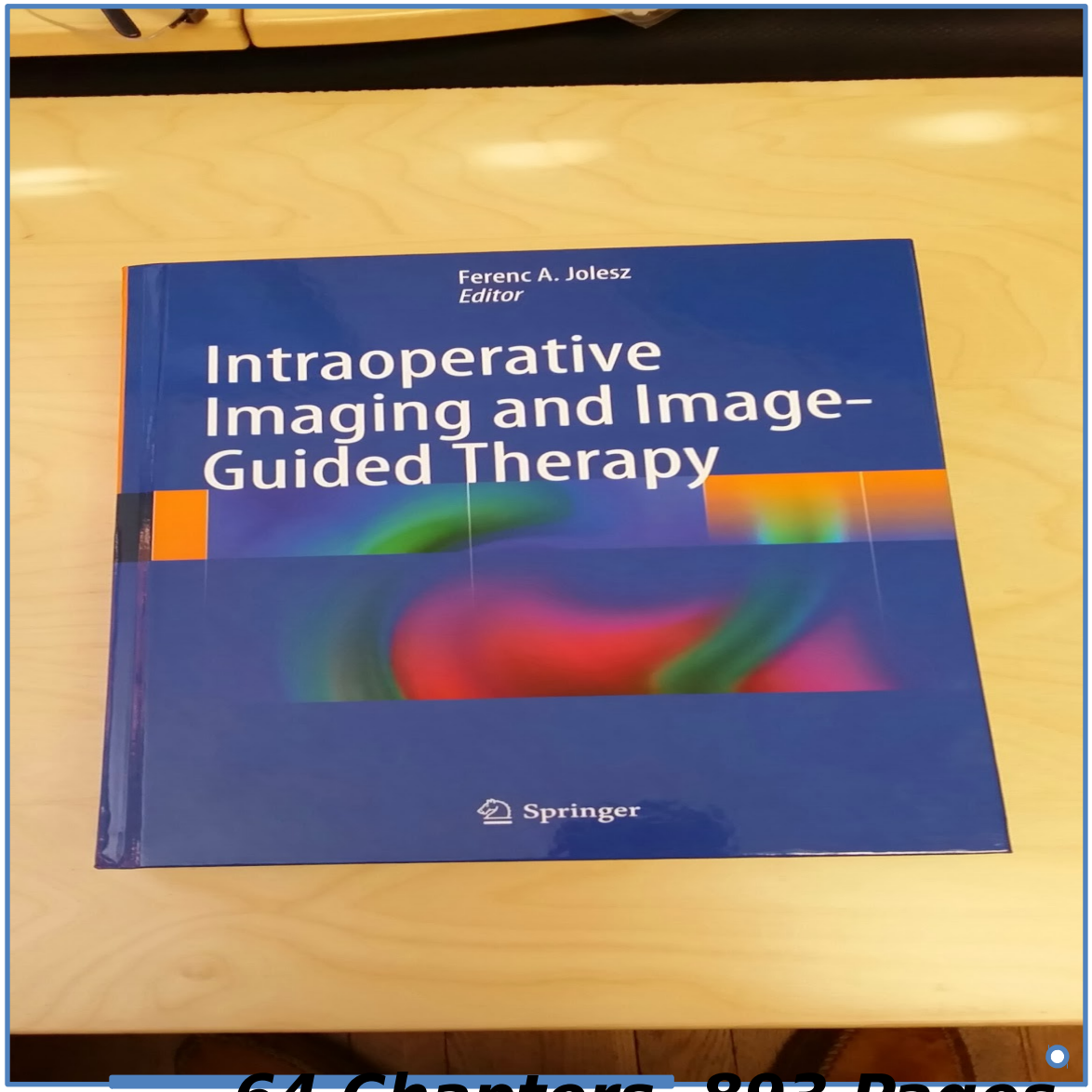
AMIGO Parathyroid Team

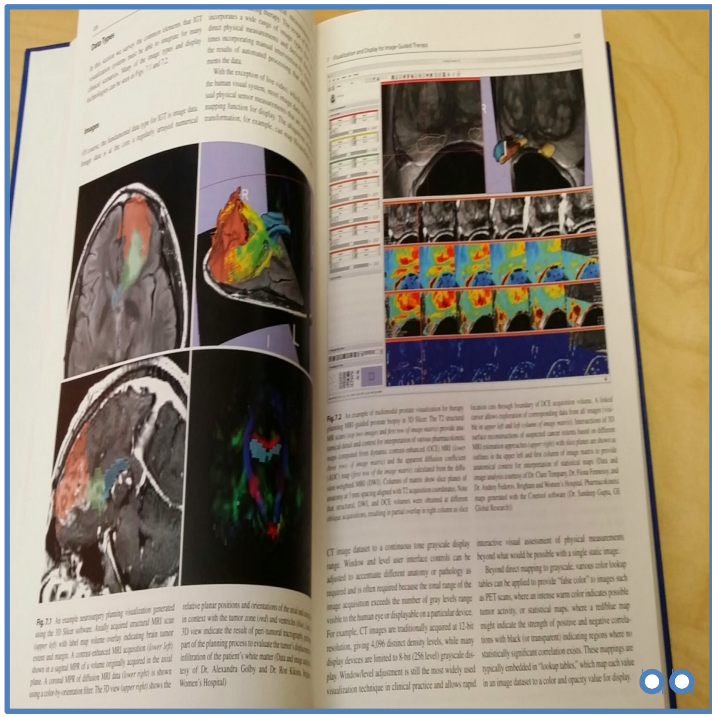
- Surgeon: Daniel Ruan, MD
- Radiologist: Thomas Lee, MD
- Navigation Scientist: Jayender Jagadeesan, PhD

AMIGO Support Team

- Techs/Nurses: Dan Kacher, Janice Fairhurst, Angela Kanan, Shivon Cesar, Sue Sheehan, Sandra Lawson, Julia Bousquet, Sean Jackson, Nikita Aristarkhov

Slide courtesy of Jayender Jagadeesan





64 Chapters, 893 Pages, 6 pounds!

May 21, 1946-Dec 31, 2014

Join 3D Slicer Community

- June 21-24, 2015: Summer Project Week in Barcelona
- January 4-8, 2016: Winter Project Week at MIT CSAIL

Acknowledgments

National Alliance for Medical Image Computing

www.na-mic.org

Neuroimage Analysis Center

Nac.spl.harvard.edu

National Center For Image Guided Therapy

www.ncigt.org

National Institute for Biomedical Imaging and Bioengineering

National Center for Research Resources

Brigham and Women’s Hospital

The End