Introduction – HMSIM: Healthcare and Medical Simulation

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How I got here…

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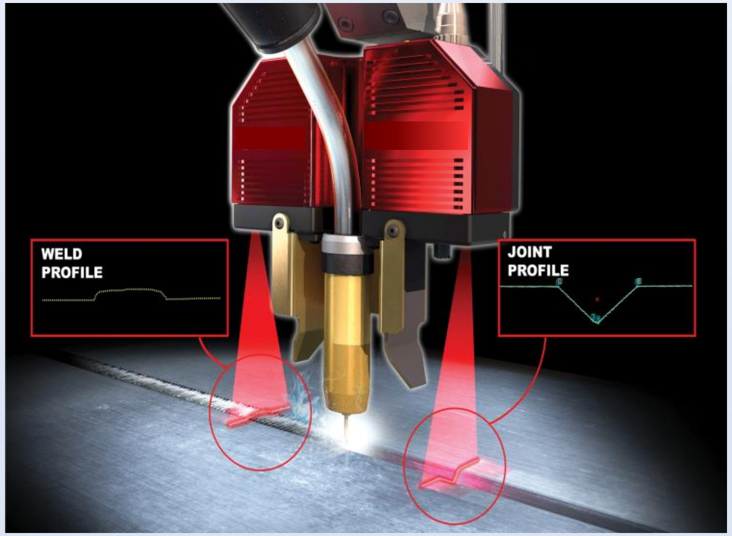
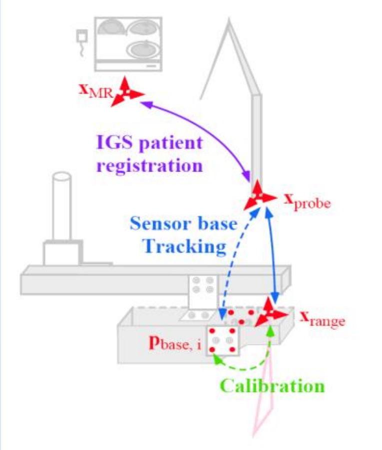
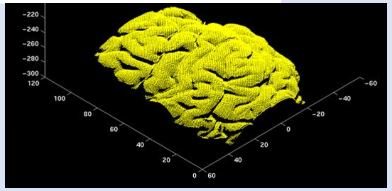
- B. Eng. EE (McGill) 1986; 1986-88 ***Flight Sim at CAE Electronics.***
  - Expertise: fooling avionics computers into thinking sim is real aircraft.
- M.Eng. EE (Ecole Polytechnique- comp. vision) 1992; ‘92-94: ***welding automation***.
- ***Ph.D. BME*** (McGill University); thesis brain shift estimation, 2001.
- Post-docs: Tsukuba, Japan 2001-05; Leipzig, Germany 2006-08; ***Kitware*** 2008-11.
- ***Assistant Prof. ODU CMSE*** ‘11-17, ***Associate Prof***. ‘17-now; ***GPD BME*** ’20







itk

vtk

imstk

Computer-Aided Medicine

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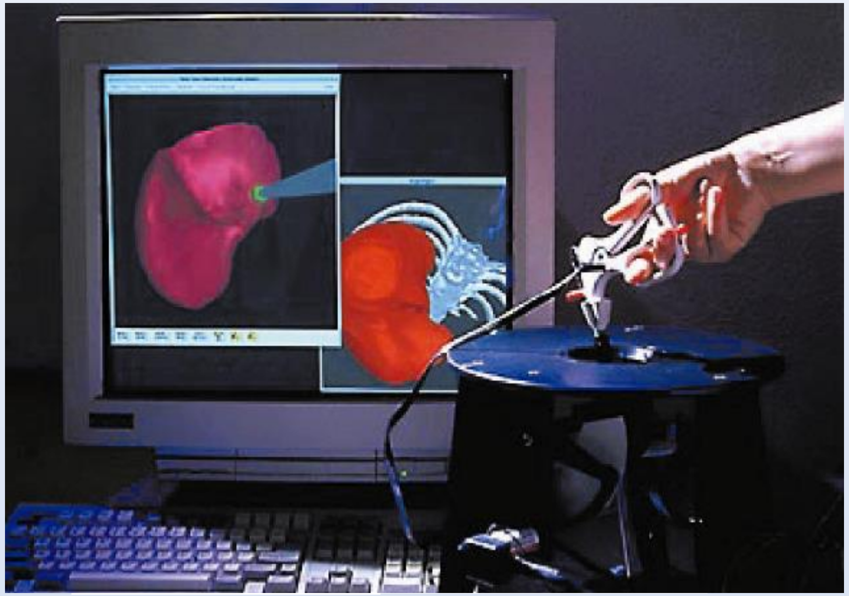
- **Medical simulation:** synthesize tissue response to surgery/therapy.
  - ***Predictive vs Interactive;*** patient, therapy (& collision) models.
- **Healthcare simulation:** large-scale processes: patient flow, epidemiology.
- **Surgical navigation –** orient surgeon w.r.t. ***patient anatomy in OR.***
- **Surgical robotics:** improve therapy accuracy, stability, workflow.



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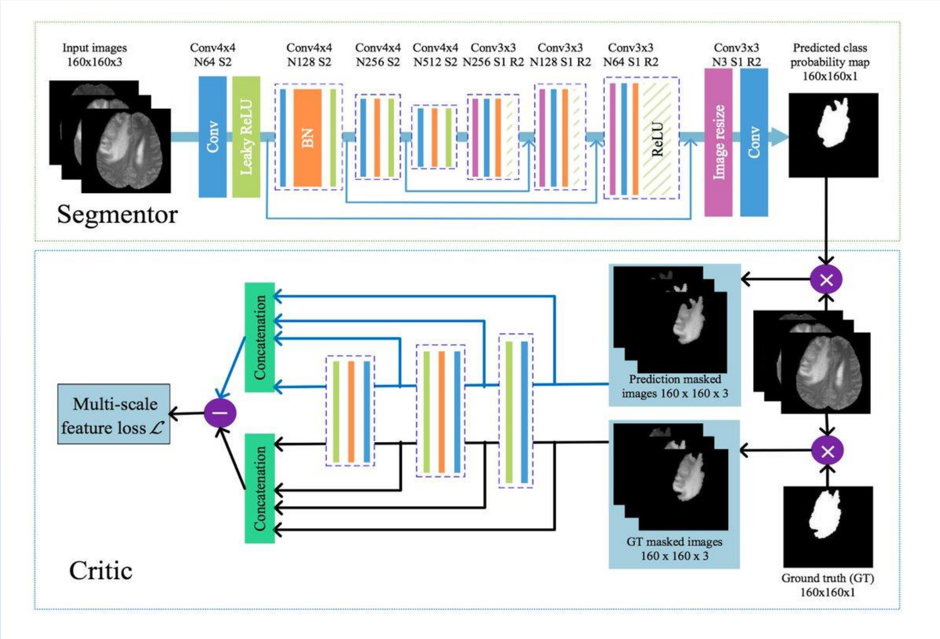
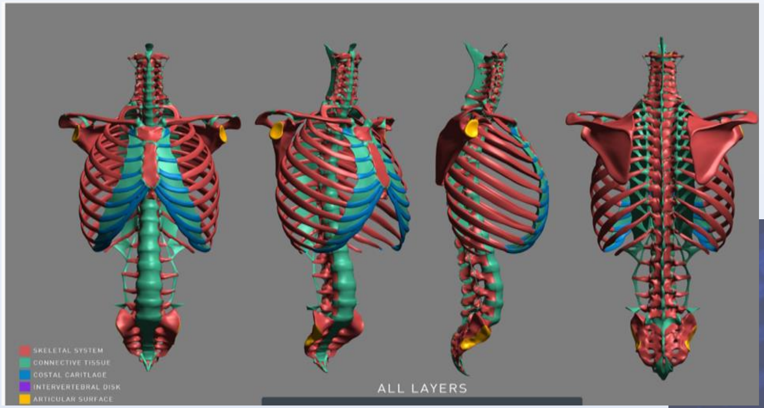
Anatomical Modeling Trends: Segmentation

- ***Patient-specific anatomical modeling.*** Revolution underway: mapping MRI CT US to tissues by ***Deep Neural Network-based segmentation & digital atlases.***
- DNNs ***identify*** visible tissues; digital atlases impose prior ***anatomical knowledge***.





Y. Xue, SegAN: Adversarial Network with Multi-scale L1 Loss for Medical Image Segmentation, www.arxiv-vanity.com/papers/1706.01805

A. Tapp, M. Audette et al, Generation of Patient-Specific, Ligamentoskeletal, Finite Element Meshes for Scoliosis Correction Planning, MICCAI CLIP Workshop, 2021.

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Anatomical Modeling Open-Source Tools

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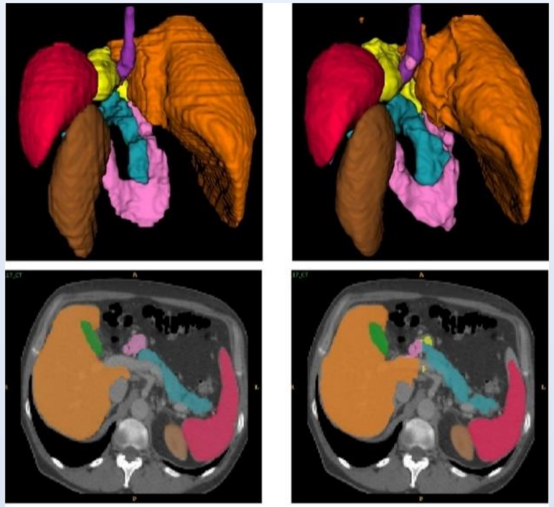
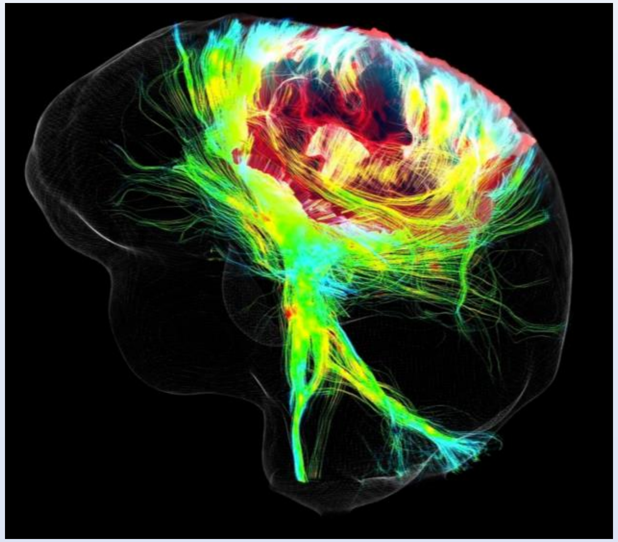
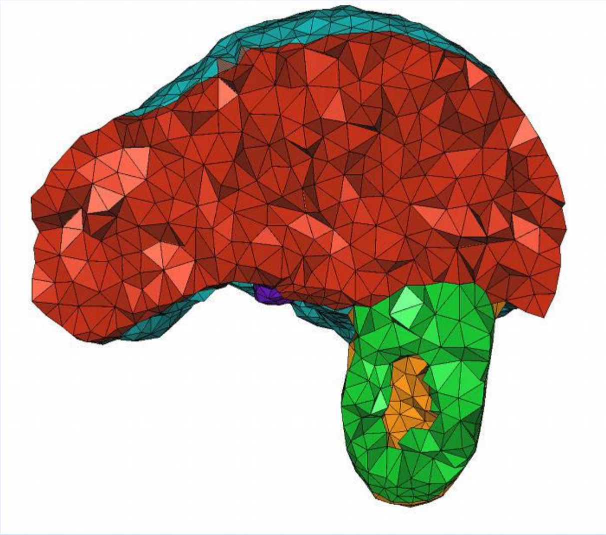
- Many professional-grade ***open-source software tools.***
- ***Deep Learning***: Tensorflow, DLTK, Caffe, NiftyNet, many more on GitHub.
- ***Medical image processing***: ITK, MITK, Slicer3D, FreeSurfer, DiPy, Elastix.
- ***Tet Meshing***: Computational Geometry Algorithms Library, Tetgen, BioMesh3D.



Reference standard NiftyNet segmentation





E.Gibson et al, NiftyNet: a deep-learning platform for medical imaging, Comp. Meth. & Prog in Biomed., 158: 113-122, 2018. www.tensorflow.org dltk.github.io caffe.berkeleyvision.org github.com/NifTK/NiftyNet github.io itk.org mitk.org slicer.org surfer.nmr.mgh.harvard.edu dipy.org scil.dinf.usherbrooke.ca elastix.org cgal.org wias-berlin.de/software/tetgen www.sci.utah.edu/software/scirun/biomesh3d.html

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Therapy & Function Simulation: Open-Source Tools

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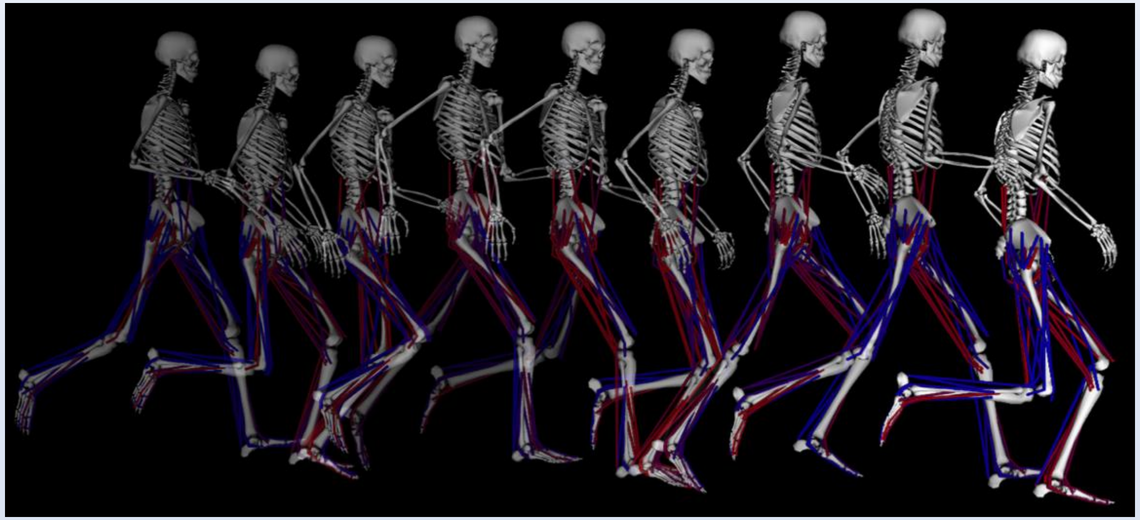
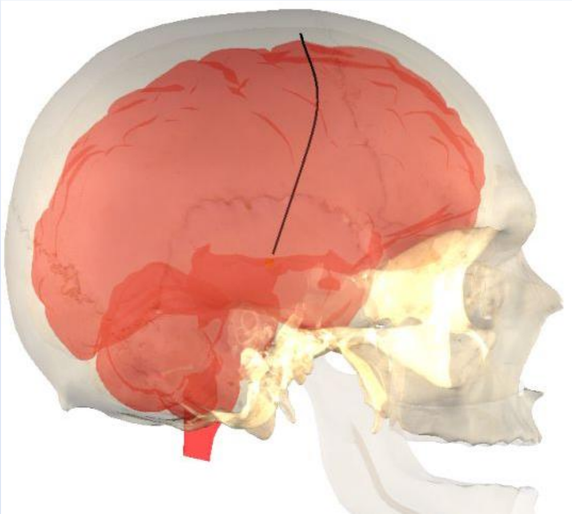
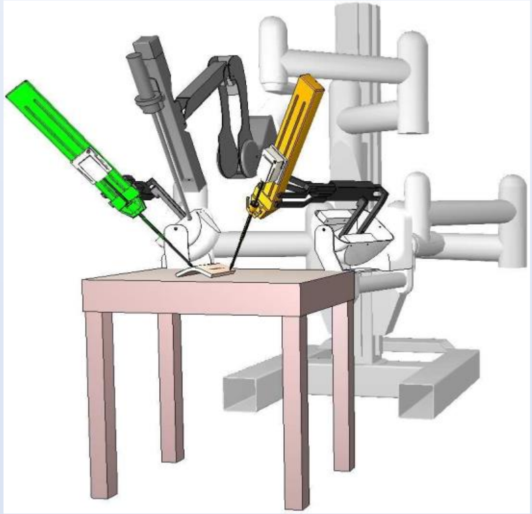
- Many ***open-software software tools*** for simulating ***tissue response.***
- ***Interactive sim: tissue & musculoskeletal mechanics***: SOFA, IMSTK, OpenSim.
- ***High-fidelity tissue response***: FEBio, OpenFoam (CFD/FSI), Virtual Brain.
- ***Image-guided therapy & robotics***: Slicer3D/SlicerIGT, PLUS, MITK.
- ***Robotics, device sim & development***: OpenRave, dVRK, Raven II (open robot).







www.sofa-framework.org imstk.org simtk.org/projects/opensim febio.org openfoam.org www.thevirtualbrain.org slicer.org github.com/SlicerIGT plustoolkit.github.io mitk.org openrave.org github.com/jhu-dvrk rll.berkeley.edu/raven/

Convergence with DNNs

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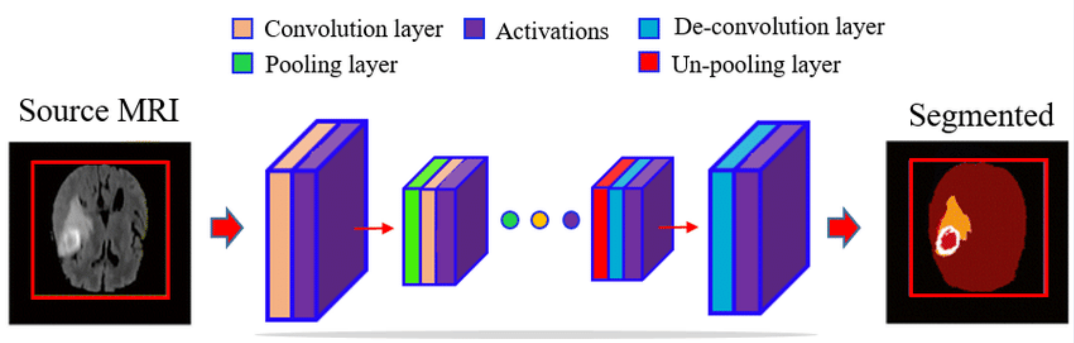
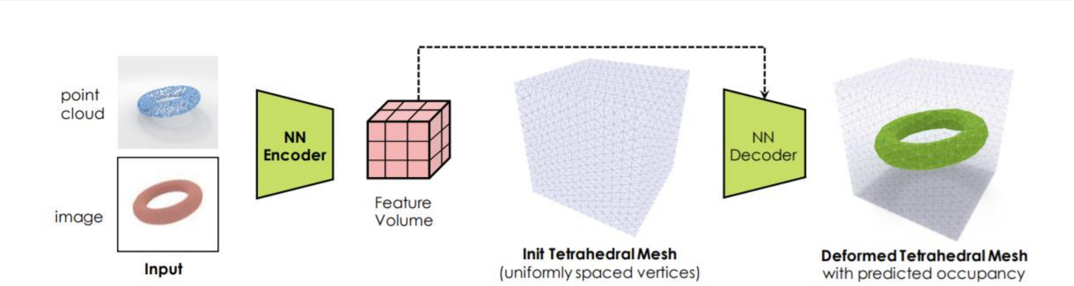
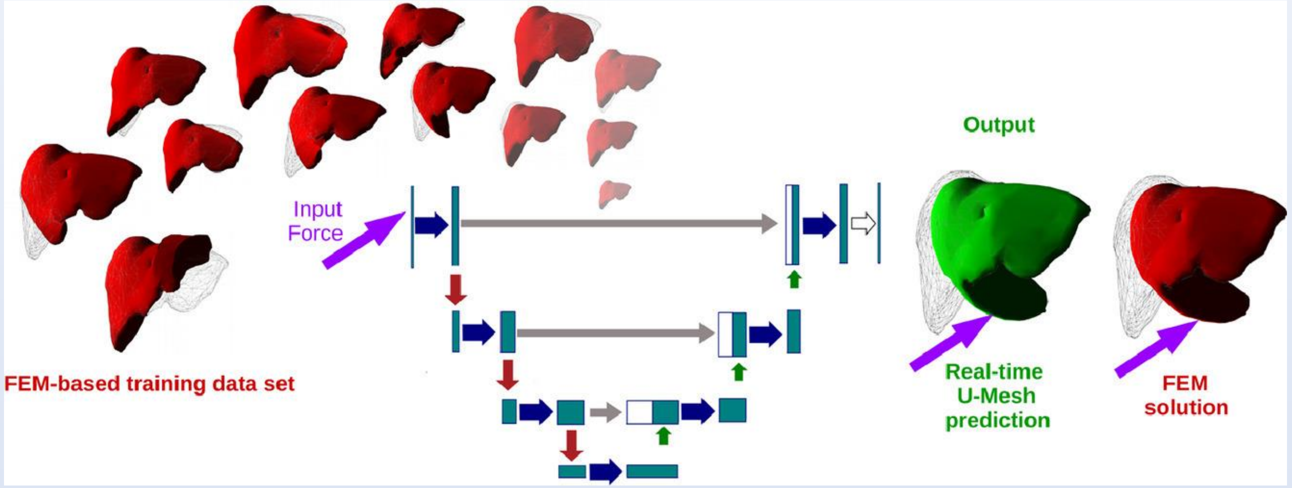
- DNNs used for both anatomy and therapy modeling.
- Anatomy modeling: Segmentation literature; for surveys see Suganyadevi ‘21 and Lei 20’.
  Meshing – New Tet mesh research emerging, e.g. DefTet- Gao ‘20
- Therapy modeling: PhyNNeSS - De ’11, U-Mesh Mendizabal ’20 – 1 sec FE solved in 4 ms.



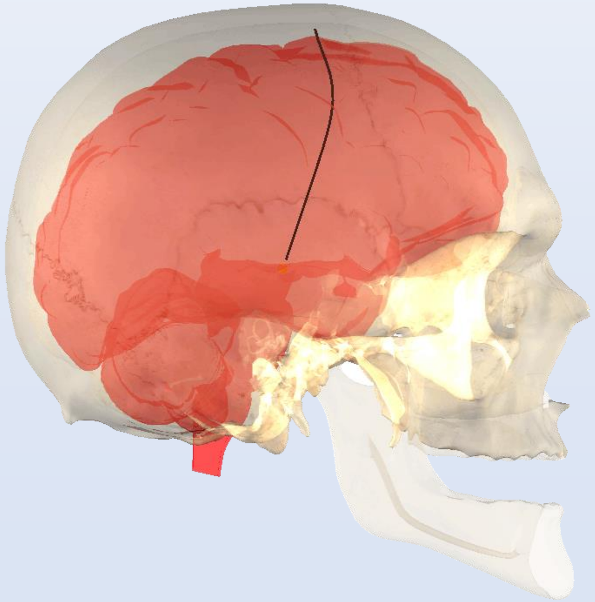


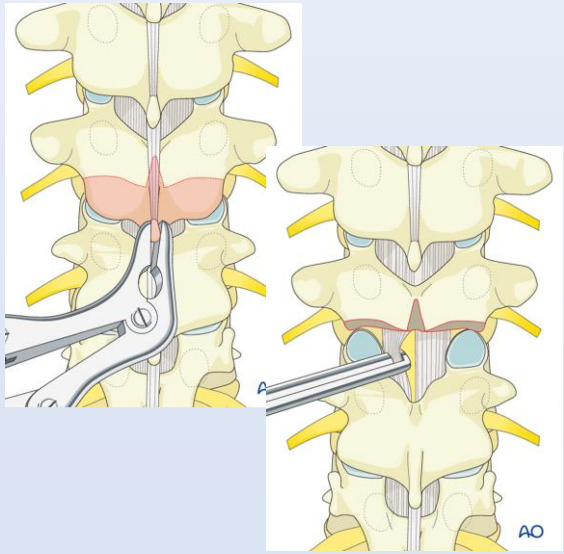


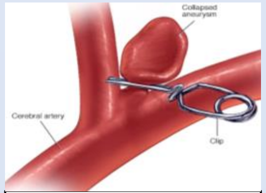
Suganyadevi, S. et al. “A review on deep learning in medical image analysis.” Int J Multimed Info Retr (2021).
Lei, Tao et al. “Medical Image Segmentation Using Deep Learning: A Survey.” ArXiv abs/2009.13120 (2020)
Gao J., et al., “Learning Deformable Tetrahedral Meshes for 3D Reconstruction, NeurIPS 2020
Mendizabal A, et al Simulation of hyperelastic materials in real-time using deep learning. Med Image Anal. 2020 Jan;59:101569.

Convergence with Computer-Assisted Medicine

- Feasible to represent both a medical device/surgical robot & a patient, via ***coupled device-anatomy interactive simulation***, potentiated by DNNs & GPUs.
  - ***Patient tissue*** simulation is typically the most onerous component.
- ***Predictive simulation*** can be integrated in ***surgical planning/navigation***.
- Requirements via ***medical ontologies;*** workflows for ***emerging therapies.***







Medical device

Positioning

Skin Incision

Interfascial Dissection

Craniotomy

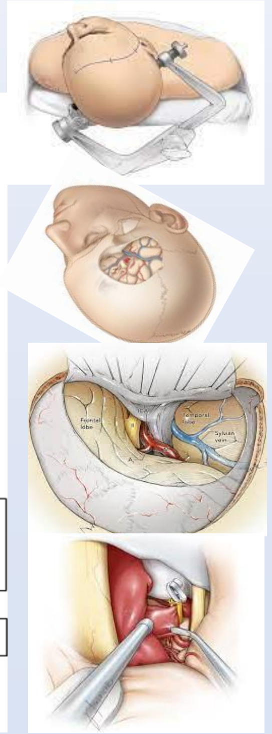
Drilling of Sphenoid Wing

Dural Opening

Opening of Sylvian Fissure And/or Basal Cisterns

Therapy/resection

Closing



Transition to Descriptive Simulation

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- Now is a ***transitional period*** in medical and healthcare simulation.
  - More open-source tools, DNN research, cheap fast h/w than ever.
- High-fidelity ***therapy models*** and ***patient-specific anatomies*** now feasible.
- Emergence of ***multi-scale modeling***; coupled ***intervention & physiology*** simulation.
- Recruitment of ***coupled medical simulation with device & patient*** also emerging.
  - Ramifications for ***device certification*** and prevention of ***adverse events.***