MAYO CLINIC

3D Technologies: Structural Dimensioning, Segmentation, CNC Fabrication

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 |

Question 1

- Today medical 3D printing is used for …
  - A) Pre-surgical educational anatomic models
  - B) “Metal” printing surgical guides
  - C) Implantable organs
  - D) A, B, and C
  - E) Only A and B

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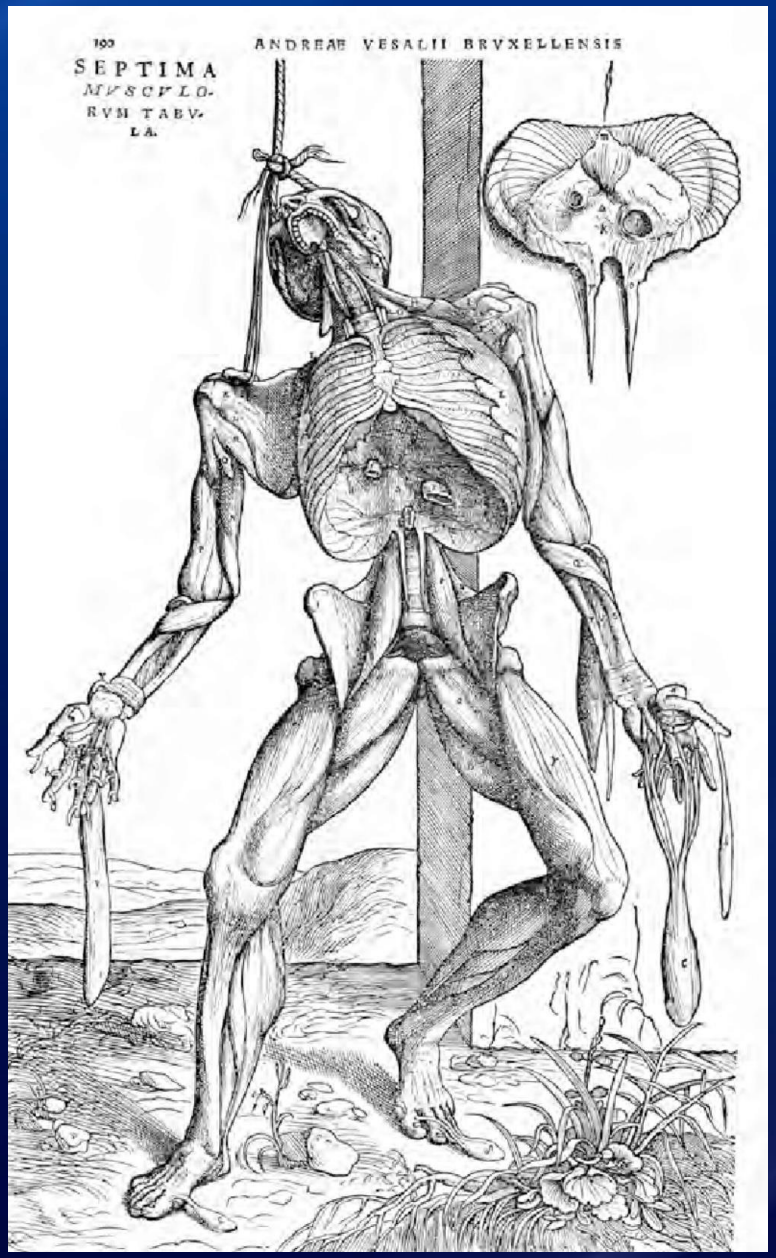
100
SEPTIMA
MVSCVLO-
RVM TABV-
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ANDREAE VESALII BRVXELLENSIS

naturhistorisches museum Basel

archive des lebens

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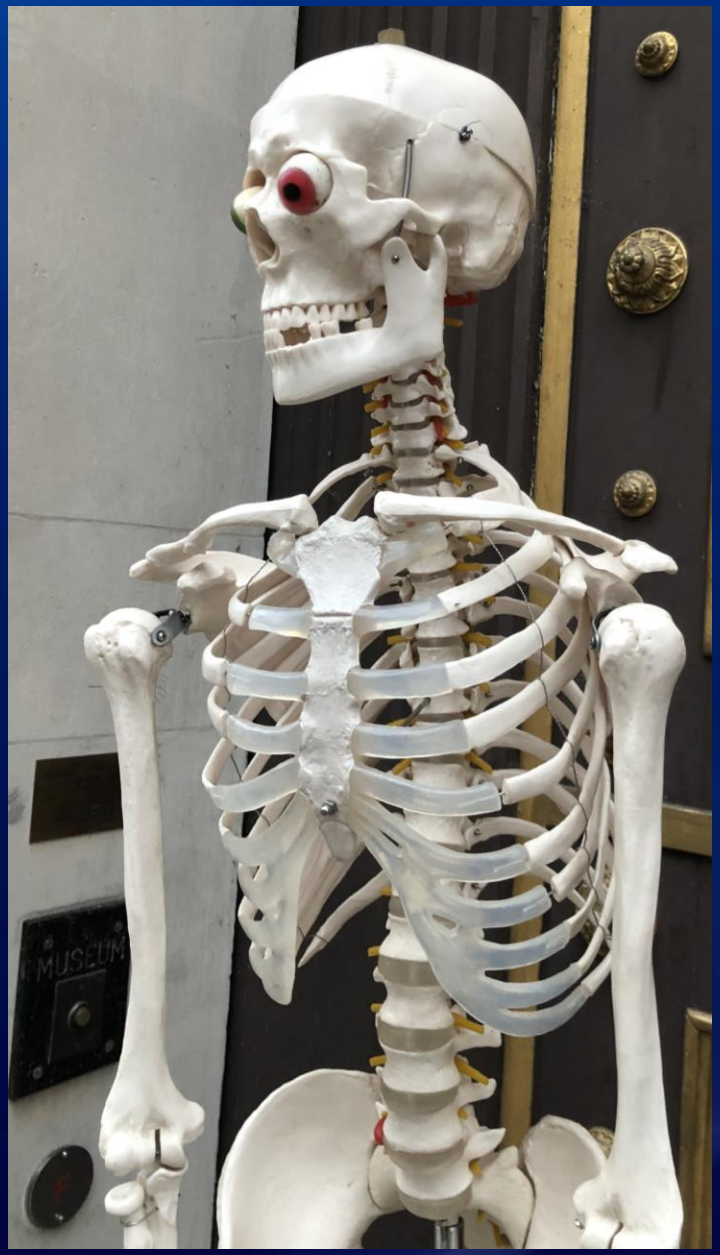
Museums-Pässe
bitte an der Kasse
vorweisen!
Veuillez présenter
votre Pass-Musées
à la caisse!



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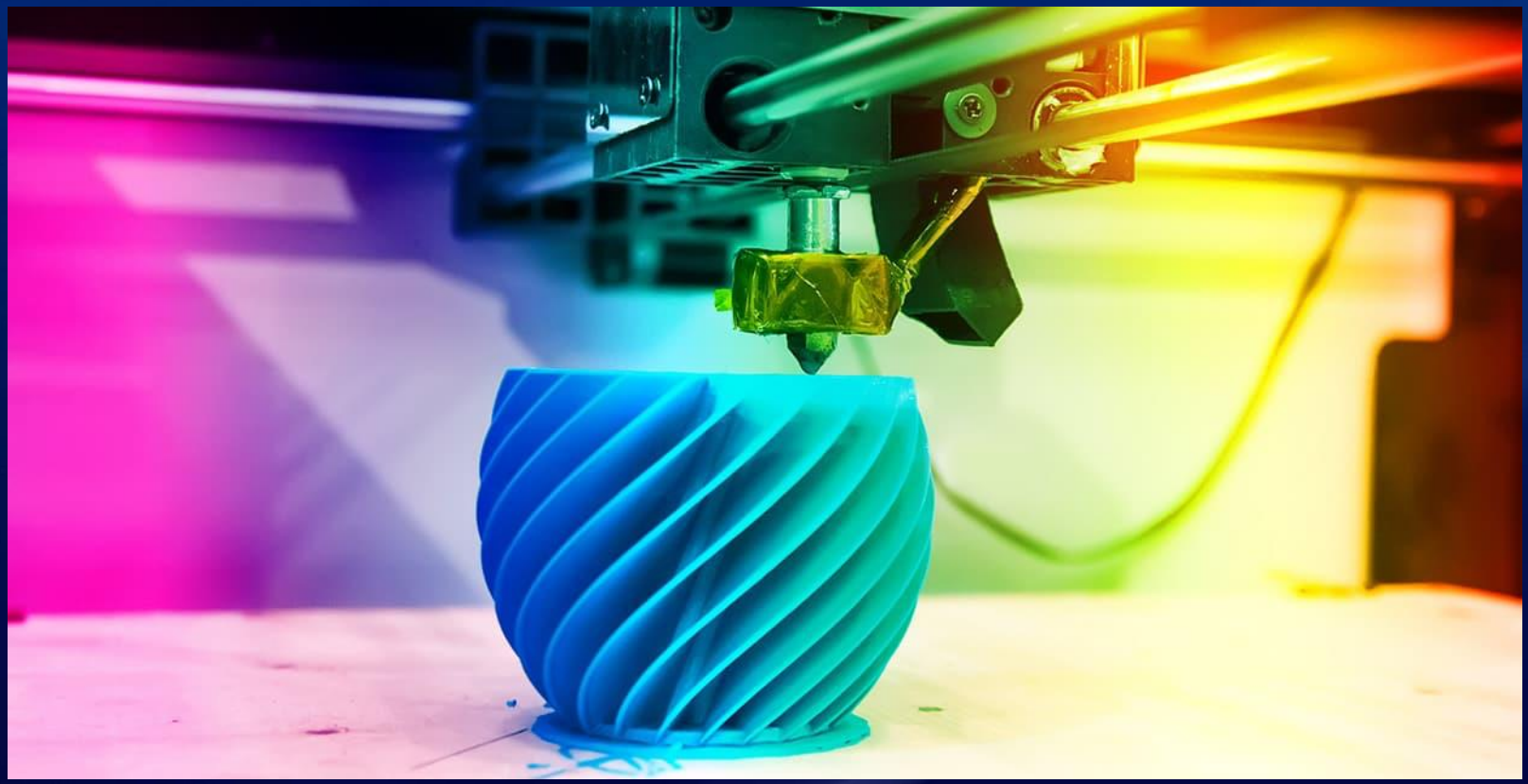
3D Printing Technology (Digital Additive Manufacturing)

Rapid prototyping – Uses computer assisted design (CAD)

Assemble successive layers of extremely thin material in additive fashion to create solid three dimensional products



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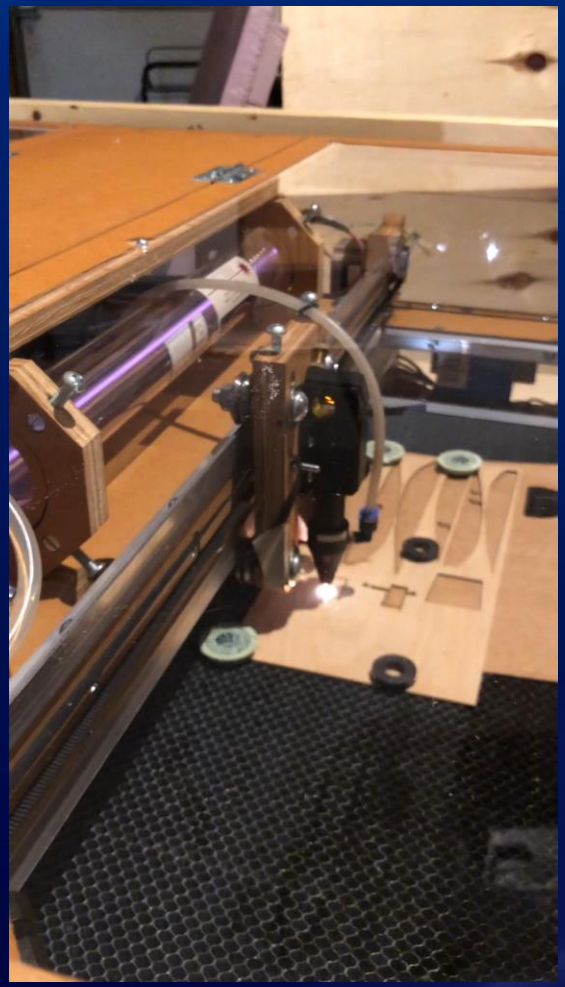
3D Milling or Laser Technology (Digital Subtractive Manufacturing)

Removes material to create solid two and three dimensional products



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3D MODEL or 3D MOLD

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3D Technologies-Goals

- Improves spatial awareness for procedural planning
- Anatomic correct (dimensional and segmented) models for education and simulation
- Tissue and device engineering.

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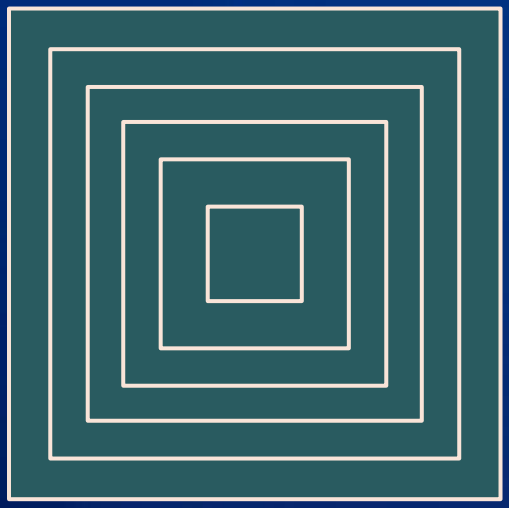
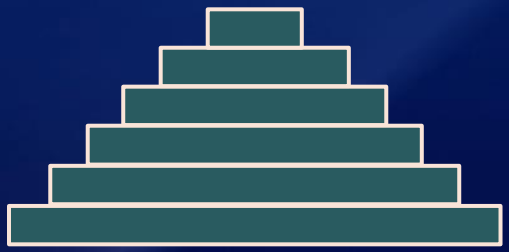
3D Printing: Basic Concept Layered Construction





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Analog versus Digital

- Continuous variable (voltage, position, power)

Versus 1 0 1 1 0 1 1 0 0 0 1 1

12-bit

- Digital variable (voltage, position, power)

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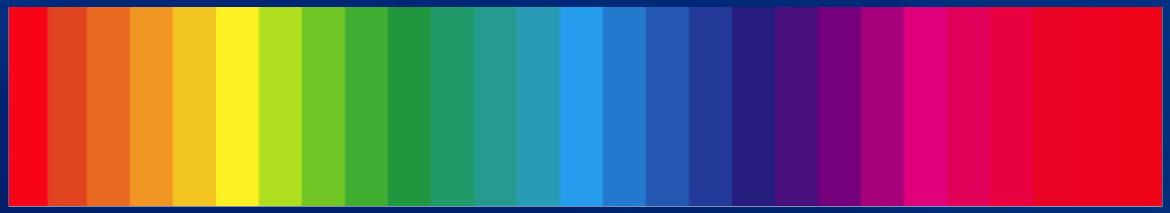
Digital Constraint

$n^8 = 256$



8-bit

$N^{10} = 1,024$

10-bit

$n^{12} = 4,096$

$n^{16} = 65,536$

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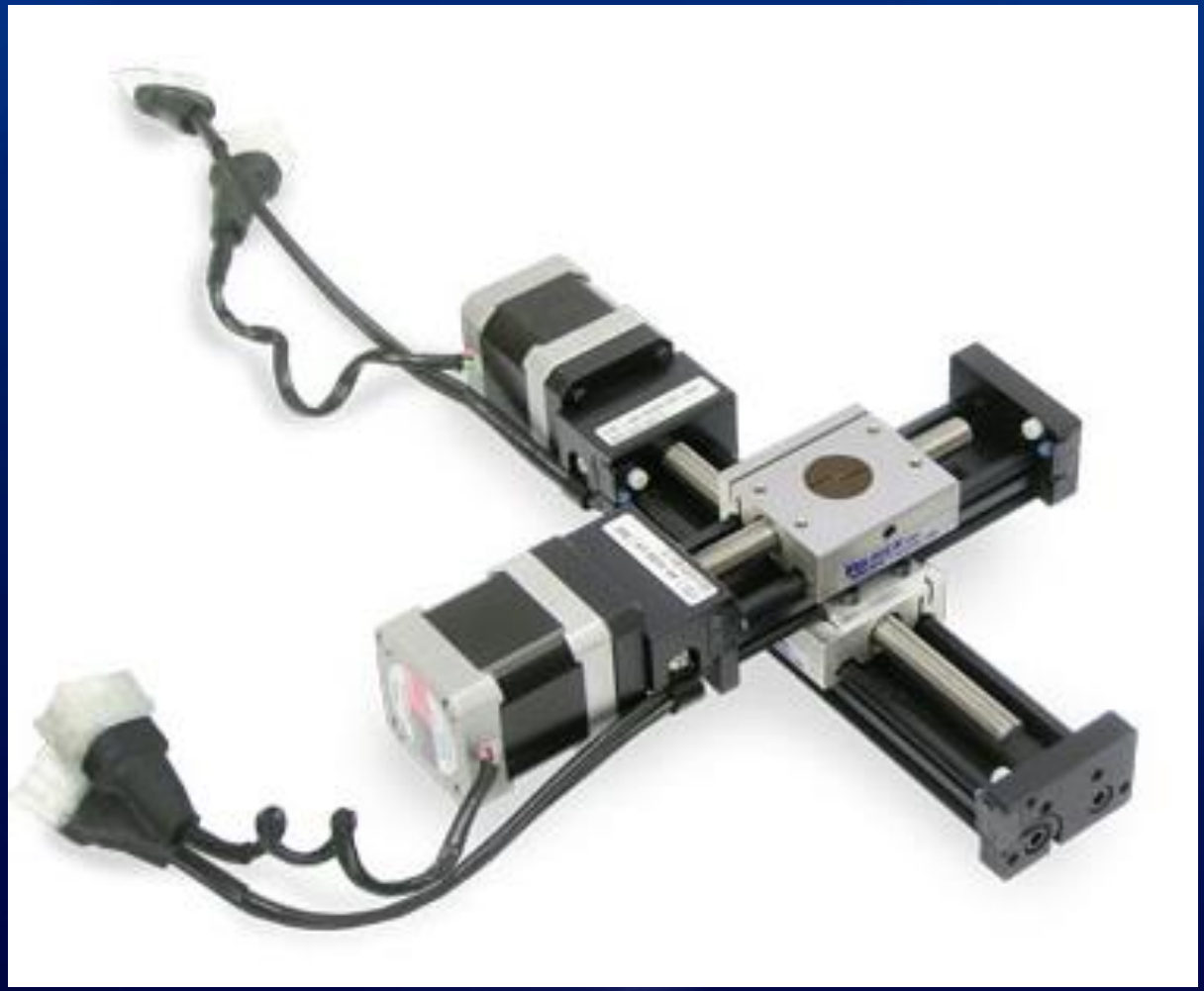
Digital Constraint: Stepper Motors

$n^8 = 256$

$N^{10} = 1{,}024$

$n^{12} = 4{,}096$

$n^{16} = 65{,}536$



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HOW DID IT START AT MAYO?

MAYO
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Broad Clinical Utilization

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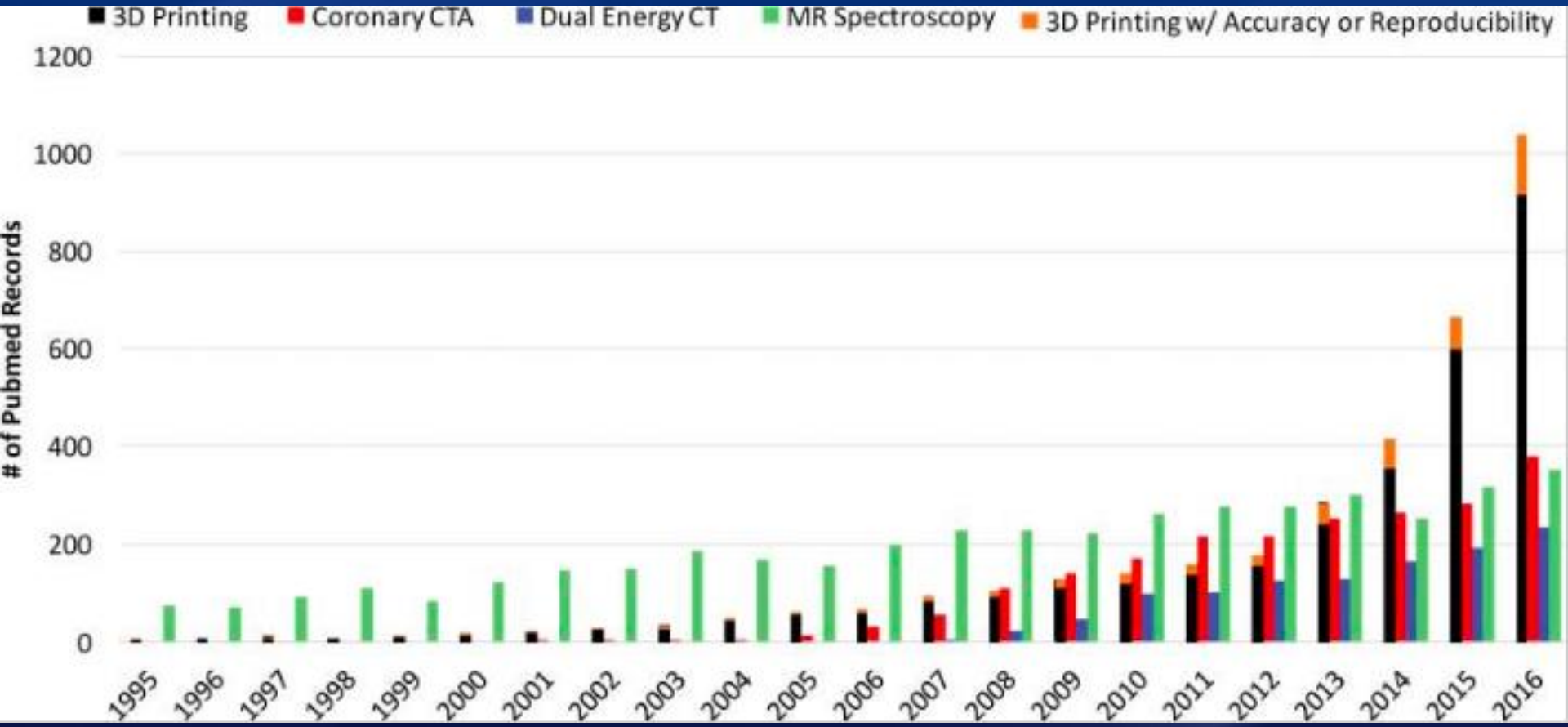
Number of Publications cited in PubMed



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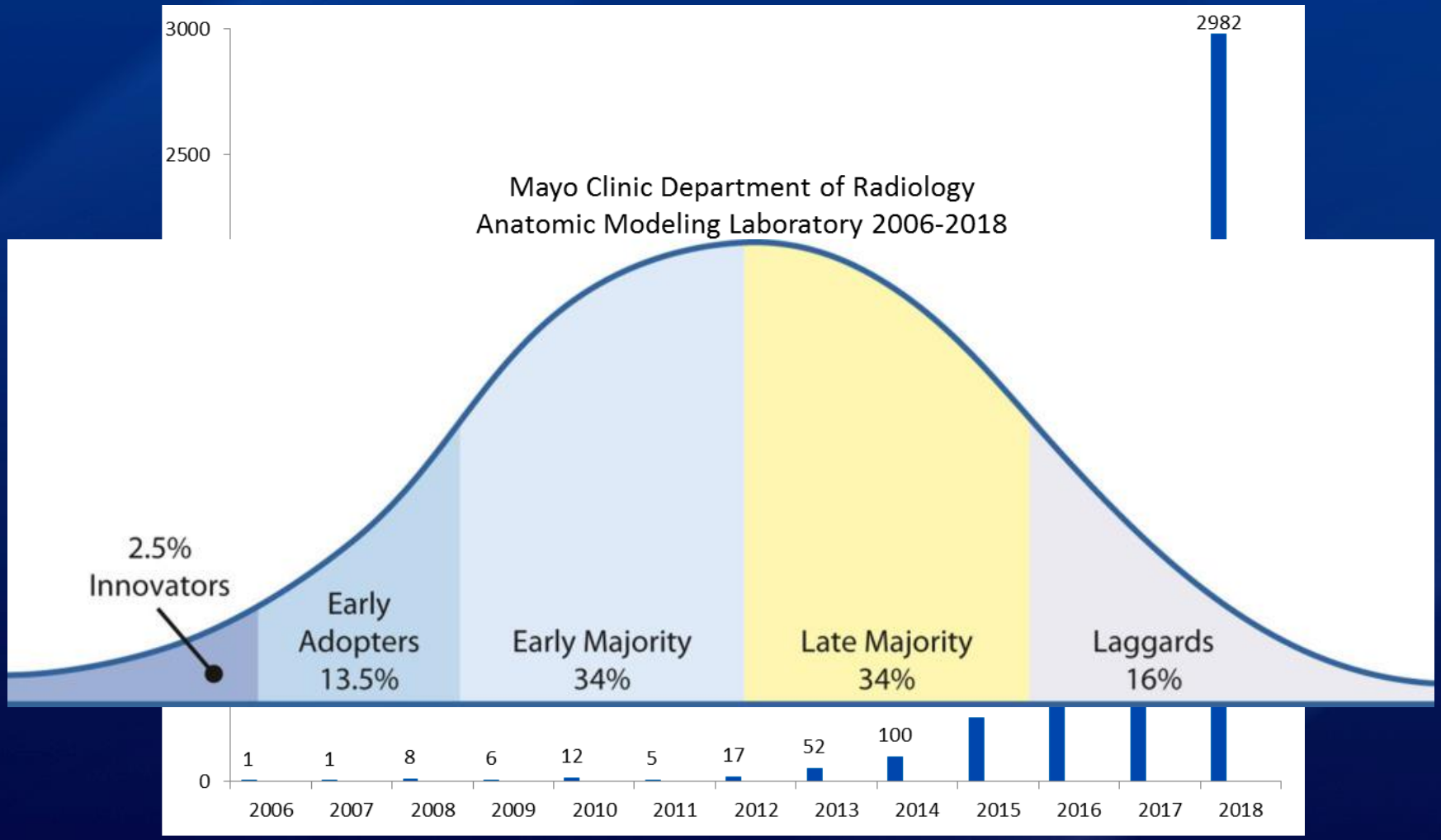
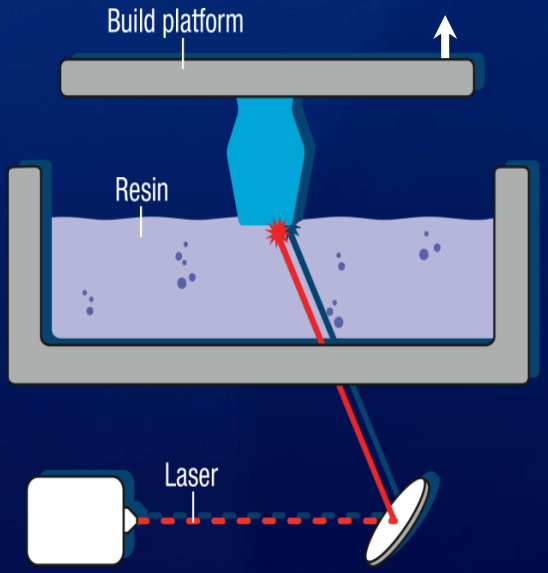
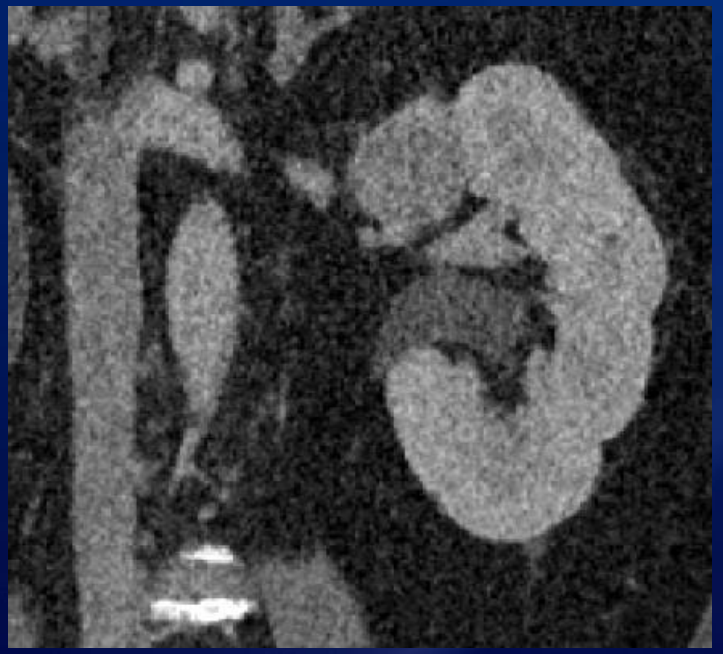


Advancing computer technology fostered the convergence of

- 3D Printing Technology
- High Resolution Imaging Acquisition



STEROLITHOGRAPHY (SLA)



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Why do 3D models help?
Can't you just look at the images

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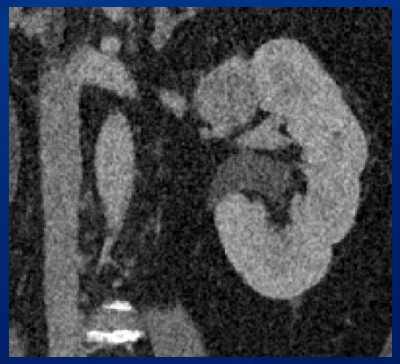
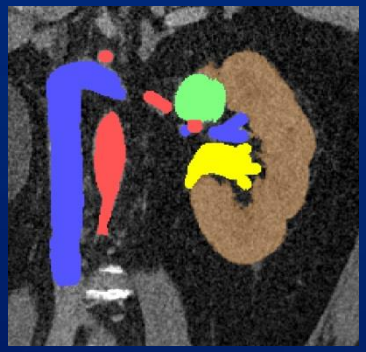
3D Printing Workflow
Methods

1



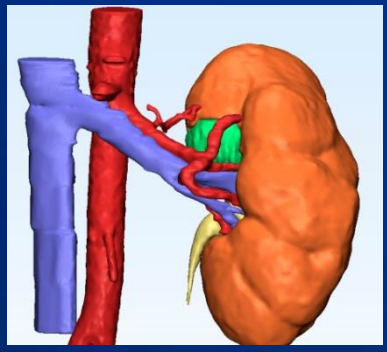
CT data acquisition

2



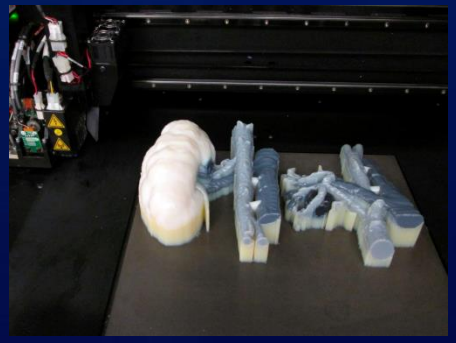
Segmentation

3



Conversion to STL file

4



3D printing of STL file

5

Post processing cleaning

6

Consult with Surgeon

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3D Technologies-Dimensioning

- Accurately measuring and fabricating parts to original specification.

- N.B. Inaccuracies due to errors occur during imaging, segmentation, postprocessing, and 3D printing steps.

3D Technologies-Dimensioning Data Source (INTERNAL ANATOMY)

- Cross-sectional imaging
  - Uses DICOM® Standard (Digital Imaging and Communications in Medicine)
    - CT/MRI
      - Three dimensional data using grayscale standard display function
      - Translates pixel density in Hounsfield units into 12 or higher data bits (0-4,095)

Hounsfield Units

Attenuation coefficients ($\mu_{material}$) is transformed to $Hu_{material}$ expressed relative to linear attenuation coefficient of water.

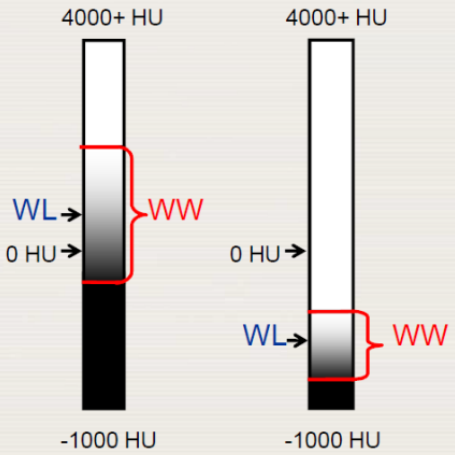
$$HU_{material} = \frac{\mu_{material} - \mu_{water}}{\mu_{water}} \times 1000$$

- It can be seen that
  - $HU_{water} = 0$ as ($\mu_{material} = \mu_{water}$),
  - $HU_{air} = -1000$ as ($\mu_{material} = 0$)
  - HU=1 is associated with 0.1% of the linear attenuation coefficient of water.

Hounsfield Units

Substance	Hounsfield unit (HU)
Compact bone	+1000 (+300 to +2500)
Liver	+ 60 (+50 to +70)
Blood	+ 55 (+50 to +60)
Kidneys	+ 30 (+20 to +40)
Muscle	+ 25 (+10 to +40)
Brain, grey matter	+ 35 (+30 to +40)
Brain, white matter	+ 25 (+20 to +30)
Water	0
Fat	- 90 (-100 to -80)
Lung	- 750 (-950 to -600)
Air	- 1000

- Hounsfield units are usually visualized in an eight bit grey scale offering only 128 grey values.
- The display is defined using
  - Window level (WL) as CT number of mid-grey
  - Window width (WW) as the number of HU from black -> white



12 bit = 0-4,095
14 bit = 0-16,383

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Hounsfield Units

Table 9-2. Common CT Window Settings

Window	Center	Width
Lung	–498 HU	+1465 HU
Bone	+570 HU	+3077 HU
Soft-tissue	+56 HU	+342 HU
Brain	+40 HU	+200 HU

HU, Hounsfield unit.

The center value is the Hounsfield density to which the central gray shade is assigned. The center value minus half the width is assigned black. The center value plus half of the width is assigned white. No standards have been established for CT window settings, so the exact values used by different institutions may vary.

Center + ½ (width) = black
Center – ½ (width) = white

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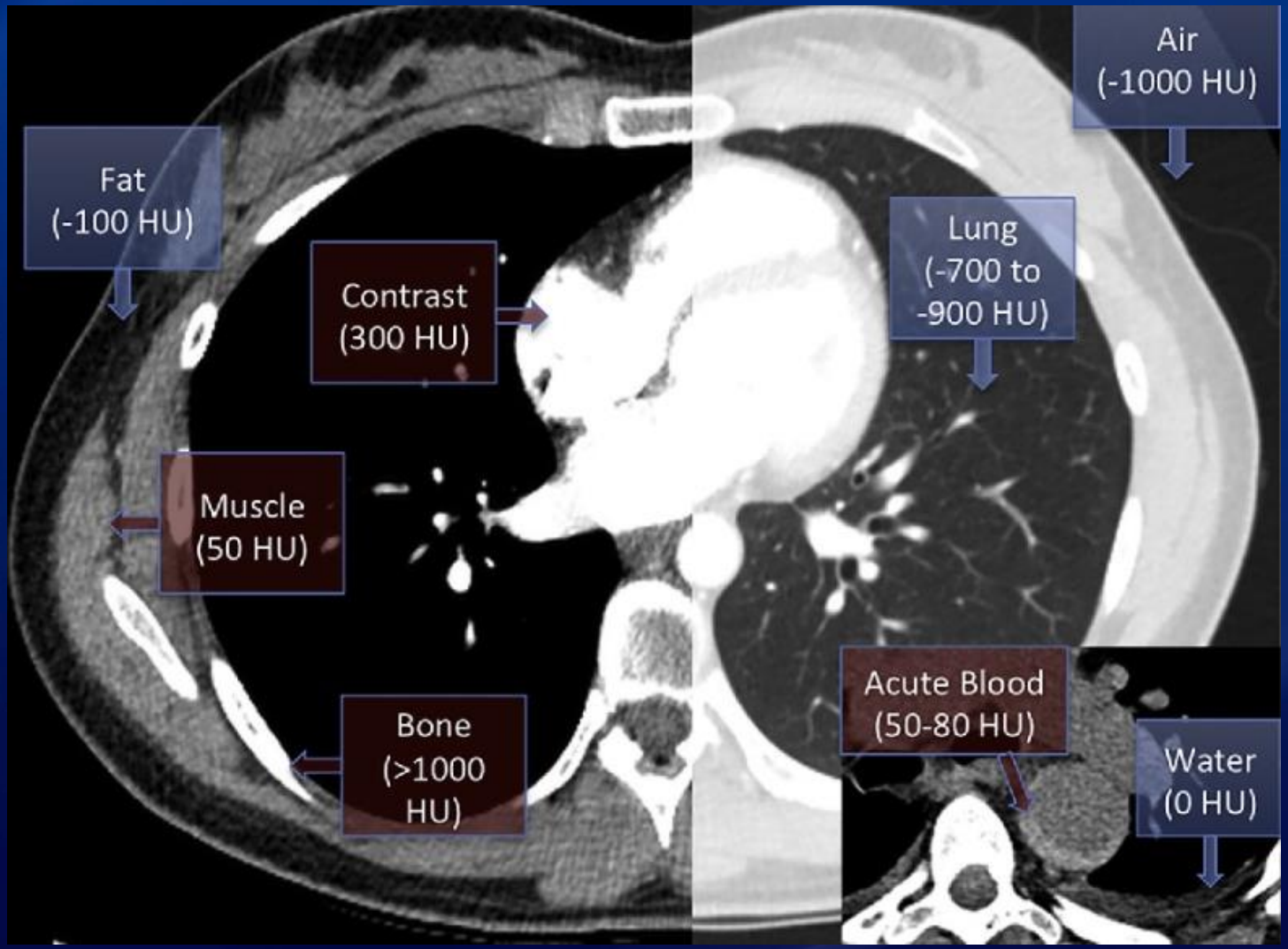
Hounsfield Units



3D Technologies-Segmentation

- Separating anatomical elements based upon differences in image density.

Introduction to 3D Printing Process

Step 1: Raw Data Import

- Patient data uploaded into Mimics
  - Most common: CT, MRI

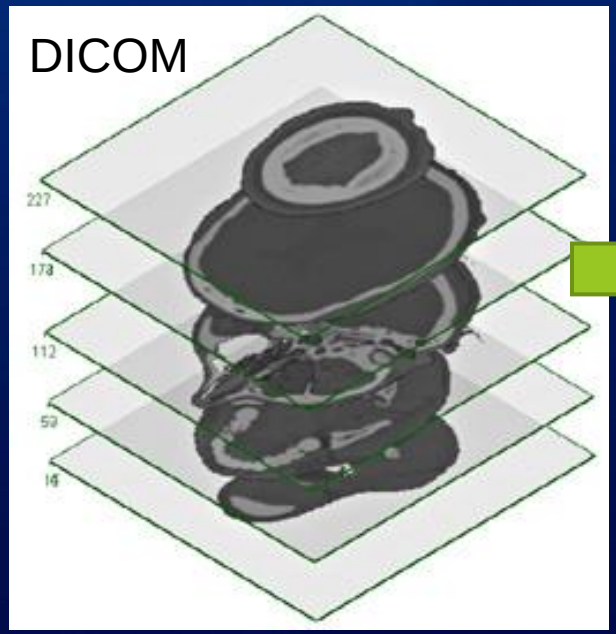
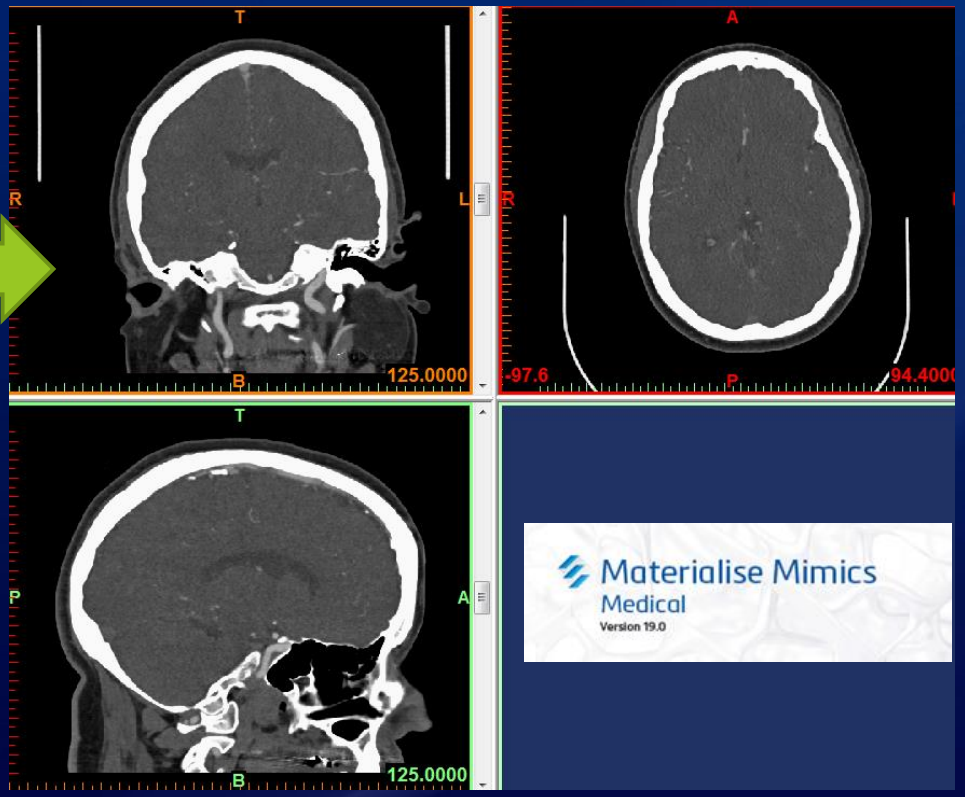


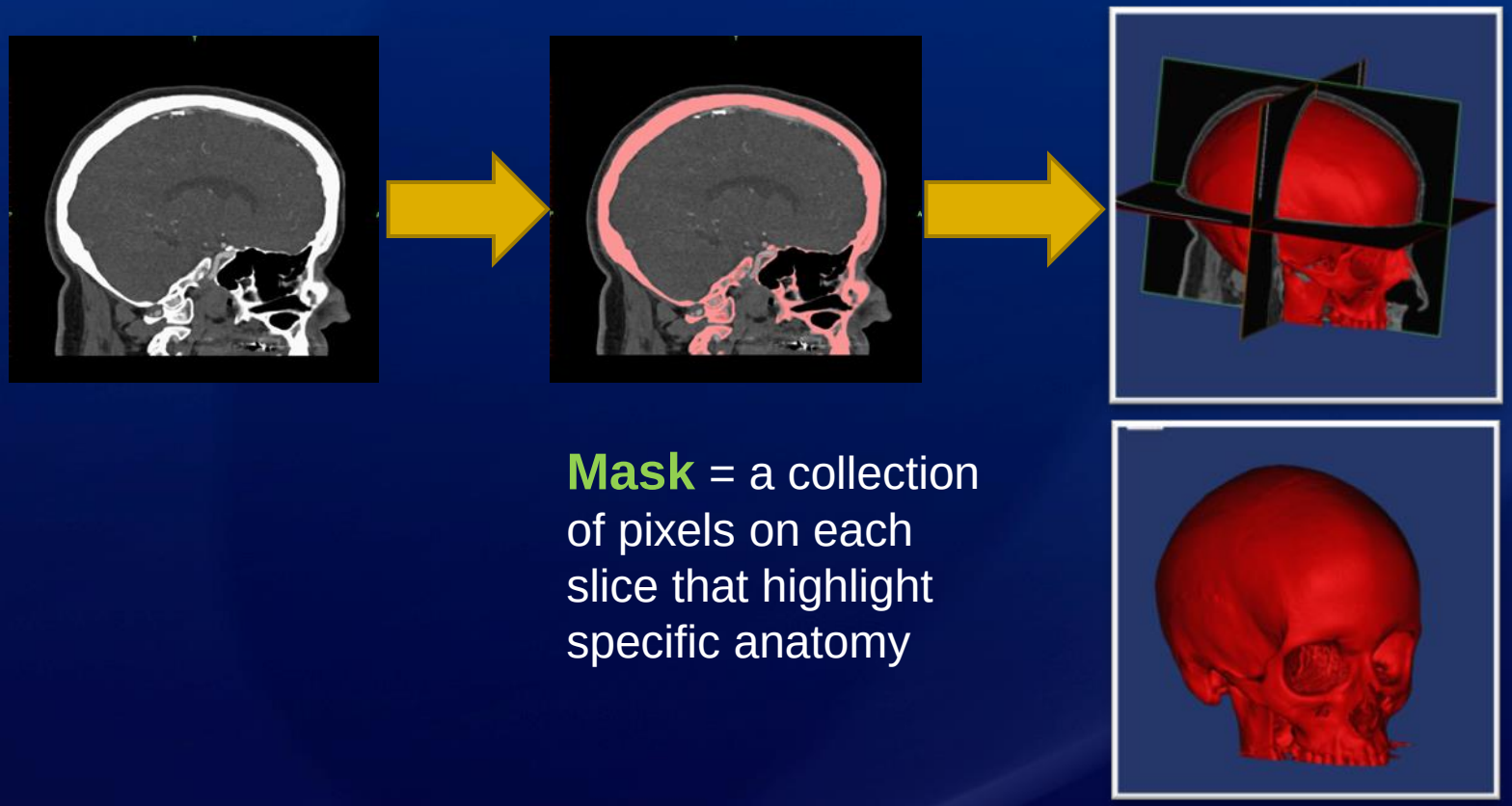
Photo credit: http://www.barre.nom.fr/medical/these/pictures.html



Introduction to 3D Printing Process

Step 2: Segmentation in Mimics

Raw Data **Creating a Mask** **3D Rendering**

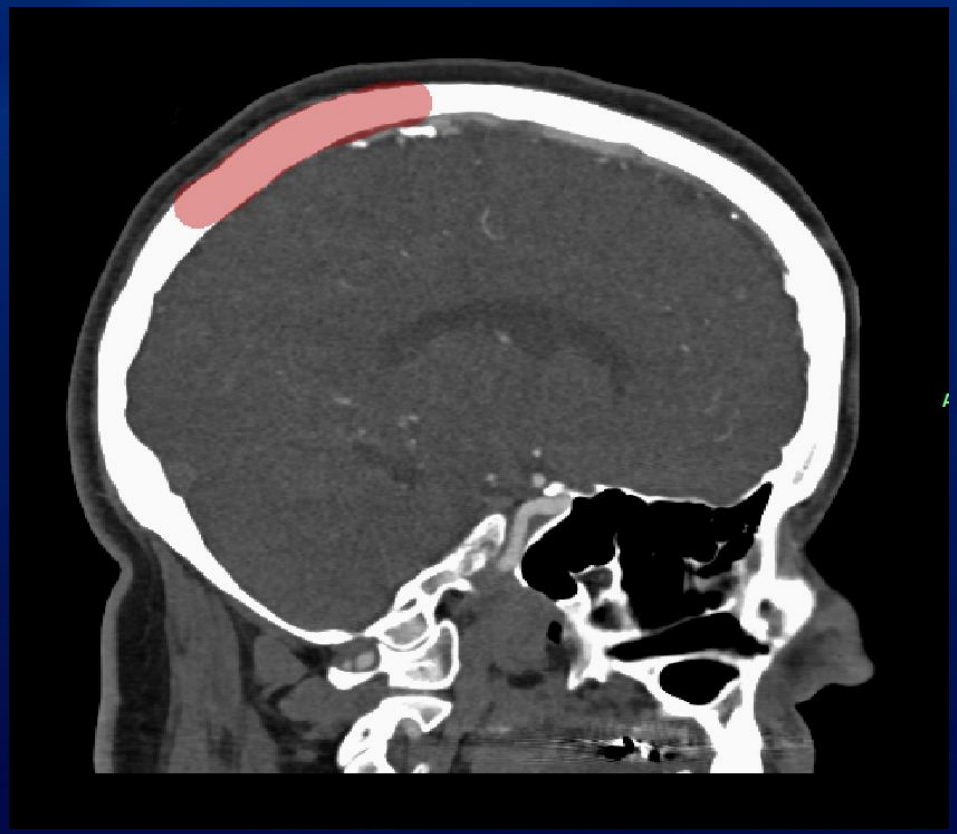


Mask = a collection of pixels on each slice that highlight specific anatomy

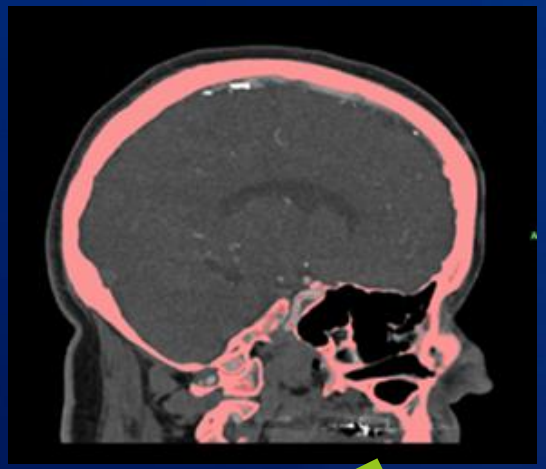
Introduction to 3D Printing Process

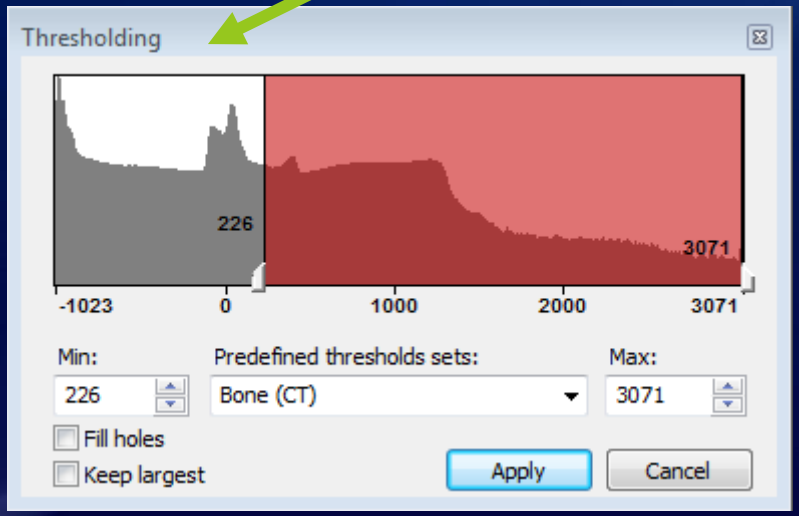
Step 2: Segmentation (Creating a Mask)

Manual



Automatic





Introduction to 3D Printing Process
Image quality

- Current 64-slice scanners accuracy range 0.6-0.9 mm in all 3 dimensions.
- Just like in digital photography there is a tradeoff of speed vs. resolution.
- Small objects resolution requires large difference in signal (Hounsfield units) compared to their direct environment.

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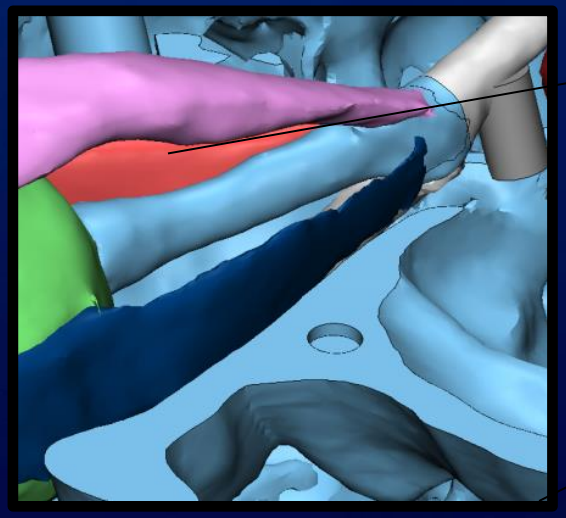
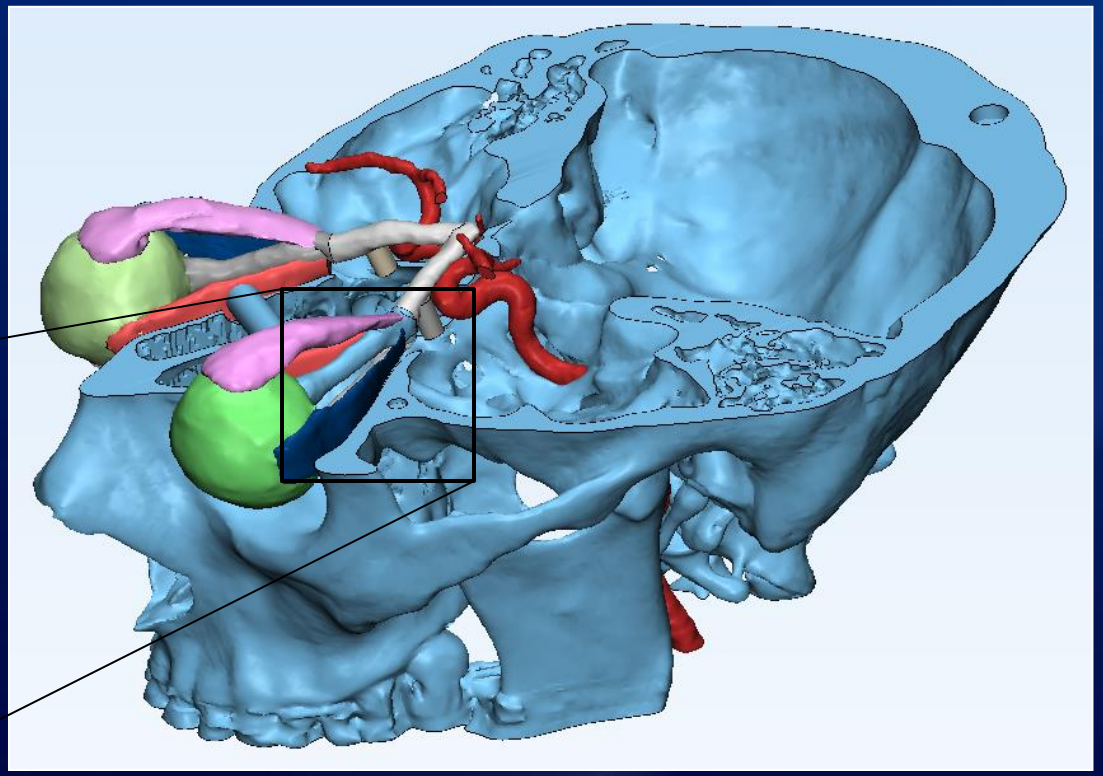
Introduction to 3D Printing Process

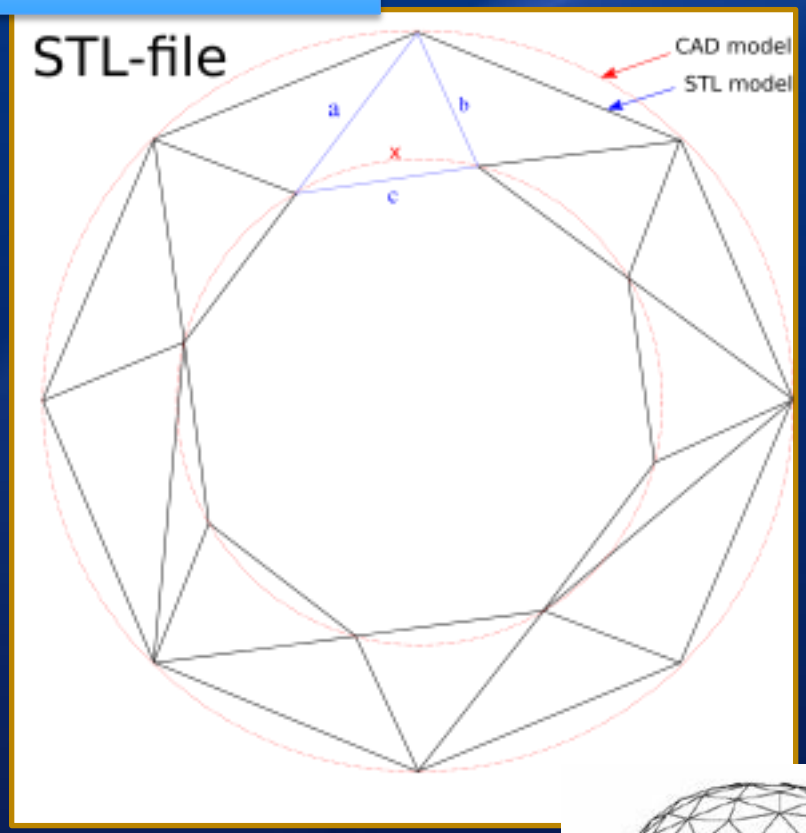
Step 3: CAD in 3-matic

- Smoothing is used to prepare model for printing





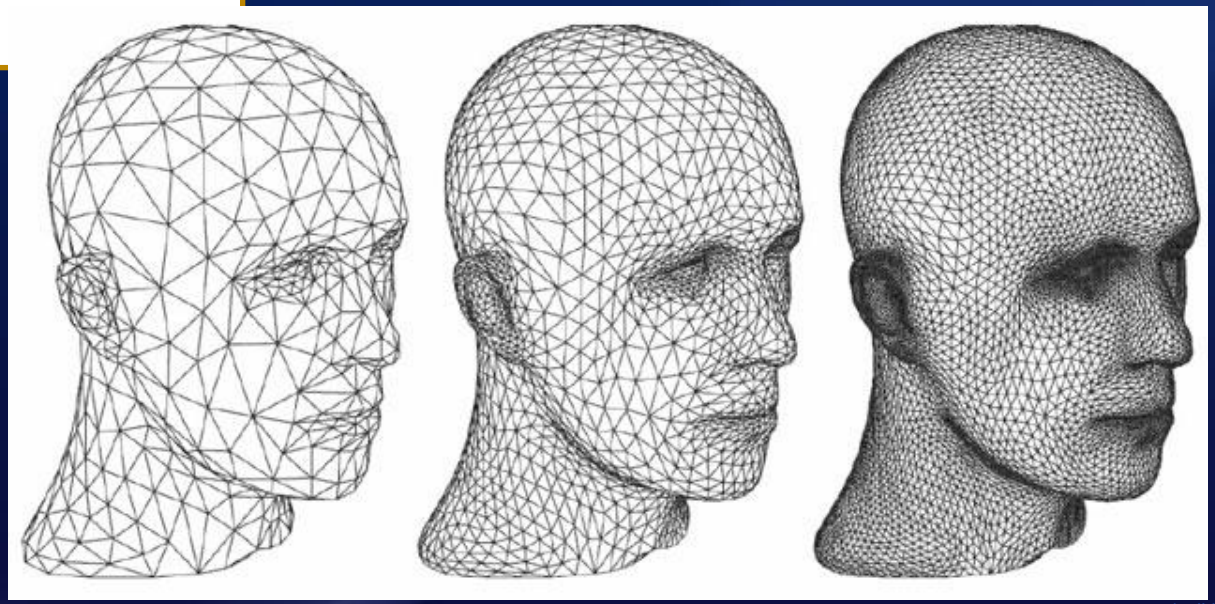
Conversion to STL file



STL-stereolithography file

Tessellation

Mesh



Question 2

- The “Digital” in anatomic 3D printing refers to…
  - A) Computer numerical control (CNC)
  - B) Computer assisted drafting (CAD)
  - C) Power control of the printing device
  - D) None of the above
  - E) All of the above

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CNC: Computer Numerical Control

- Object to be manufactured gets translated in an international standard language called G-code
- G-code is stored in and executed by the machine control unit (MCU), microcomputer
- Instructions contain: tool instructions
  - Positioning path(x, y, z), speed, power, material feed rate, etc.

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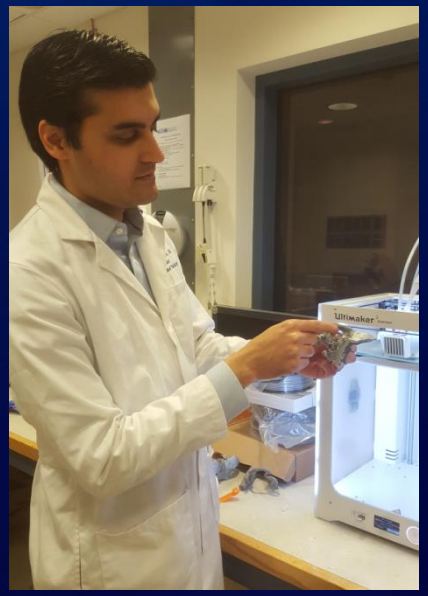
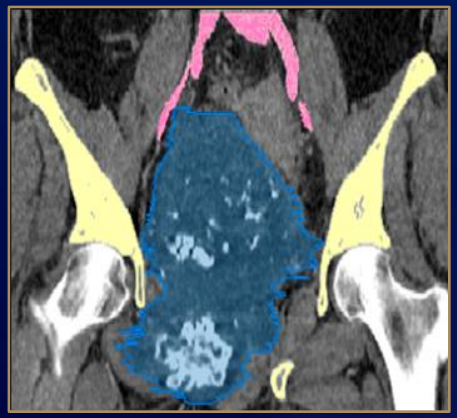
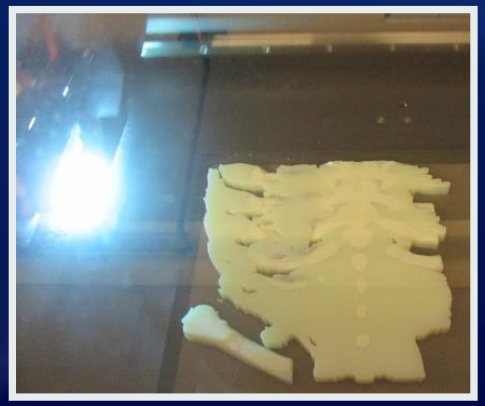
1. Take the Opportunity-Start it up

Entry Level is Relatively Low Cost - Needs

- 1 Image acquisition for dimensioning, radiologist
- 1 segmentation software, CAD
- 1 3D printer, fabricators







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3D Printers

Material Extrusion

VAT Photopolymerization

Material Jetting

Binder Jetting

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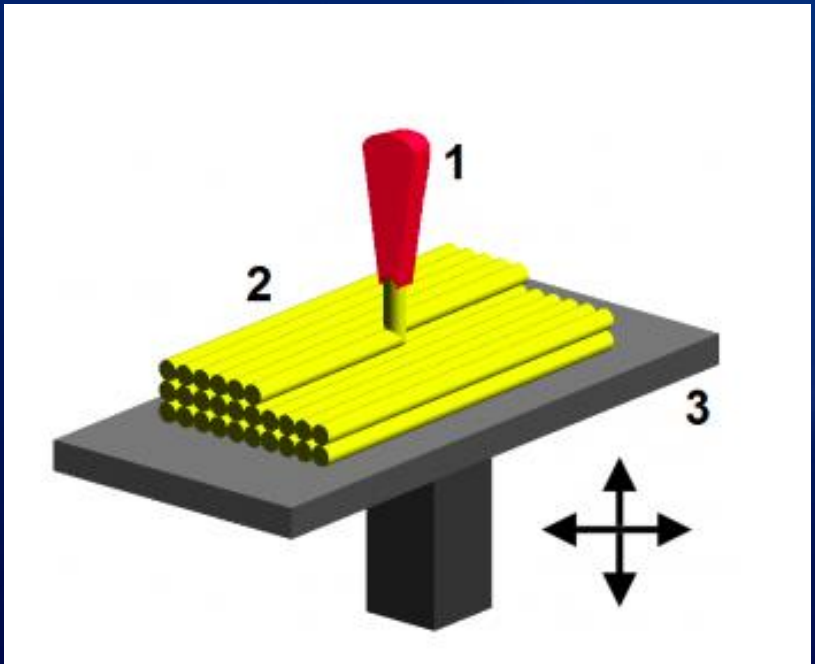
Fused Deposition Modeling (FDM) Technology

Extrudes thermoplastic filament through nozzle onto the base

- Rapid prototype
- Strong
- Requires Slicer software
- Visible lines
- Clean support required



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Fused Deposition Modeling (FDM) Technology

CREALITY

CR-10S PRO €519,99

- Both automatic leveling and auxiliary leveling modes
- Resume printing function, restart and continue printing
- Double gear extrusion mechanism, has a large extrusion to make sure feeding smoothly
- Filament detection, the transparent filament can also be detected
- V2.4.1 Motherboard, four-layer PCB board, TMC ultra-quiet drive 256 subdivision, print more precision
- With high-quality Teflon tube, high temperature resistant makes the feeding smoother, improves the printing quality
- 5 minutes quickly heating up to 110°C

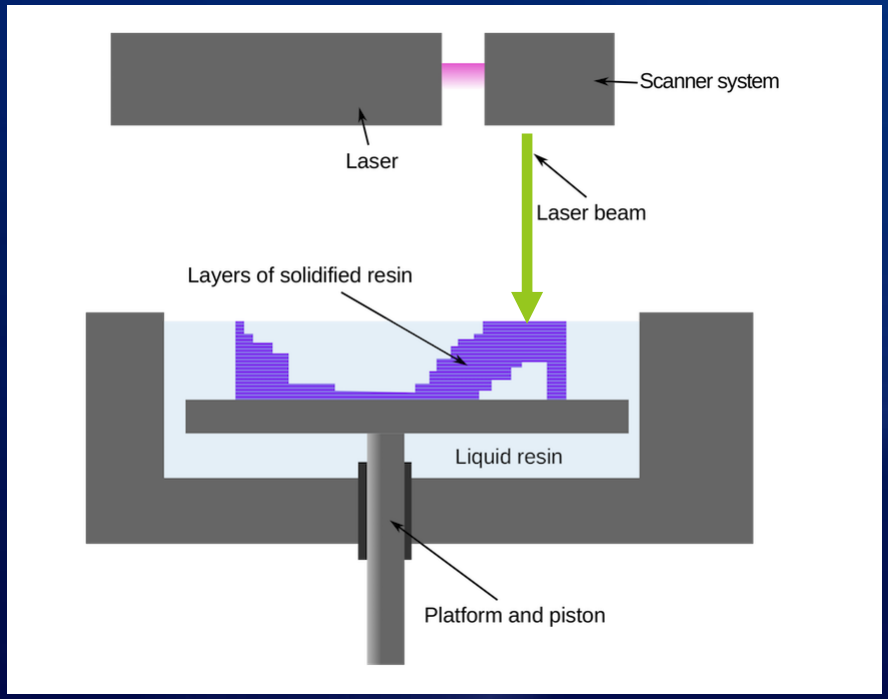
BUY NOW

Polylactic Acid (PLA) thermopolymer

Stereolithography (SLA) and Polyjet Technology

Laser cure of liquid polymer 1 layer at a time

- Serious accuracy and precision
- Chemical bath to remove any excess resin.
- Post-cure in an ultraviolet oven.
- Polyjet: multiple colors, multiple polymers, multiple hardnessess.



Stereolithography (SLA) and Polyjet Technology

Alfawise W10 UV Imprimante 3D à Volume de Construction 98 x 55 x 140mm - Vert Prise US

Marque: Alfawise ★★★★☆ 4.6 5 Avis des Clients | Référer à la description anglaise

VENTE FLASH 25 Vendu
La Vente Flash se termine dans 02 jours 06:29:52

Prix: **235.56€** Liste des prix: ~~269.22€~~ 13% de réduction

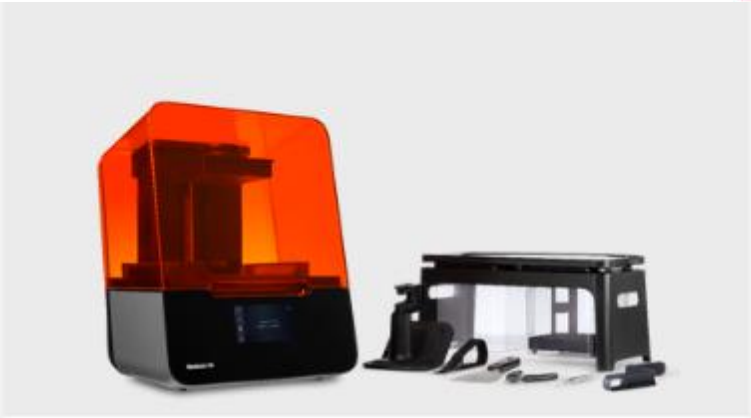
Promo: Montant déjà > 18.13€, pouvez obtenir 1 article d'Add-on à 0.10€.... Voir Plus >

Nouveaux Clients Obtenez un supplémentaire via PAYPAL de $3 OFF sur $50.Seulement pour les 2500 premiers commandes par jour

Livraison: LIVRAISON GRATUITE en France Via Poste aérienne enregistrée

Couleur: Vert

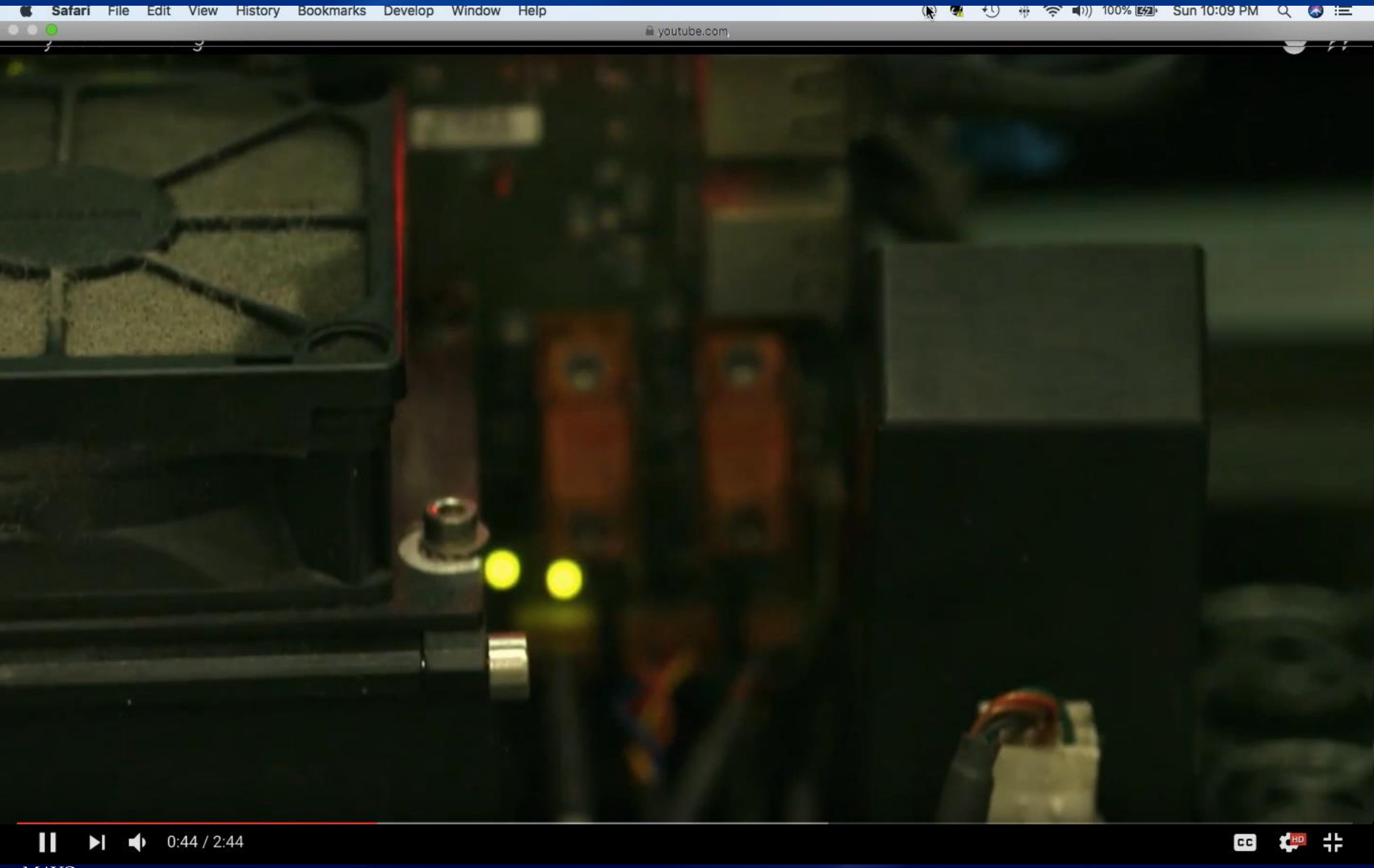
Taille: Prise US PR



Form 3 Basic Package

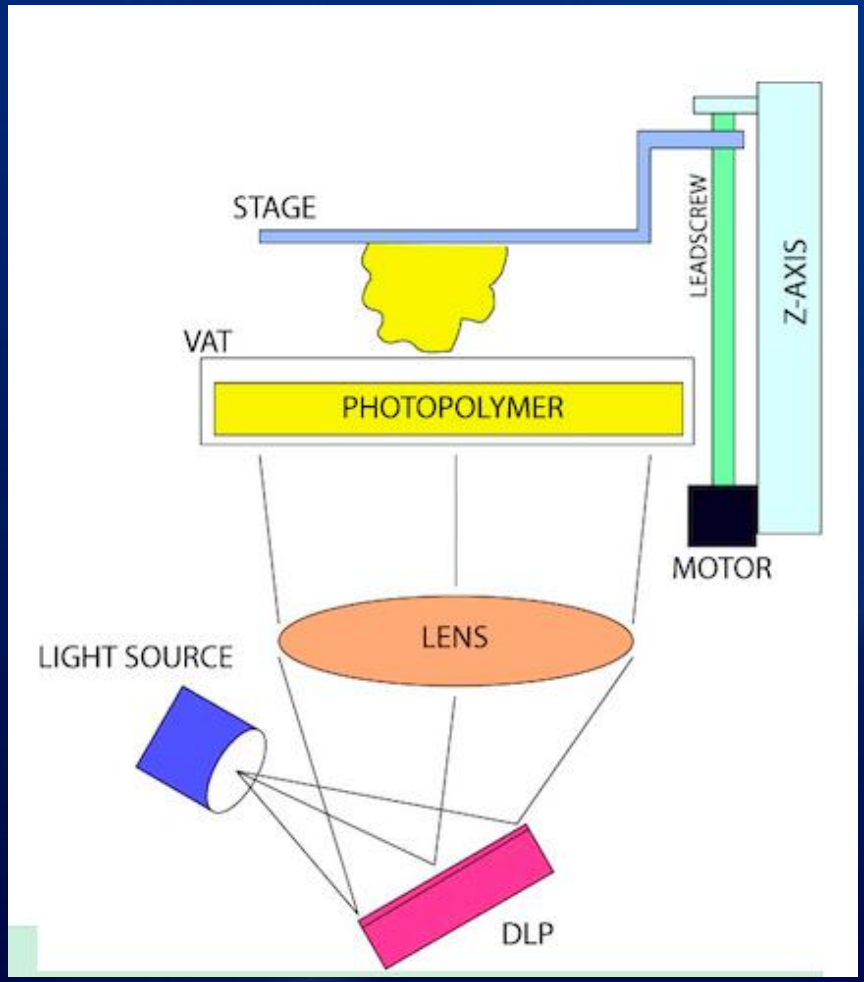
Starting at $3,499.00

3D printing of STL file

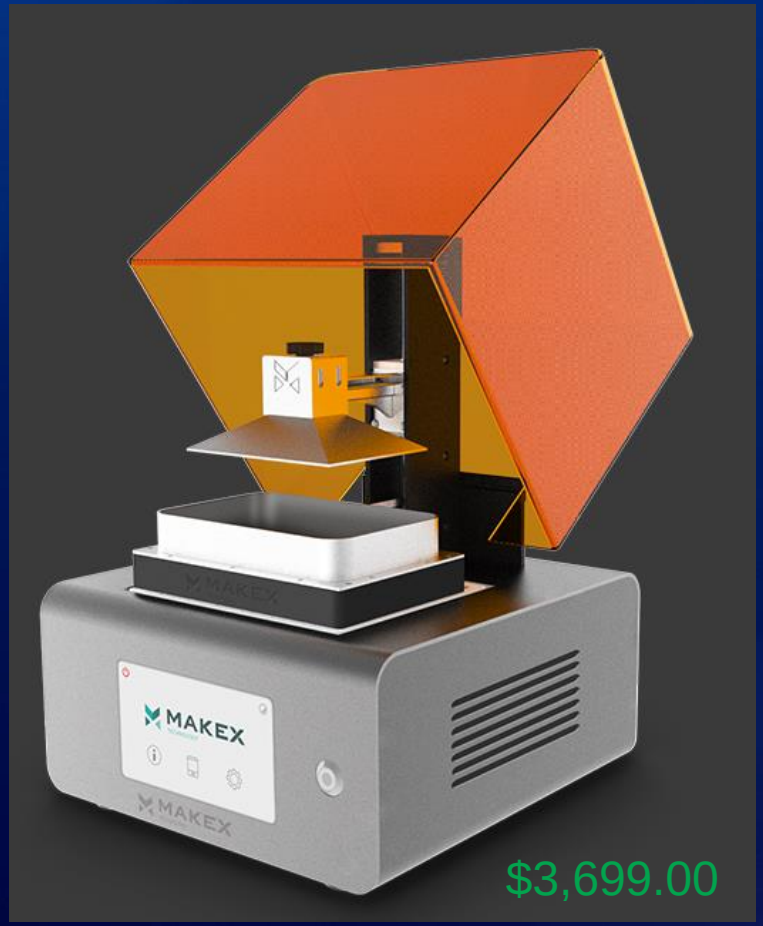


Digital Light Processing (DLP)

- Fast
- Light exposed to entire layer at once
- Smaller format than SLA



Digital Light Processing (DLP)



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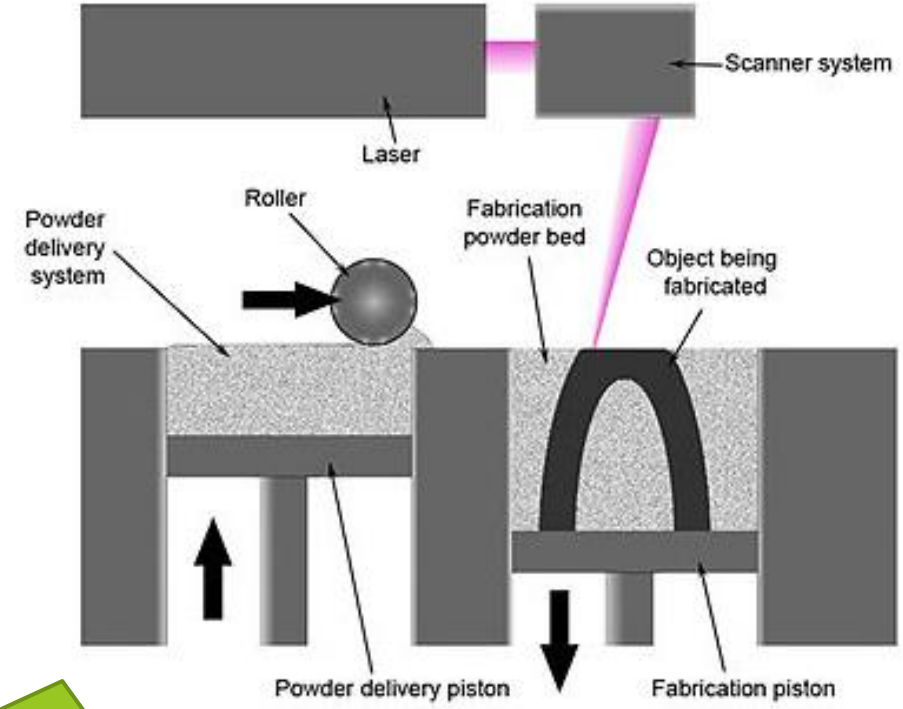
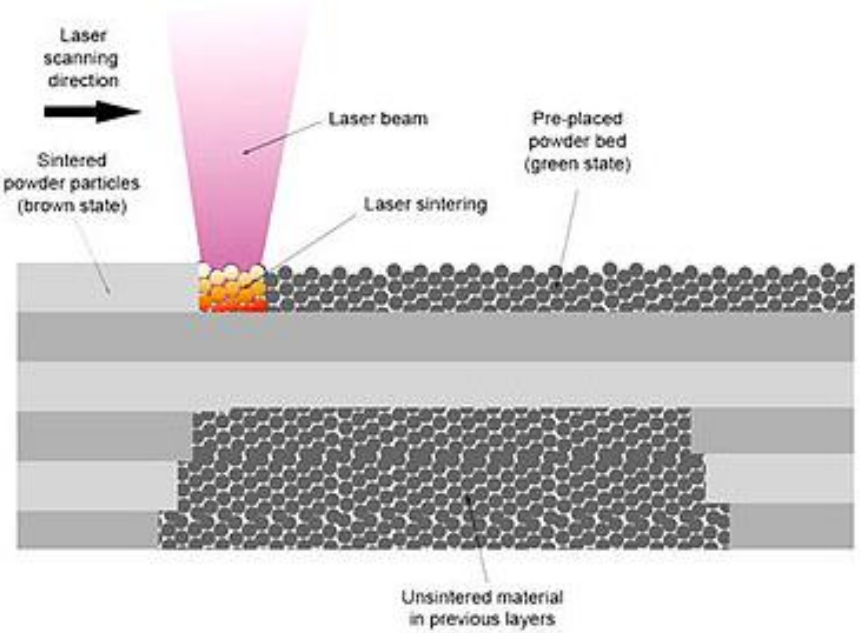
Selective Laser Sintering (SLS) Technology





- CO_2 lasers fuse particles together.
- Powdered metal (titanium) or materials (white nylon powder, ceramics, glass)
- Surgical guides, metal implants

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E-Beam AM Equipment

Arcam Model A1
- Electron Beam Melting (EBM)
  - Powder Bed
  - Vacuum
  - Elevated Temp
  - Low Distortion
  - Excellent Properties
- Model A1
  - 200mm x 200mm x 180mm
- Materials
  - Ti and Ti Alloys
  - CoCr
  - Nickel Alloys (Inconel)
  - Steel Alloys
  - Others???
- CSRIO Level 3 Training

3D printing of STL file

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Our Workhorse 3D Printer

- Printer: Stratasys Objet500 Connex3
  - Material Jetting 3D Printer
  - Commercial grade
- UV-cured photopolymer resin
- Different materials
  - Support material
  - Model material

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Introduction to 3D Printing Process

Specifications

SYSTEM SIZE AND WEIGHT
1400 x 1260 x 1100 mm (55.1 x 49.6 x 43.4 in.); 430 kg (948 lbs.)
Material Cabinet: 330 x 1170 x 640 mm (13 x 46.1 x 26.2 in.); 76 kg (168 lbs.)

BUILD SIZE
Objet350: 342 x 342 x 200 mm (13.4 x 13.4 x 7.9 in.)
Objet500: 490 x 390 x 200 mm (19.3 x 15.4 x 7.9 in.)

LAYER THICKNESS
Horizontal build layers as fine as 16 microns (.0006 in.)

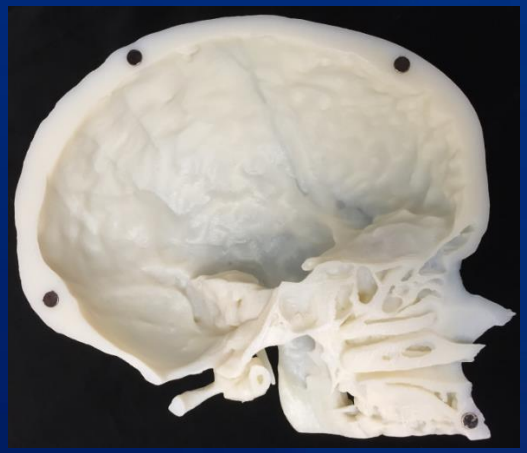
ACCURACY
Up to 200 microns for full model size (for rigid materials only, depending on geometry, build parameters and model orientation)

BUILD RESOLUTION
X-axis: 600 dpi; Y-axis: 600 dpi; Z-axis: 1600 dpi

Introduction to 3D Printing Process

Step 5: Post-processing

- Work done after printing
  - Cleaning off support material
  - Magnets
  - Clear coat



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Printing and Cleaning Models

- Objet Printer

- Projet Printer

Printer Technology*	Description	Typical Three-Axis Resolution†	Model Surface	Advantages	Disadvantages
Material extrusion with FDM	Thermoplastics are melted and extruded by a tip onto the build platform	z-axis: 0.1–0.5 mm x-y–axis: 0.1–0.4 mm	Very rough	Low cost Strong materials Models can be printed by using one or two materials, which may be different colors and rigid or flexible	Slow Spatial resolution lower than that with other modalities Models can be permeated by liquids owing to layer adhesion imperfections
Material jetting	Droplets of epoxy- or acrylic-based liquid photopolymers are jetted onto a tray and polymerized and solidified by means of exposure to ultraviolet light	z-axis: 0.03 mm x-y–axis: 0.05 mm	Slightly rough	Most versatile for anatomic models (same model can have multiple colors and be composed of multiple materials) Short-term biocompatible material is available for surgical guides and tools	Expensive Slow
Vat photopolymerization with SLA	Photopolymer held in a vat is polymerized by, for example, an ultraviolet laser by means of illumination of the top or bottom surface of the liquid	z-axis: 0.02–0.20 mm x-y–axis: 0.075–0.200 mm	Smooth	Ideal for hollow vascular models because they can be printed without support material in hollow portions, depending on the orientation Biocompatible materials are available	Labor-intensive removal of support struts Only one material can be used for each model
Binder jetting	A liquid adhesive is jetted onto a bed of gypsum or ceramic powder	z-axis: 0.05–0.10 mm x-y–axis: 0.05 mm	Rough	Vibrant full-color models No supports required; can constituently print complex shapes	Fragile models that need infiltration with acrylics or elastomers after printing Only one material is used
Powder bed fusion involving SLS, direct metal laser sintering, and electron-beam melting	Powder of plastic, metal, ceramic, or glass is sintered by a high-power laser	z-axis: 0.1–0.2 mm x-y–axis: 0.075–0.200 mm	Rough	Materials include implantable metal alloys (eg, titanium, cobalt-chrome) or synthetic polymers (eg, nylon, polyether ether ketone) No supports required	Expensive Models need substantial machining post-processing (eg, polishing)

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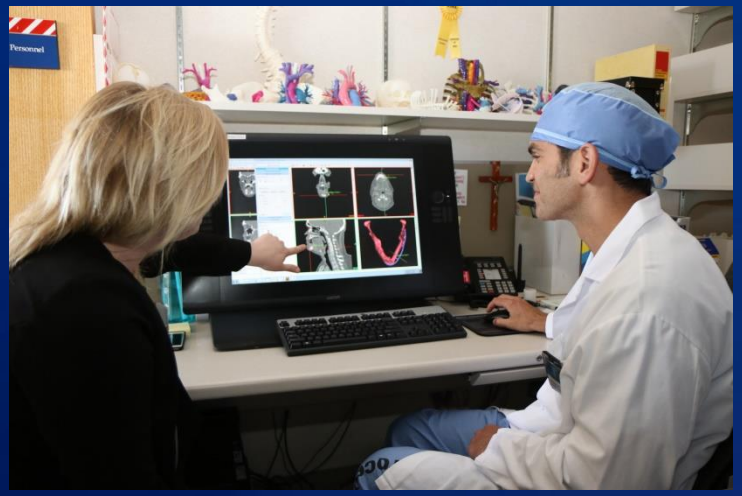
Discuss the Model with the Surgeon



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3D Technologies-Dimensioning Data Source (INTERNAL ANATOMY)

- Examples
  - Carcinoid tumor
  - Pancoast tumor
  - Mediastinal ganglioma
  - Lung segmentectomy
  - Thoracic osteosarcoma
  - Sterncostal reconstruction

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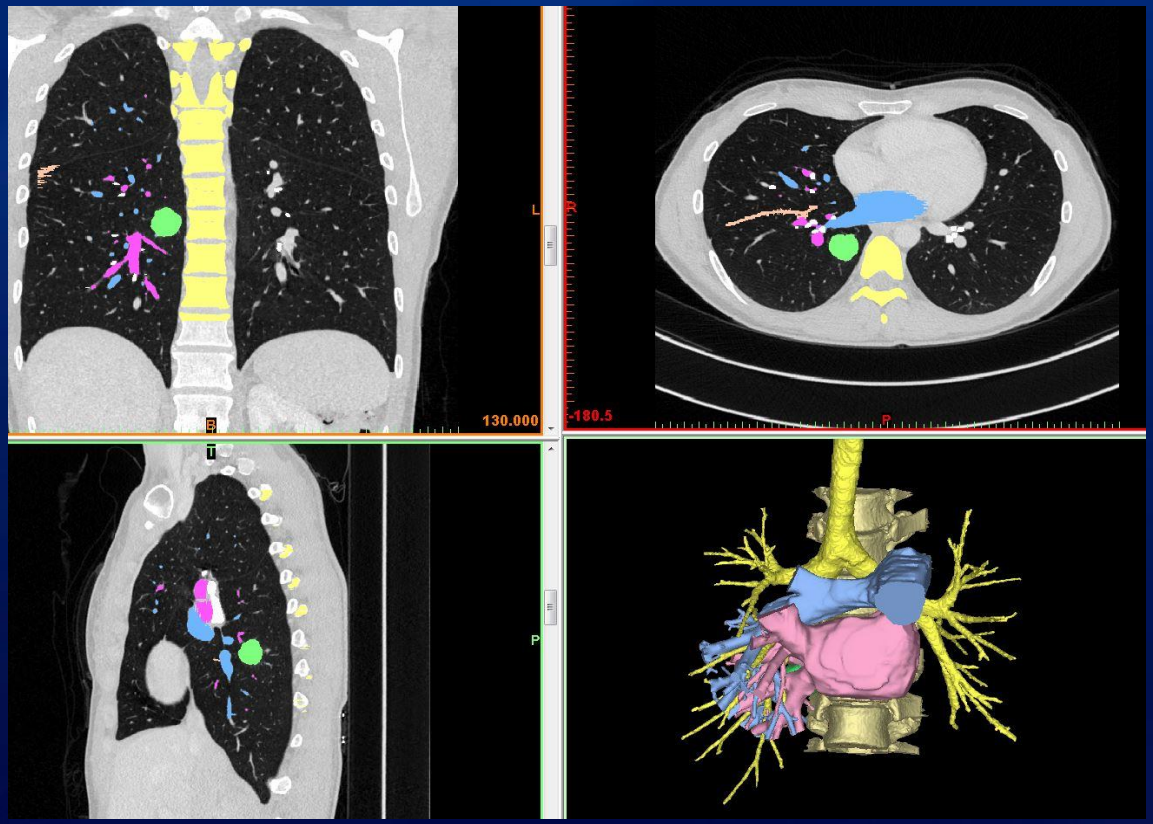
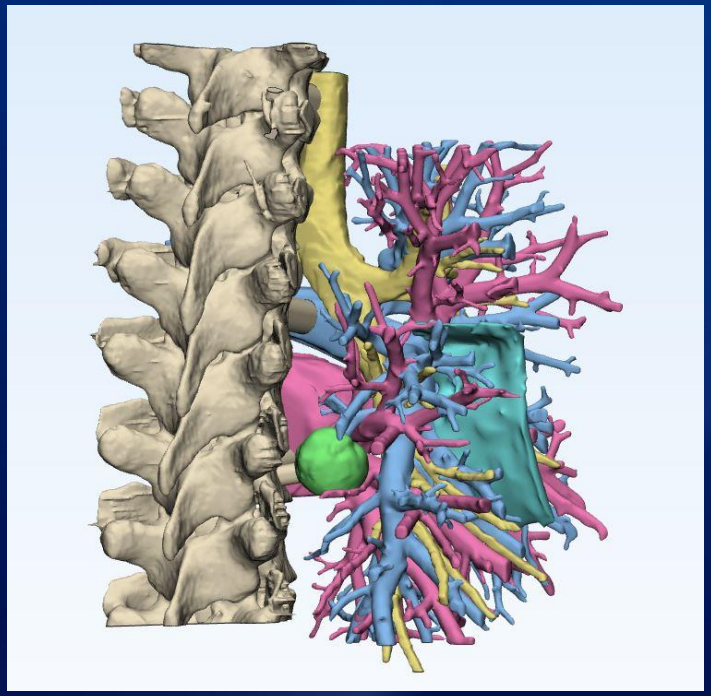
Carcinoid Lung Tumor

Segmentation and CAD processing





"Surgery is moved up…I need it tomorrow"

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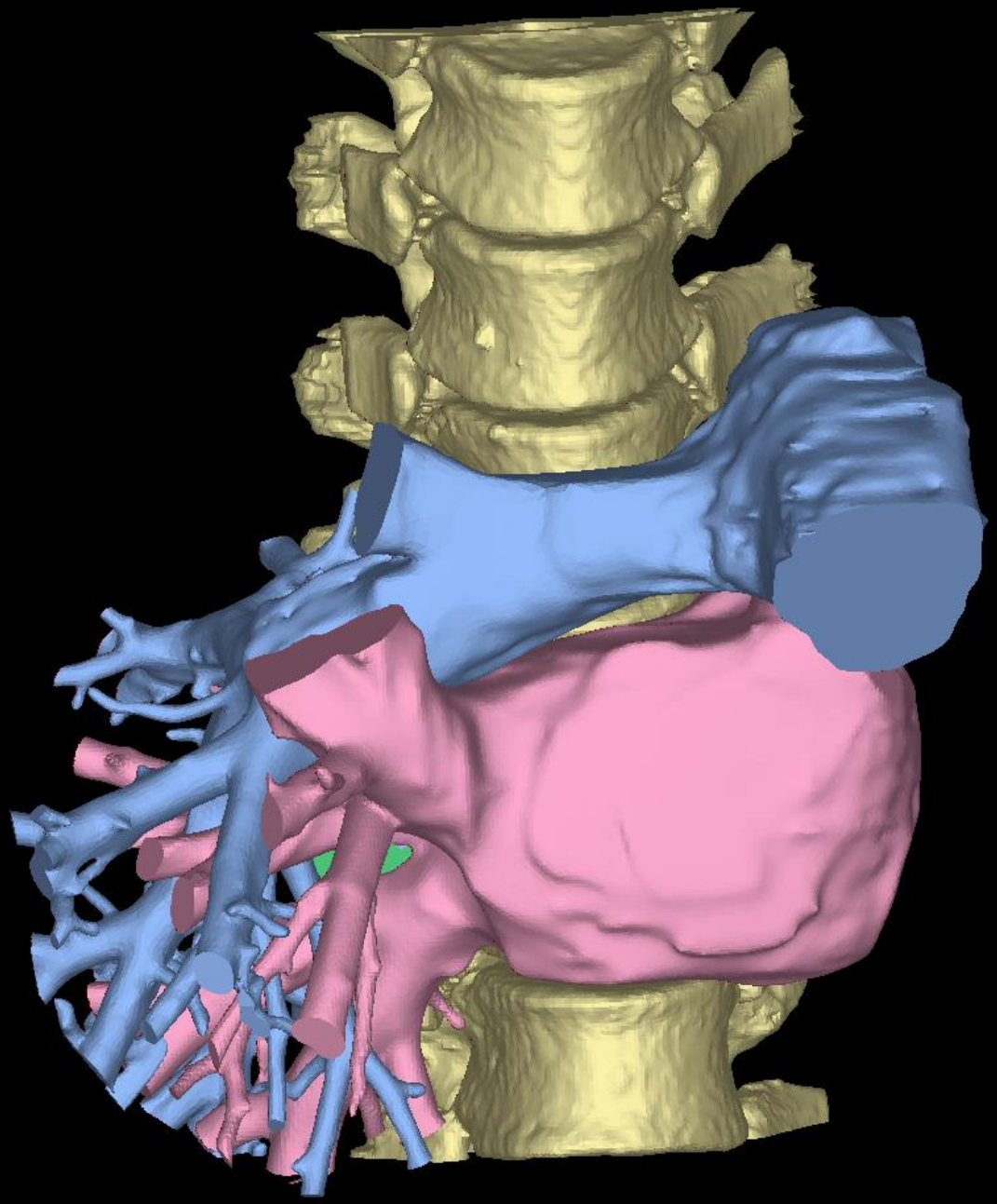
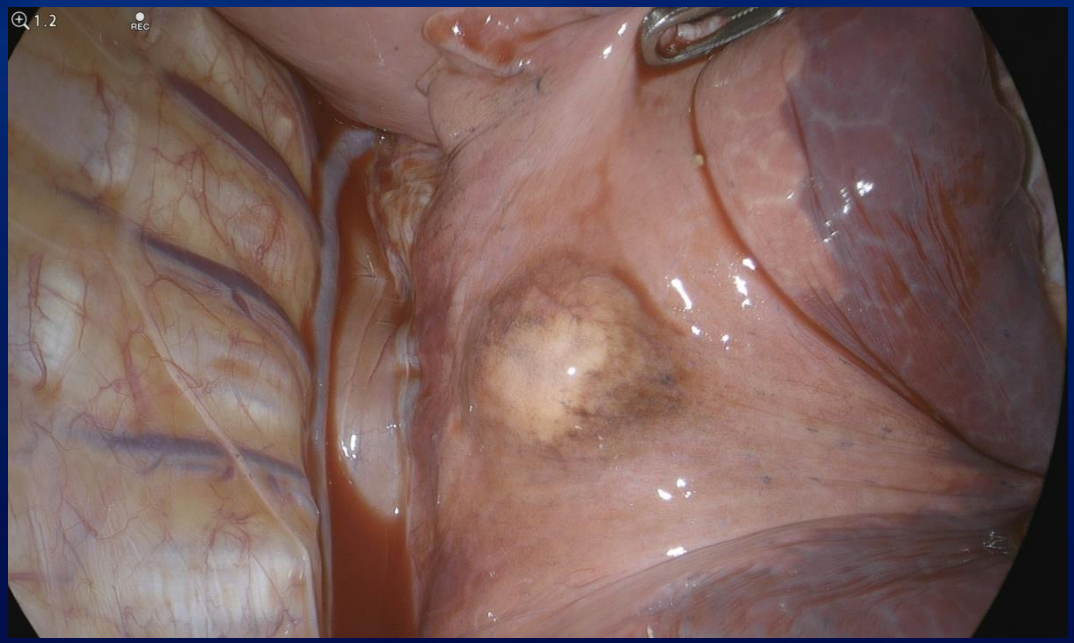
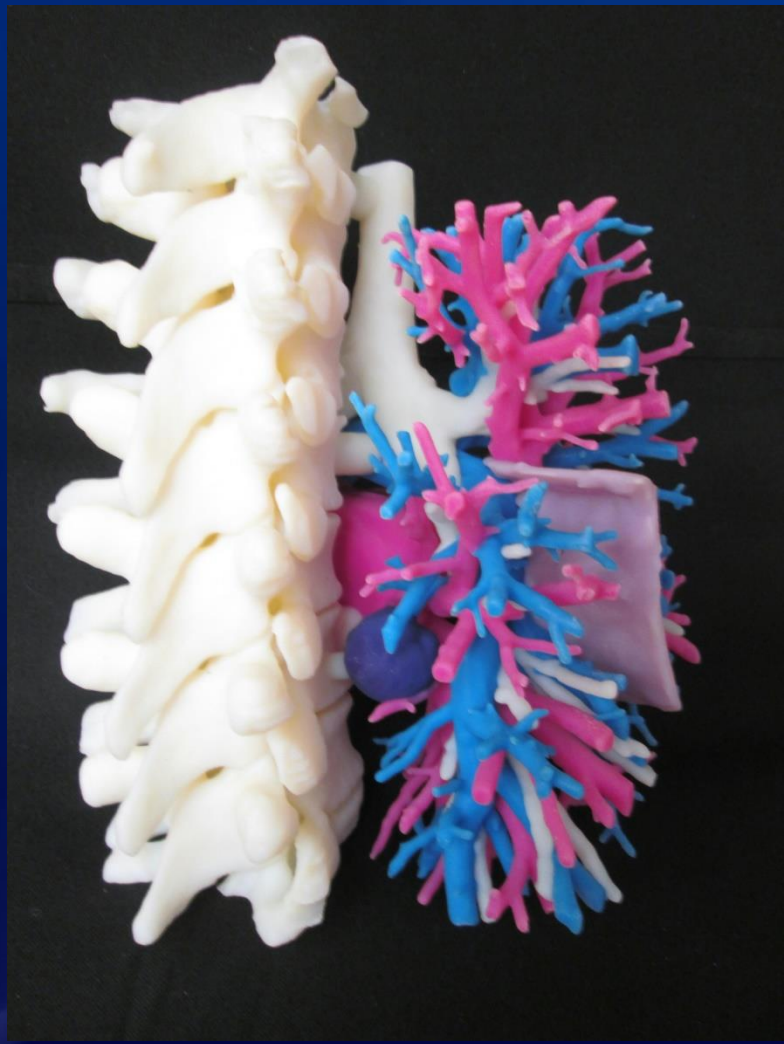


Carcinoid Lung Tumor





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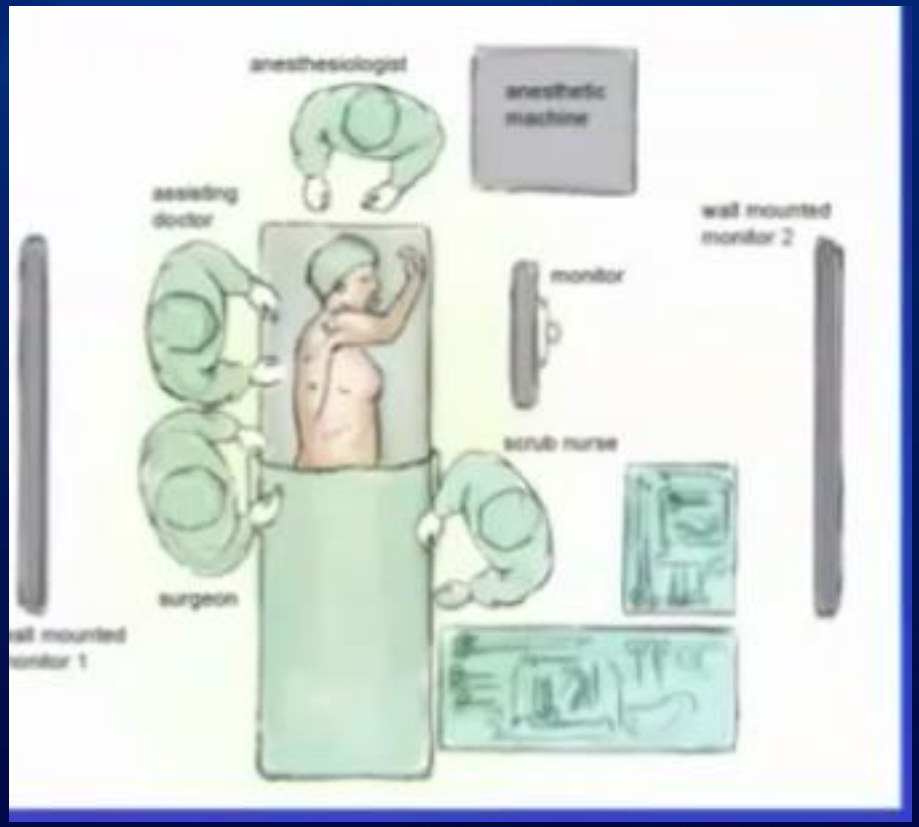
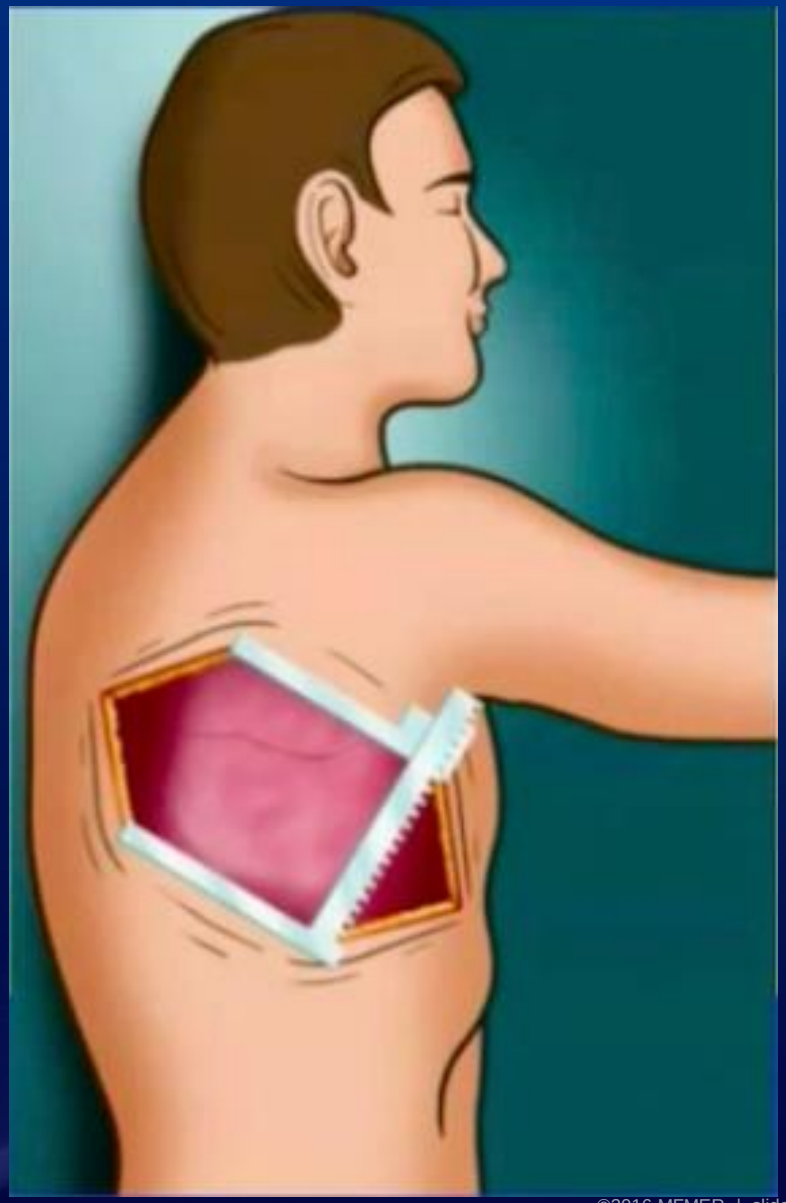
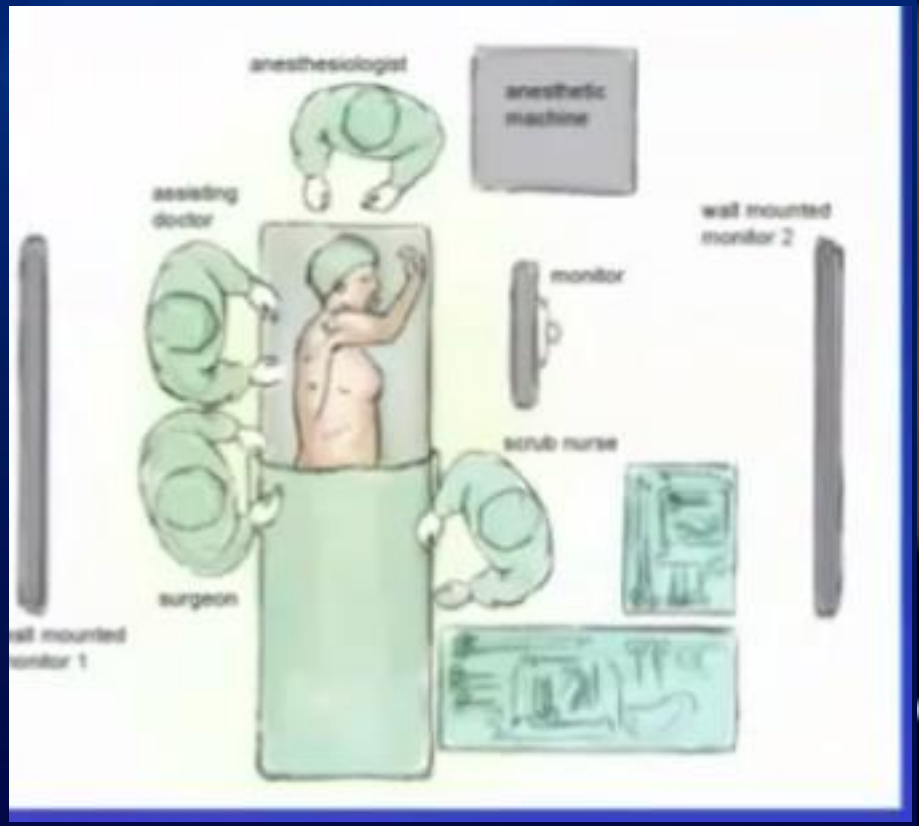
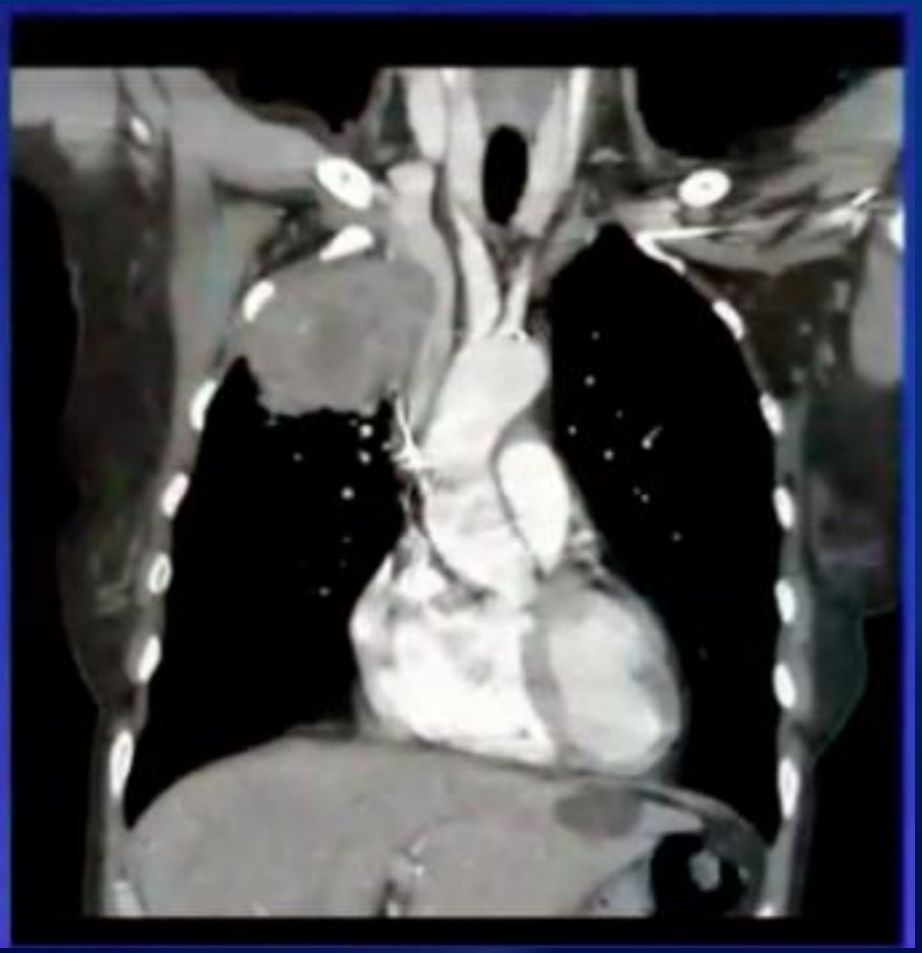
Pancoast Tumor-minimally invasive?





Pancoast Tumor-minimally invasive?





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Pancoast Tumor

Surgeon comment: “I would not think I could do this without the model”.

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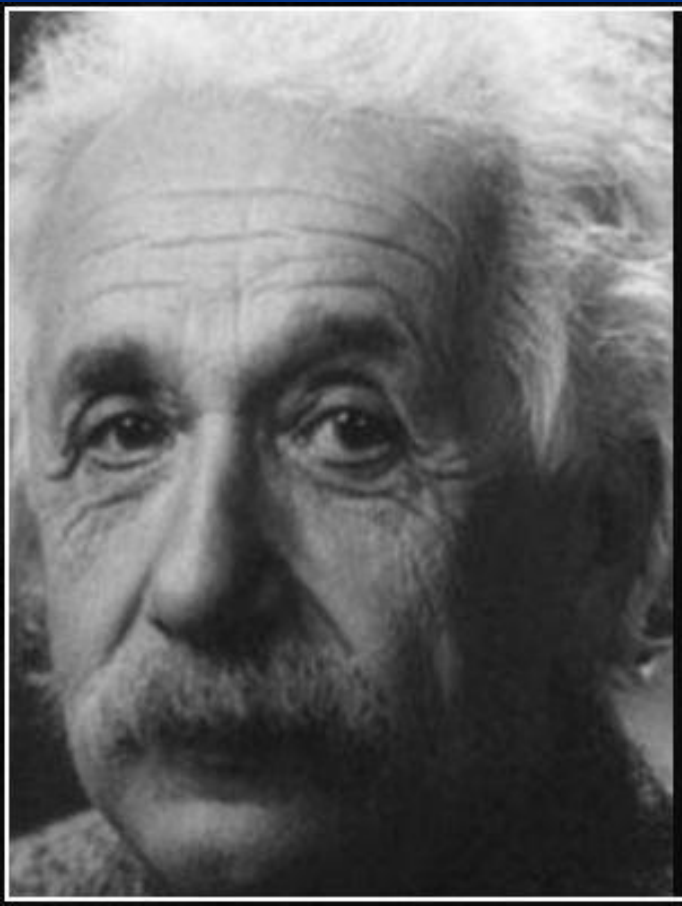
Mental Gymnastics



Genius is making complex ideas simple, not making simple ideas complex

— Albert Einstein —

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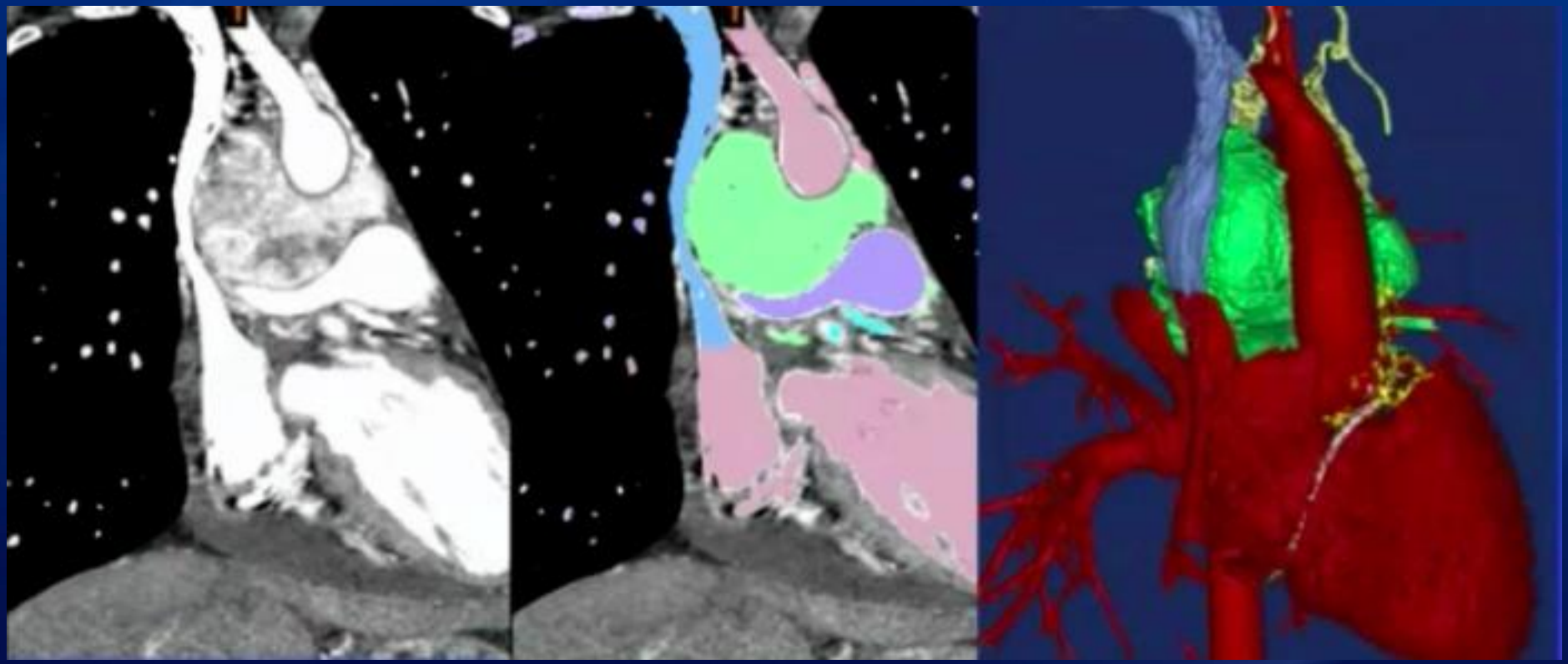
Mediastinal Paraganglioma



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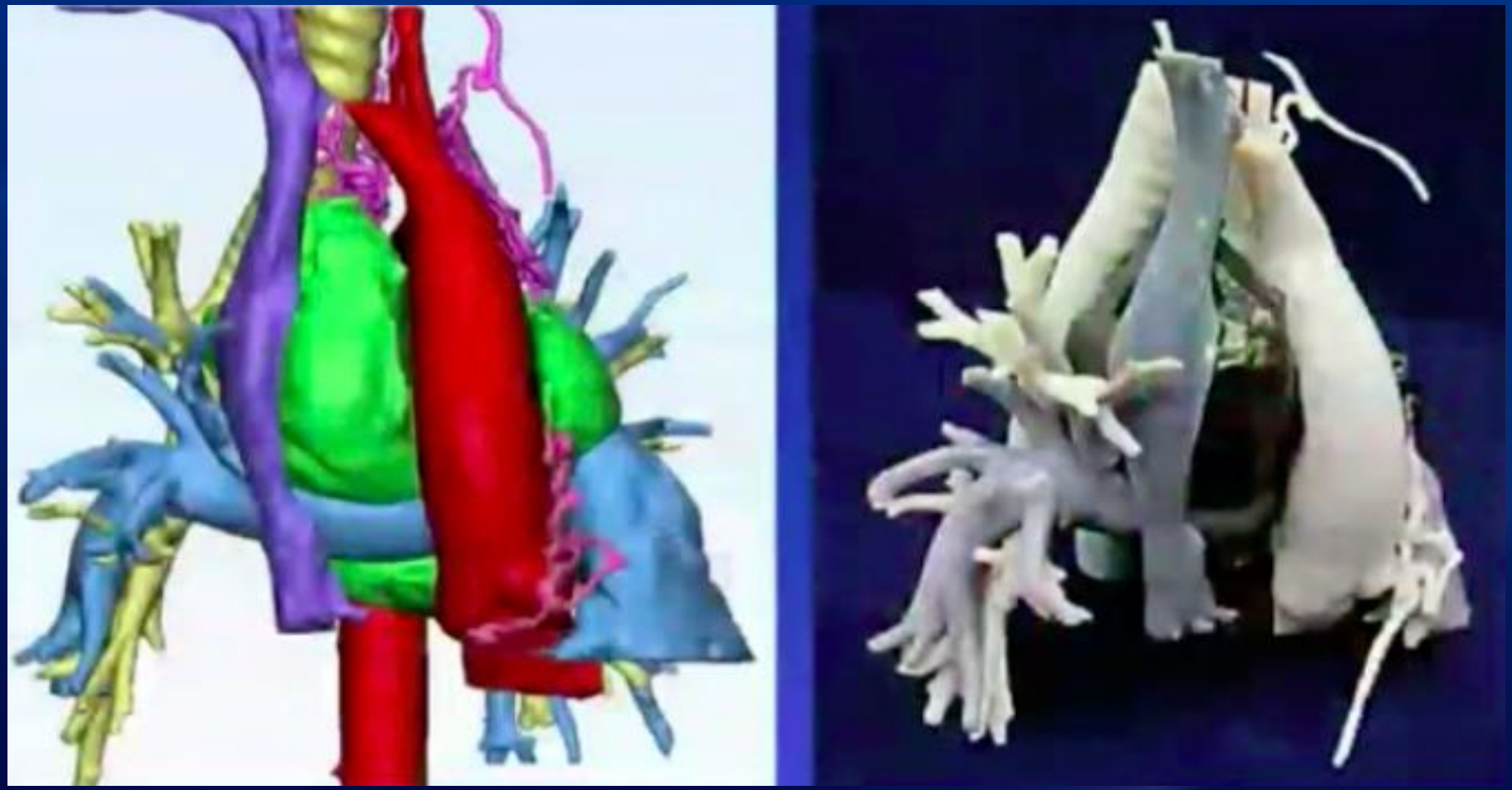
Mediastinal Paraganglioma



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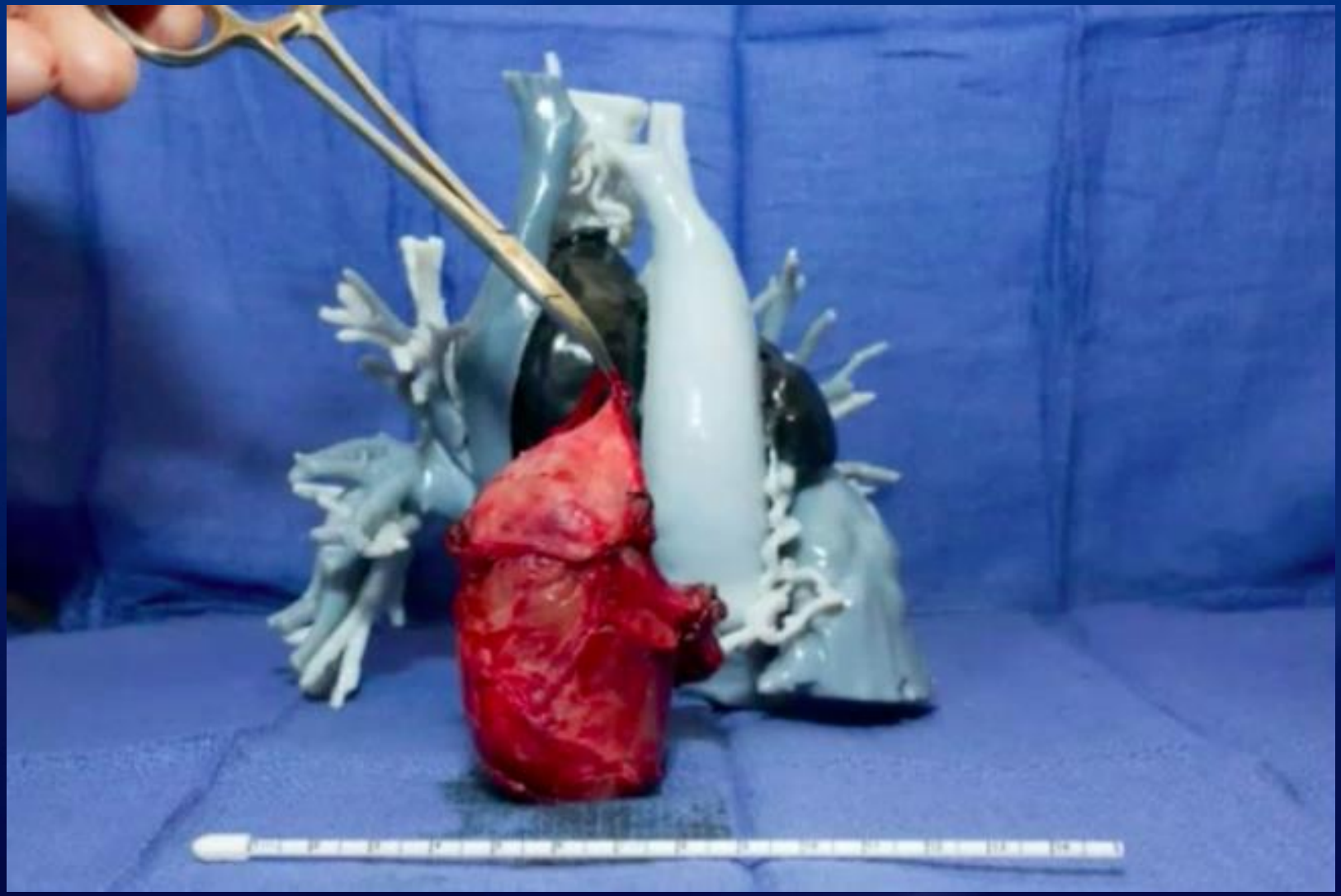
Mediastinal Paraganglioma



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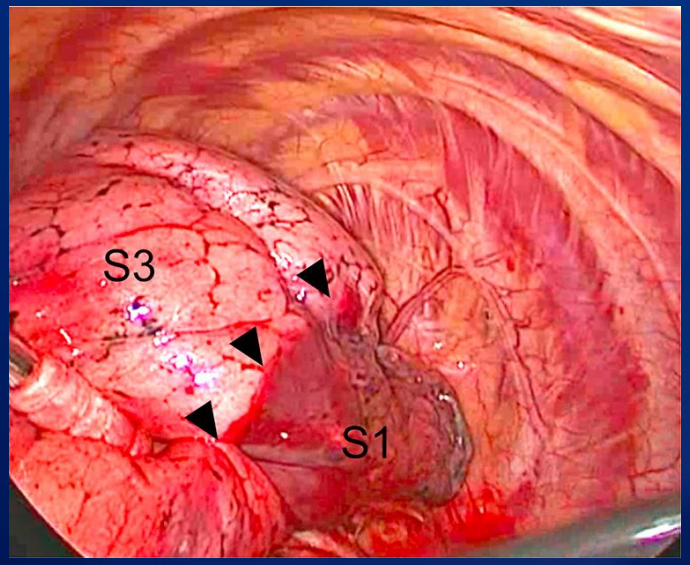
Lung Segmentectomy

- Inflation and deflation of segment
- Thermography
- Indocyanine green (ICG)



- Problem: For either method, the segmental artery or segmental artery/bronchus/vein must be correctly recognized intraoperatively.

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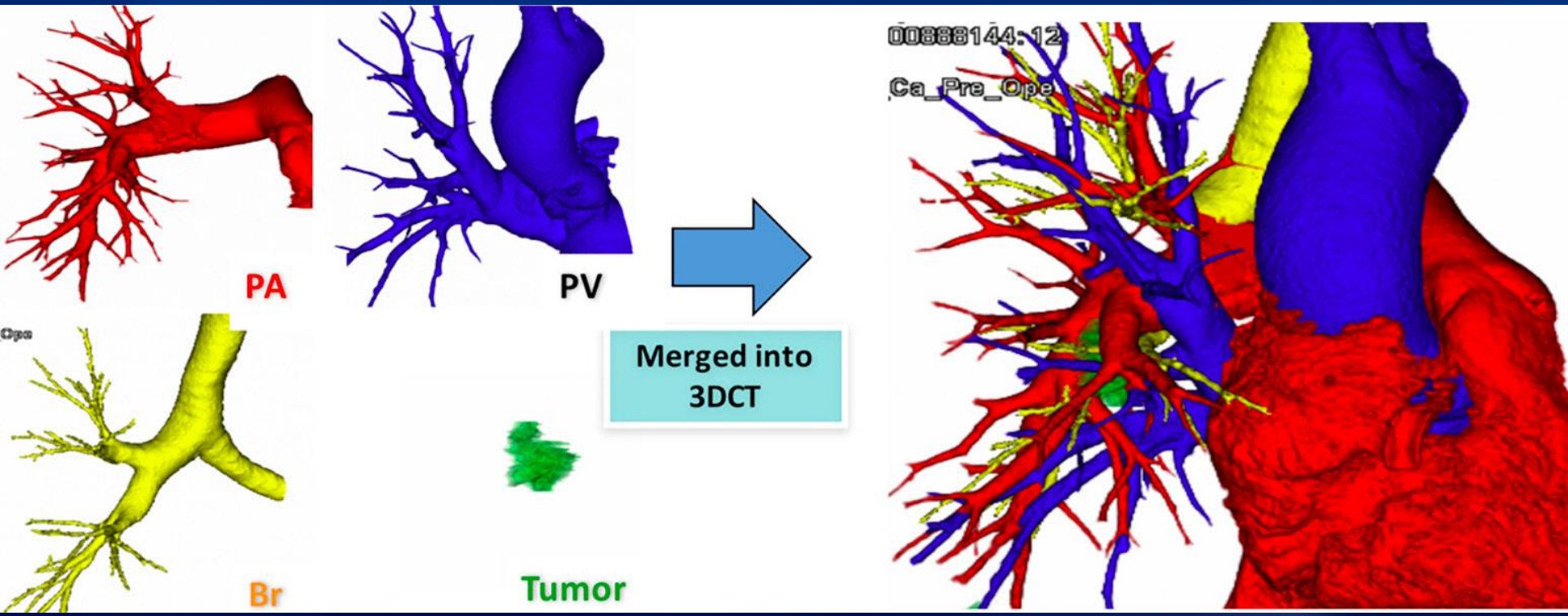
Segmentectomy



Journal of Visualized Surgery, 2017

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Segmentectomy

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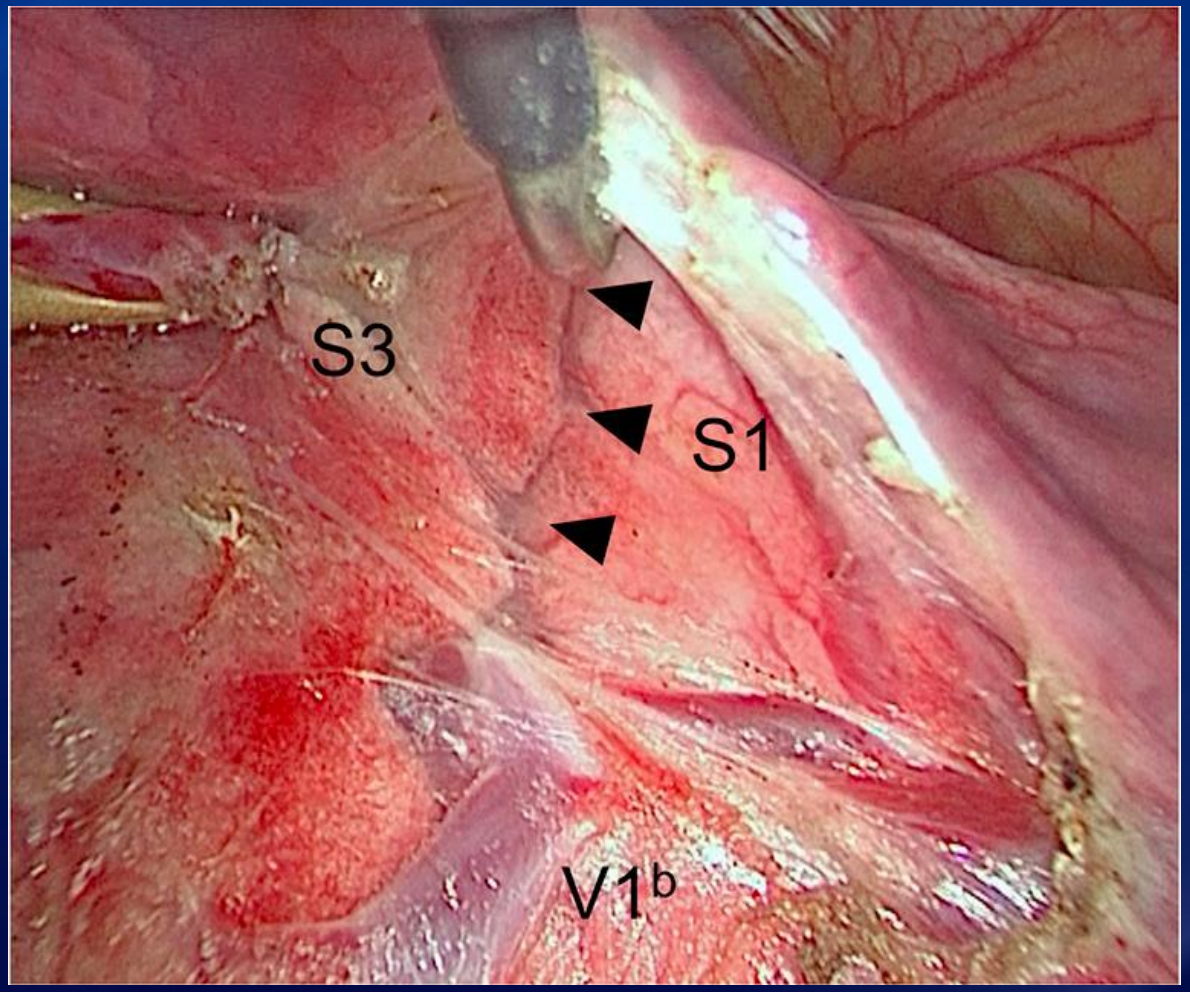
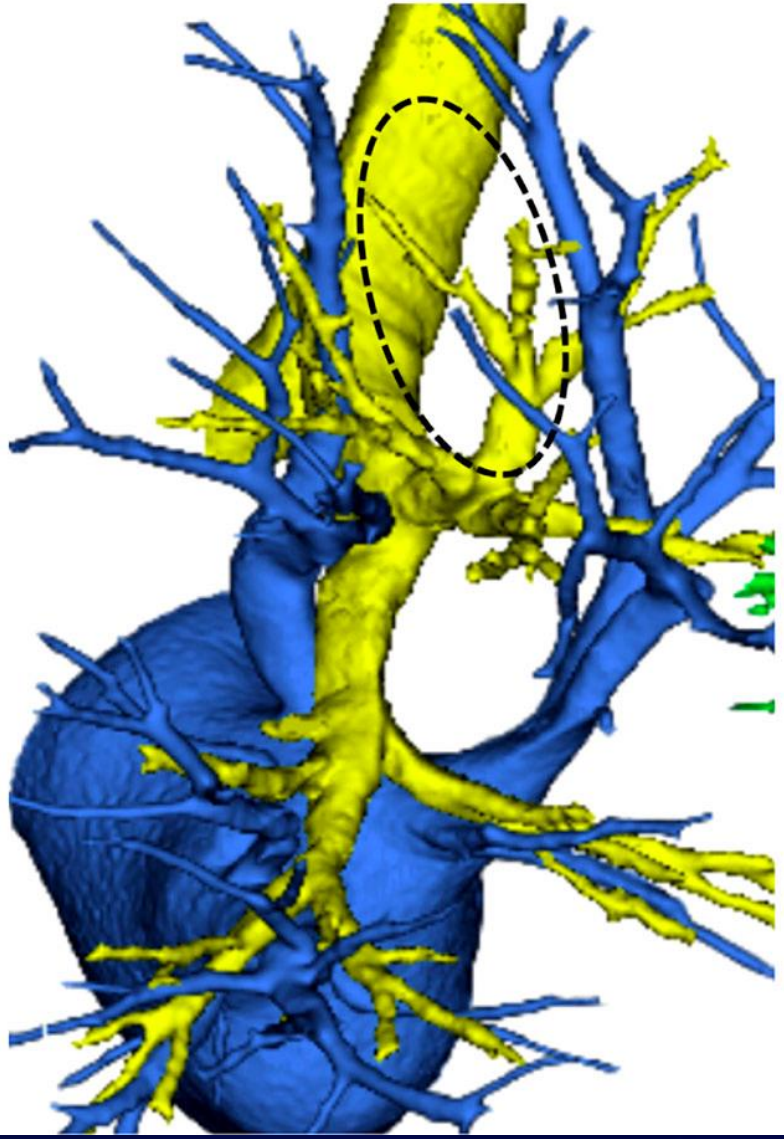
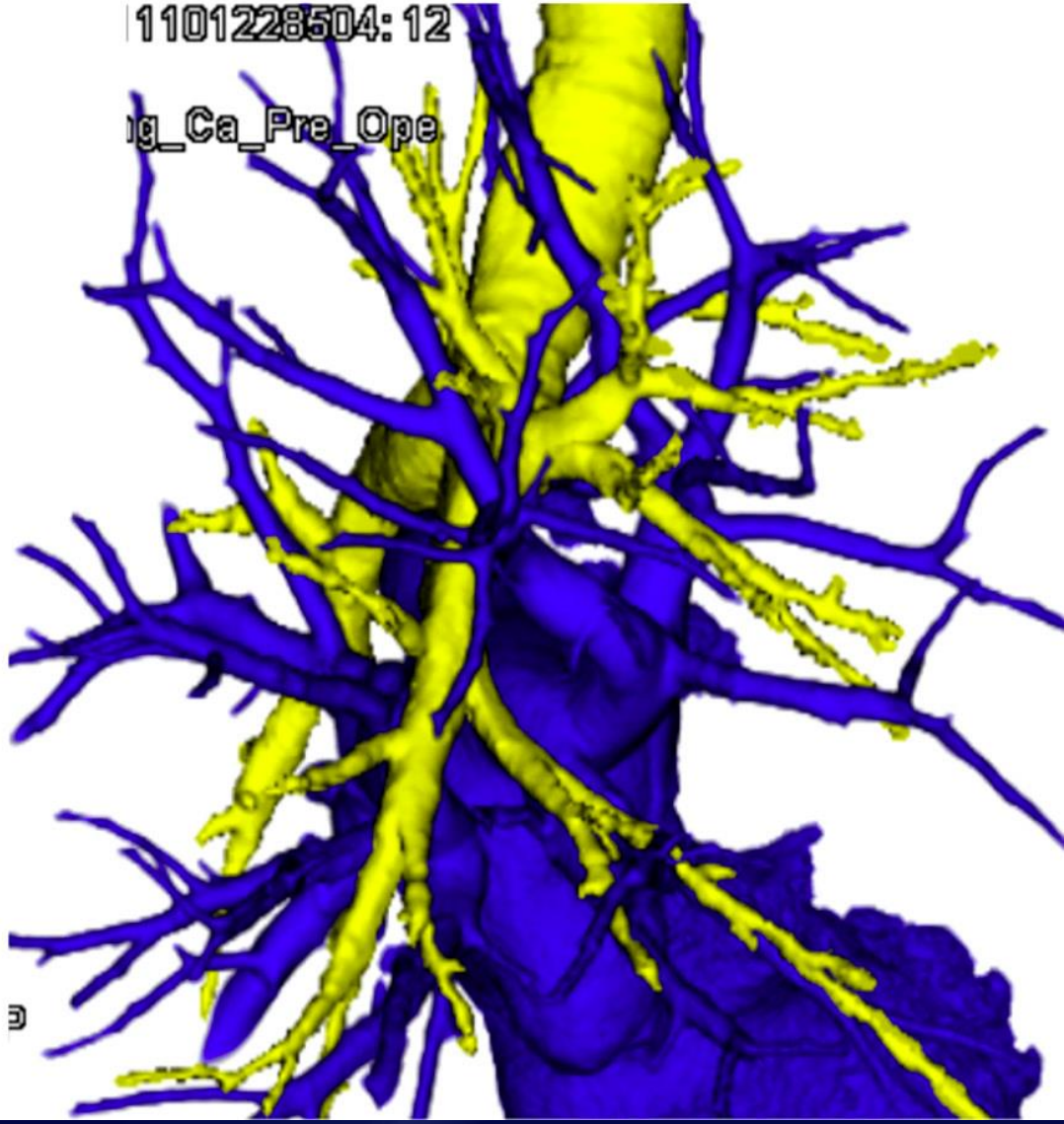
Segmentectomy



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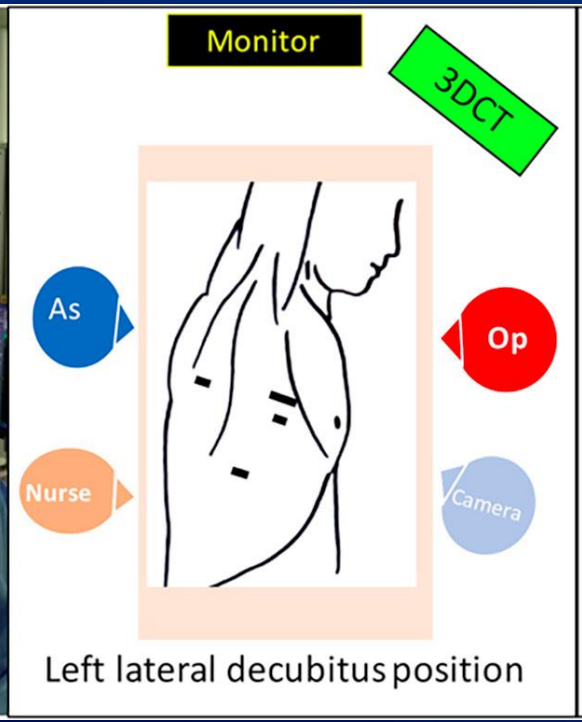
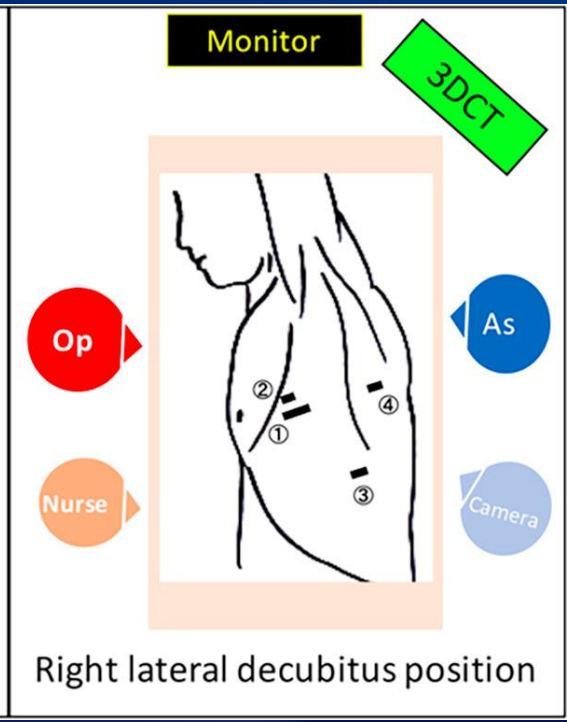
Segmentectomy





Journal of Visualized Surgery, 2017

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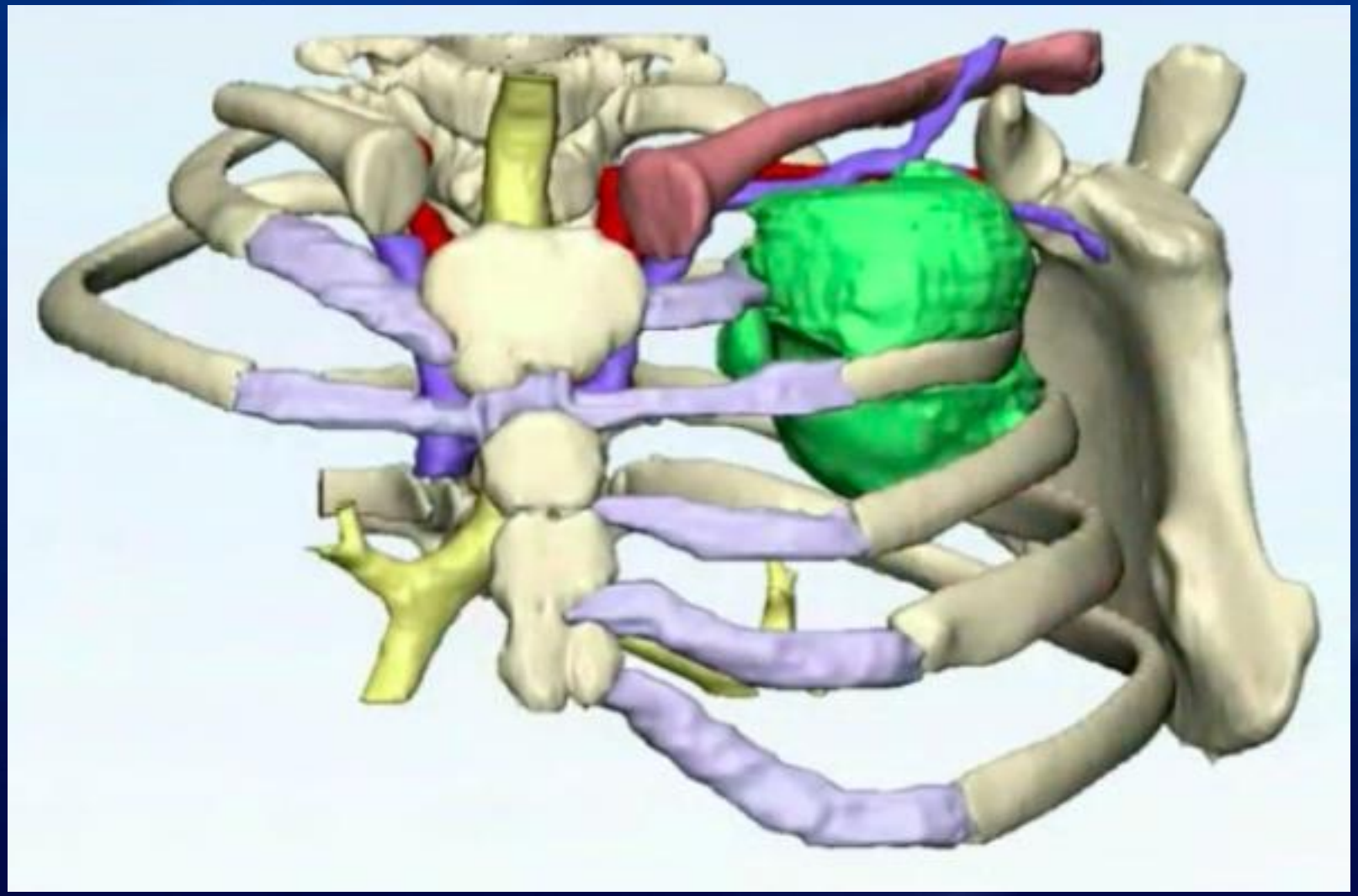
Pediatric Osteosarcoma



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Pediatric Osteosarcoma

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SITUATIONAL AWARENESS

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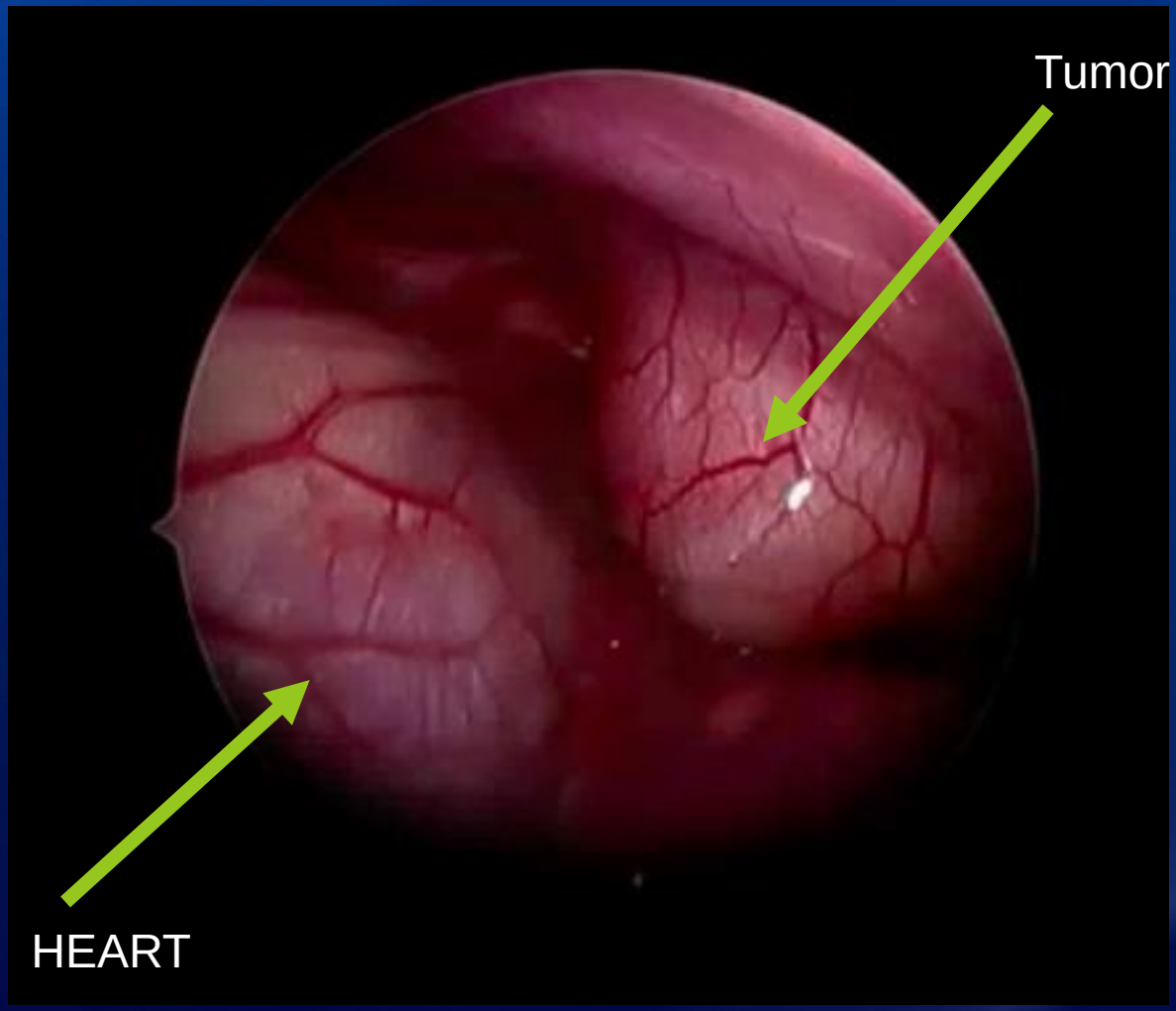

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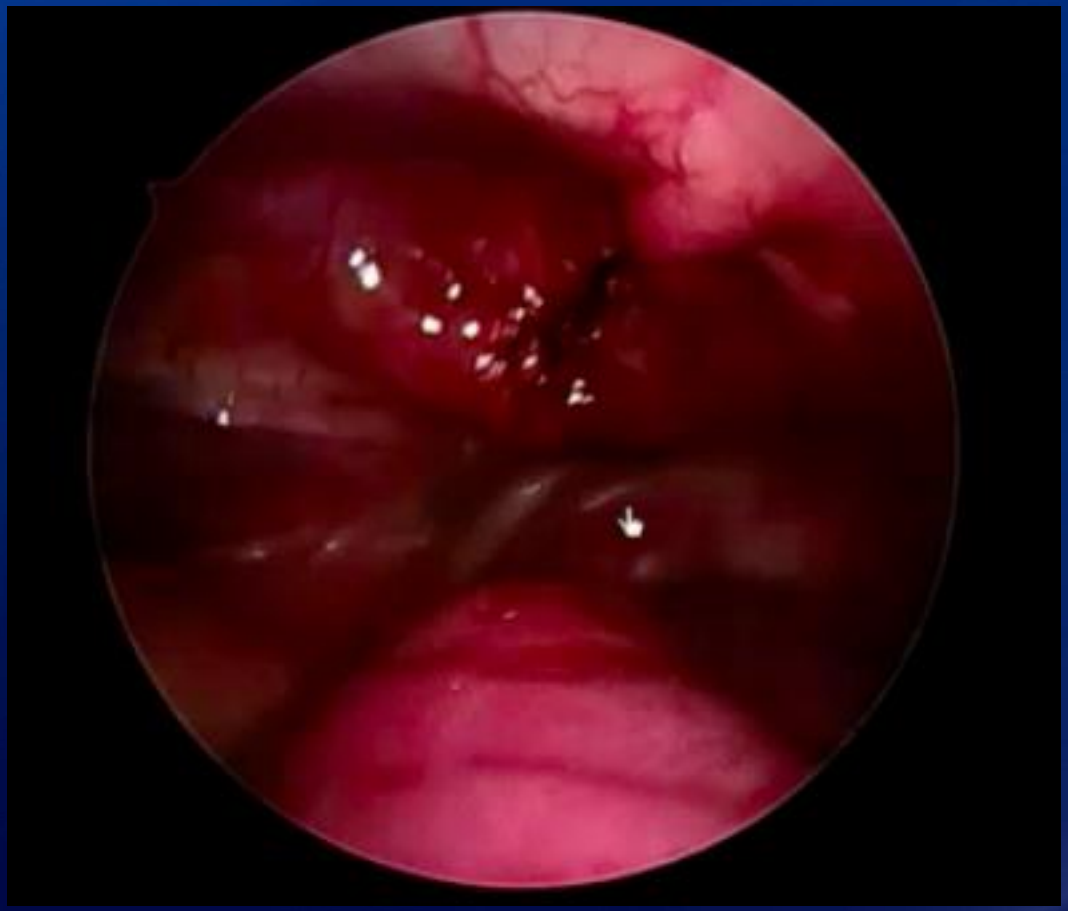

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Models are Lifesize

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Published Benefits of Surgical Models

- Median time savings of 20% in operating room and anesthesia time.

- 62% of surgeons believe models are important for proper diagnosis

JOMFS Volume 57, Issue 9, September 1999, Pages 1040-1043

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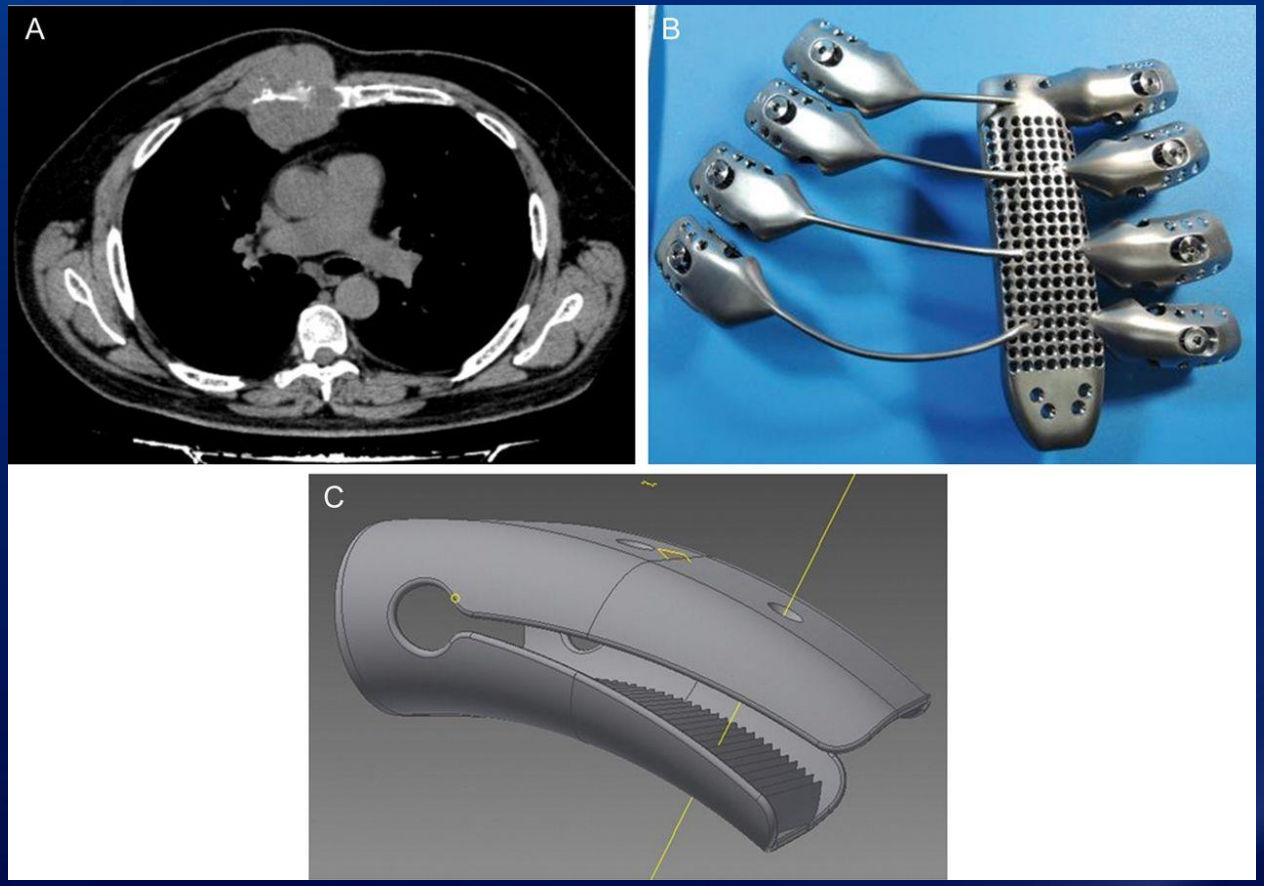
Tridimensional titanium-printed custom-made prosthesis for sternocostal reconstruction



European Journal of Cardio-Thoracic Surgery, Volume 48, Issue 4, October 2015, Pages e92–e94

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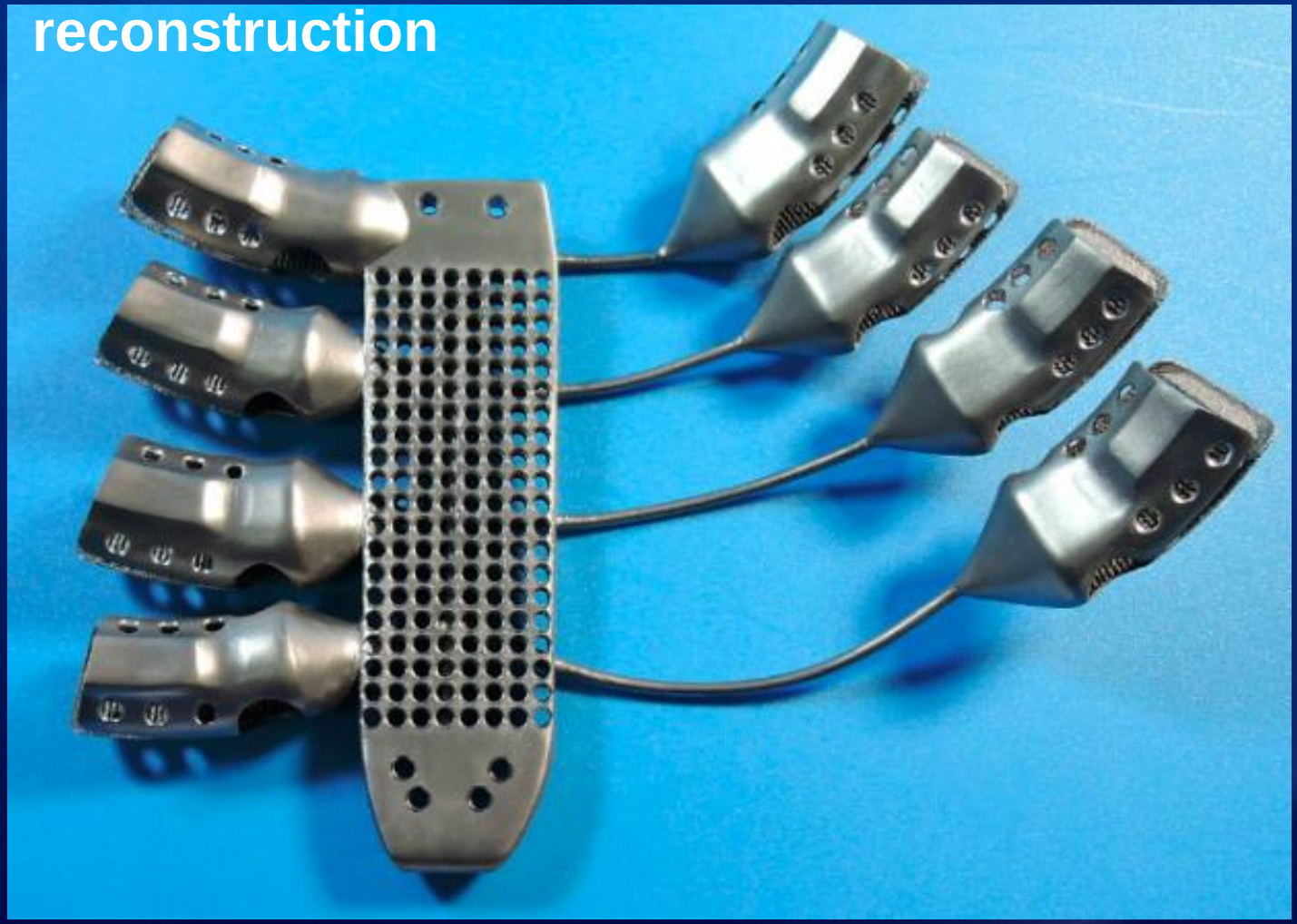
Tridimensional titanium-printed custom-made prosthesis for sternocostal reconstruction



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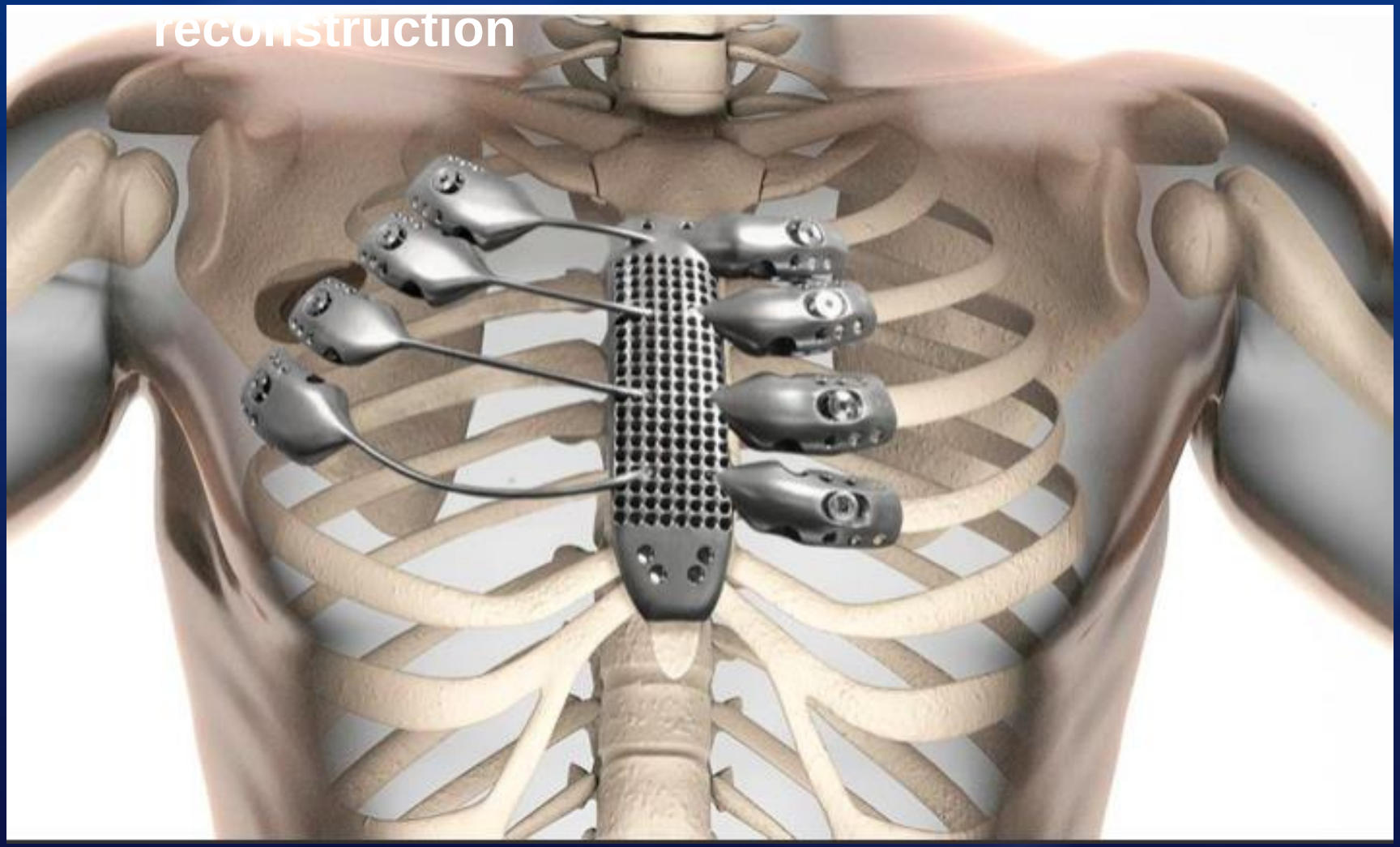

European Journal of Cardio-Thoracic Surgery, Volume 48, Issue 4, October 2015, Pages e92–e94

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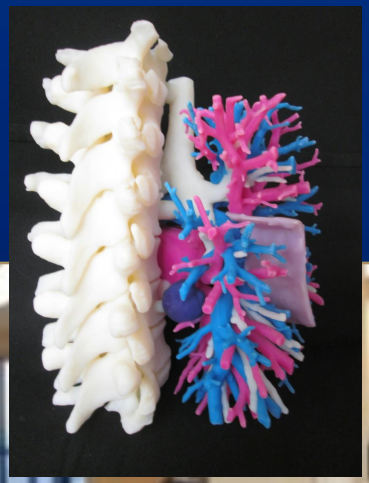
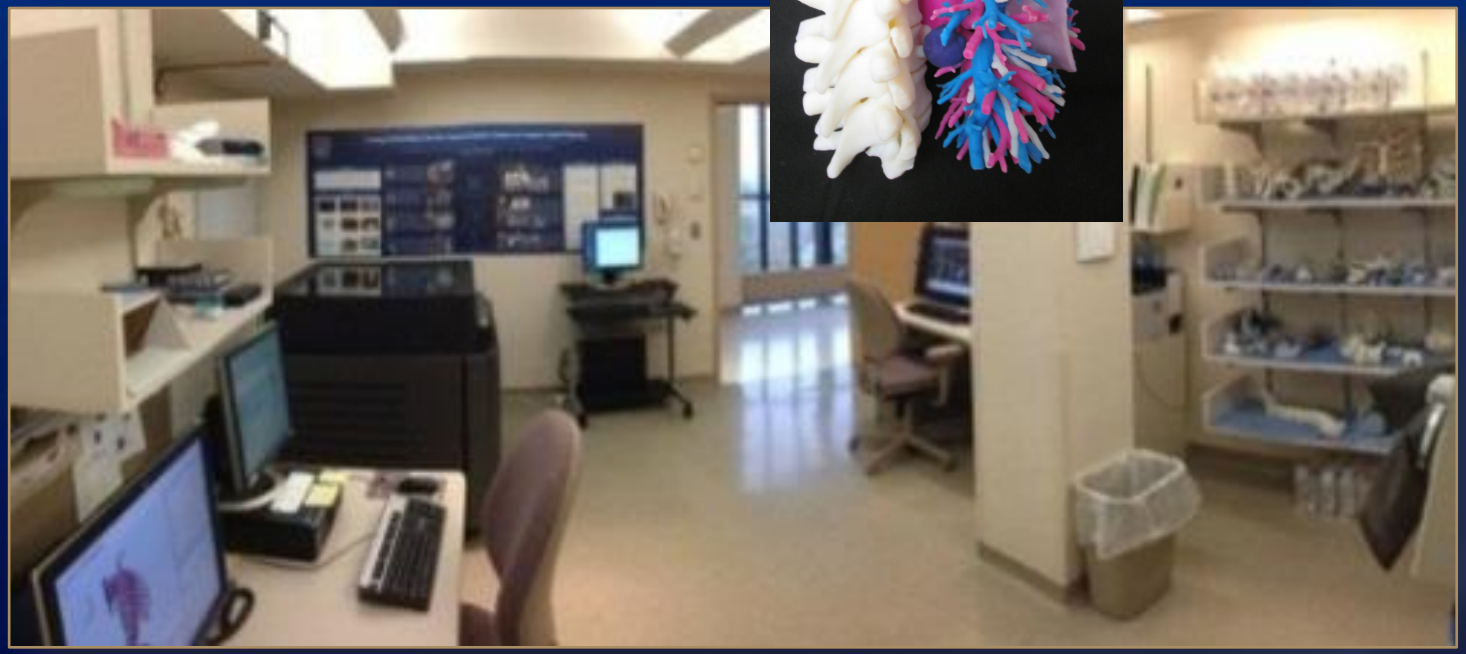
Location, location, location

Hospital Based Practice





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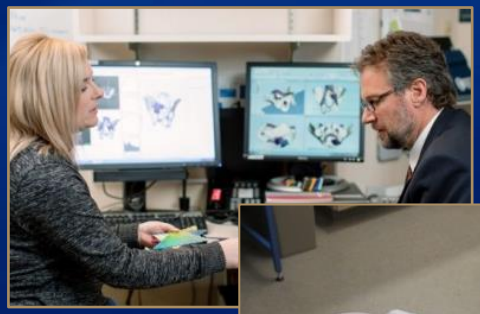
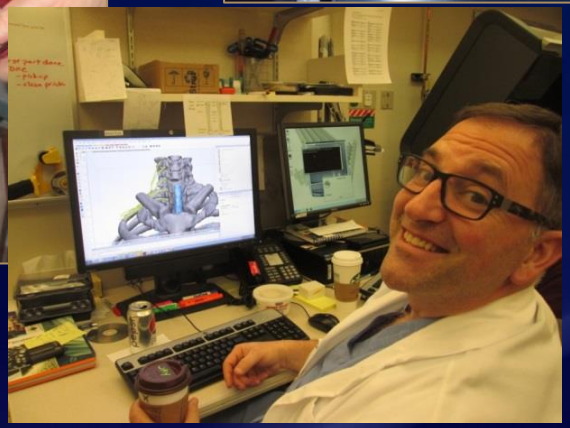
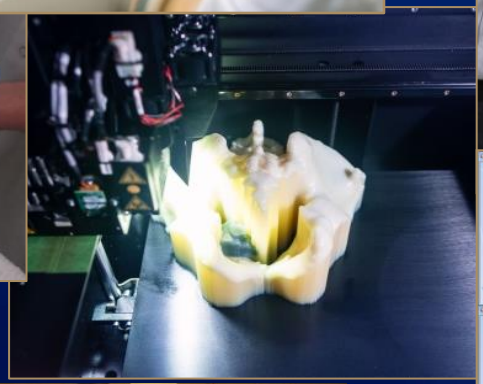
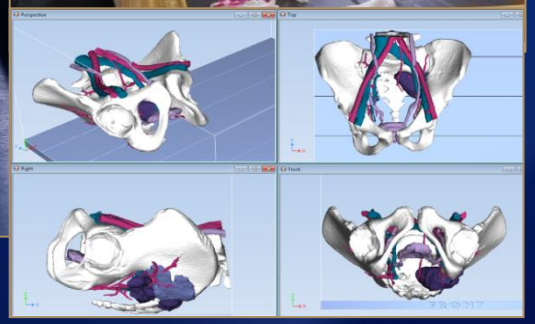
Hospital printing is like running a small shop with many moving parts……







5. Collaboration is essential

Develop closer ties to surgical colleagues.

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3D Technologies-Dimensioning Data Source (EXTERNAL ANATOMY)

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Infants and CPA:P

- Premature infants & children with sleep disorders require CPAP machines

- Problems with CPAP:
  - Ill-fitting devices—leak
  - Drying and tearing fragile skin

- Goal: Custom CPAP masks
  - Decrease leak & skin pressure

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Common types of CPAP for Infants

Hamilton Medical Infant CPAP Mask

Hudson RCL Infant Nasal CPAP

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Common types of CPAP for Infants

Hamilton Medical Infant CPAP Mask

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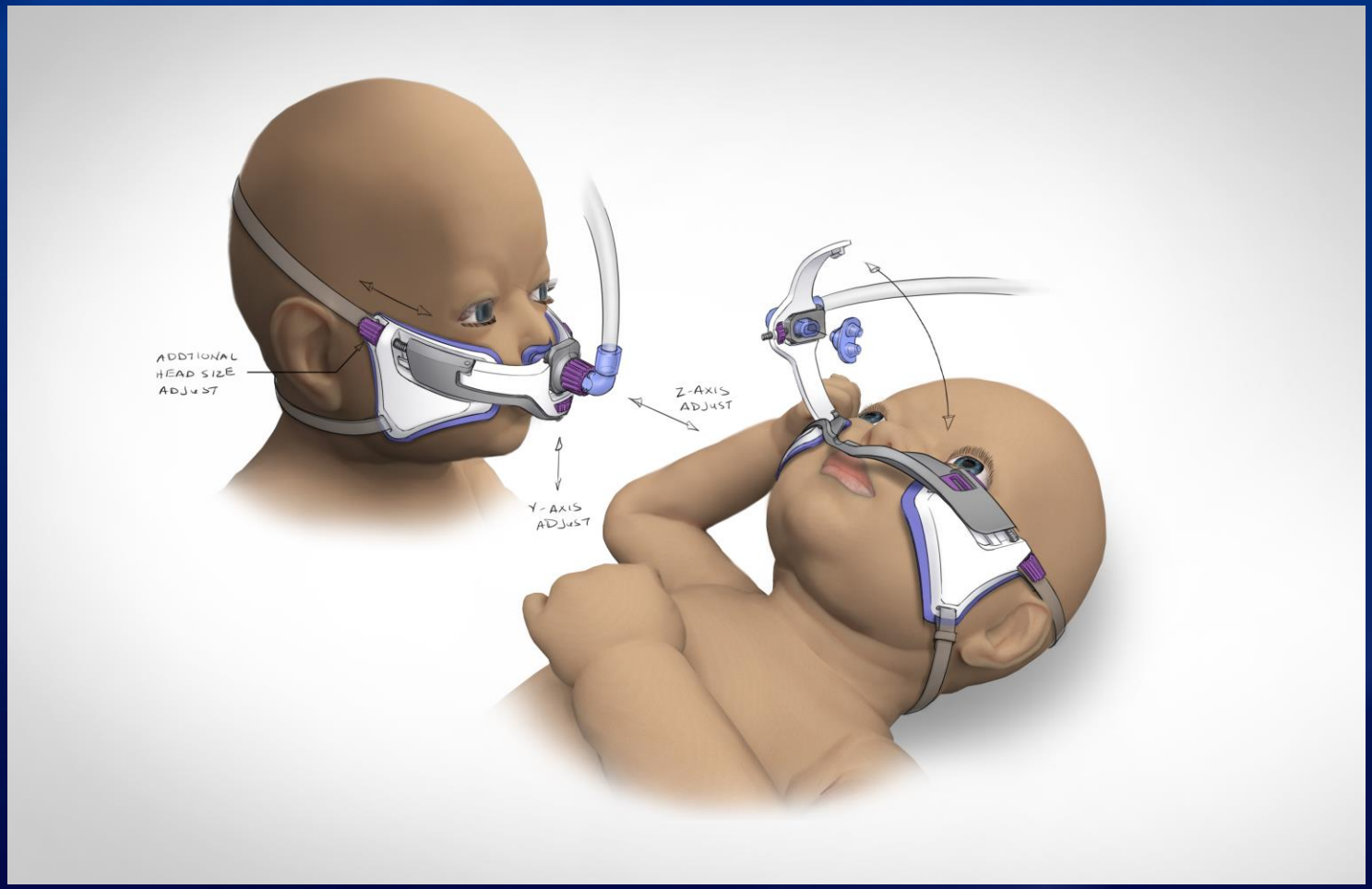
CPAP Prototype



Objectives

- Create 3D models of infants faces
  - Accurate shape and hardness
  - Inexpensive
  - Non-invasive
  - Repeatable

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Hypothesis

- A custom CPAP mask insert will reduce the overall skin pressure and mask tension to achieve no leak between the mask and the face.

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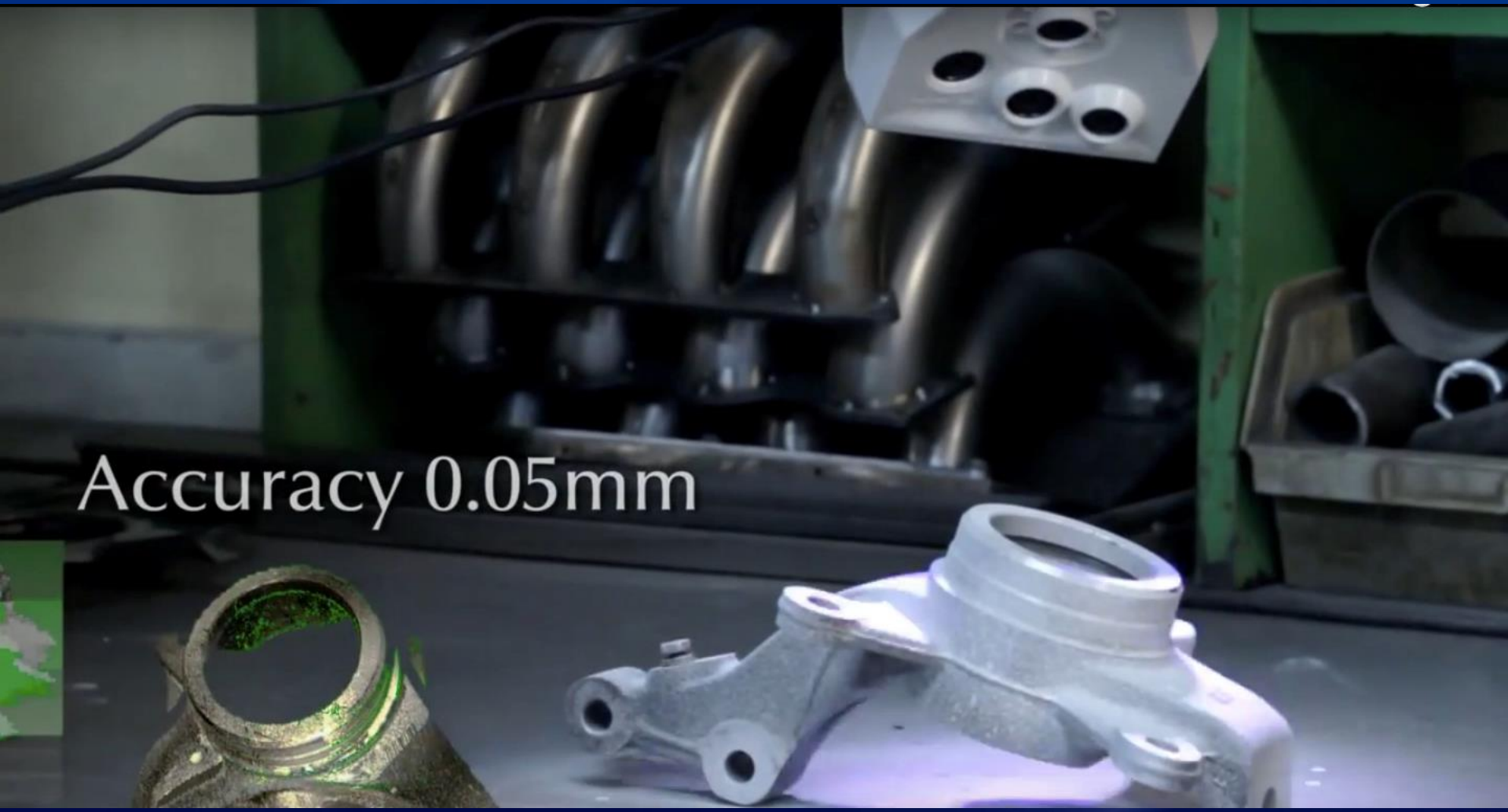
3D Surface Scanning Technologies

Computed Tomography (CT)	Laser Scanning	Photogrammetry	Structured Light Scanning
• X-ray based • Costly • Radiation	• Laser light and/or blue light • Movement • Difficulty scanning shiny surfaces	• Inaccuracy • Cumbersome • Movement artifact • Landmark registration	• New technology • Accuracy • iPHONE 10
			
			

LASER SCANNING



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LASER SCANNING

- Potential danger eye damage
- Scan time in minutes (too long)

http://1849462378.rsc.cdn77.org/wp-content/uploads/formidable-gallery/images/485/laser-scanner-artec-1030x775.jpg

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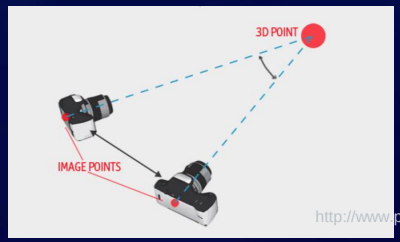
Photogrammetry

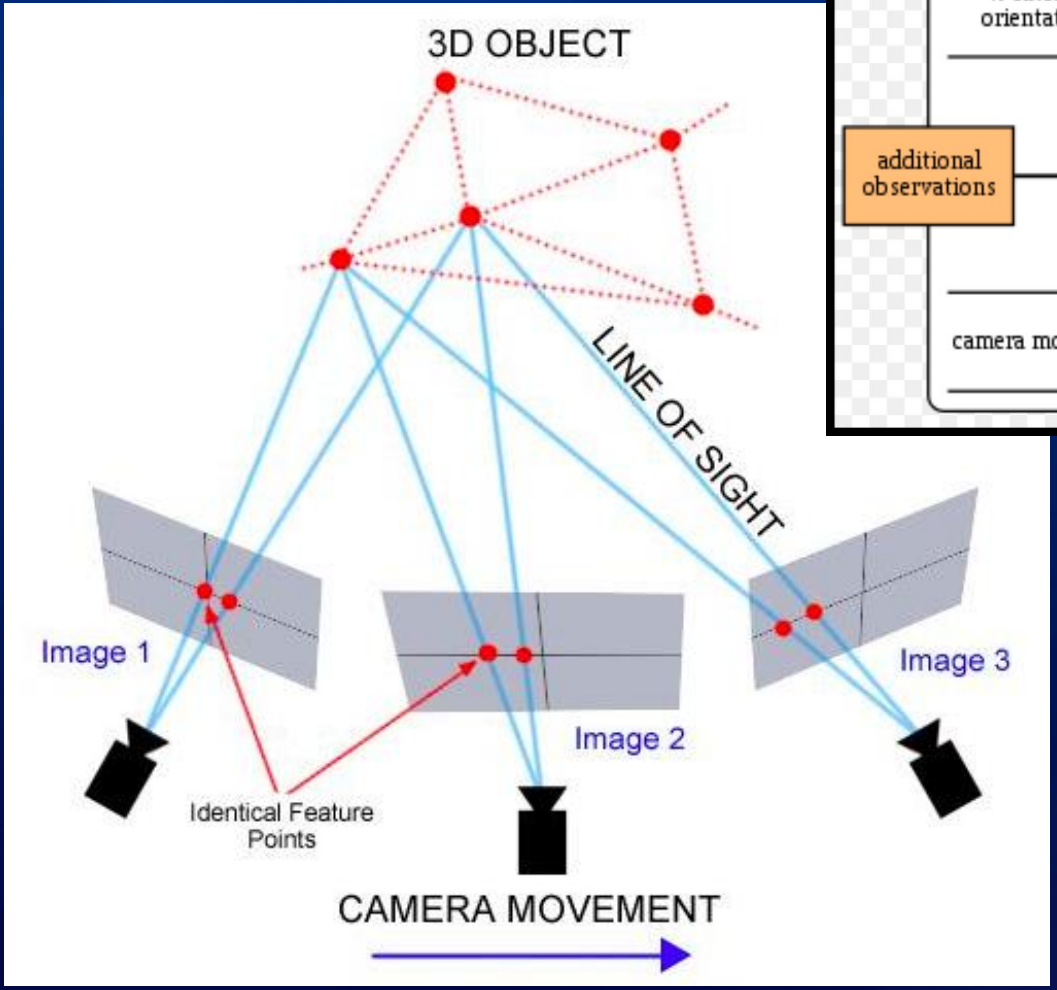
- The science of making measurements from photographs.
  - Take photographs with multiple common points
  - Software detects the camera's position and angle from the object
    - Point cloud
    - Triangulated mesh
  - Mesh creates the 3D image

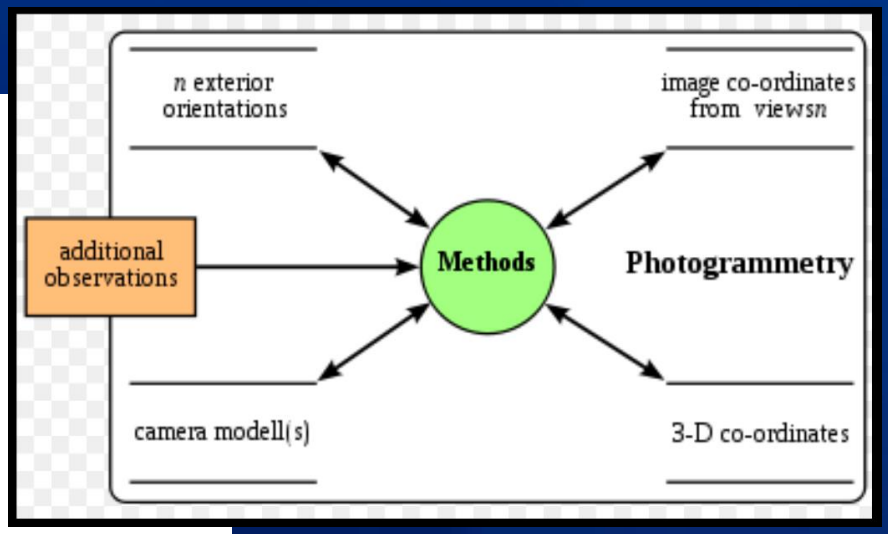


http://www.photomodeler.com/products/how-it-works.html

https://www.infotechenterprises.net/image/3D-Modelling-Meshing.jpg

Photogrammetry





Photogrammetry

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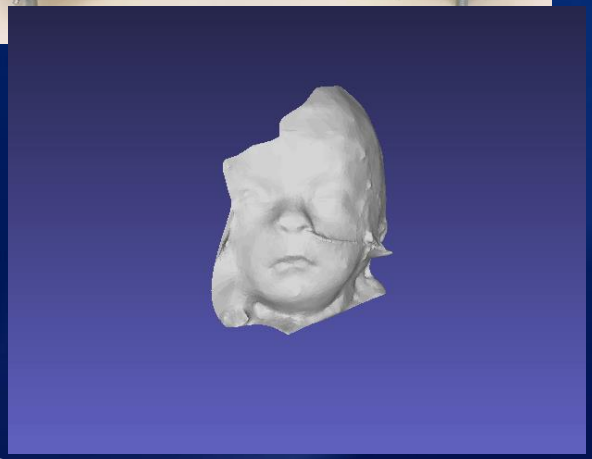
Neonatal CPAP Project

- Added texture
  - “mask” made of light
  - Ultrasound gel



- Macro and magnifying lenses
  - Macro lenses for quality of image
  - Magnifying lenses to account for wide FOV

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Partnered with a 3D modeling and surface scanning company to create a custom rig

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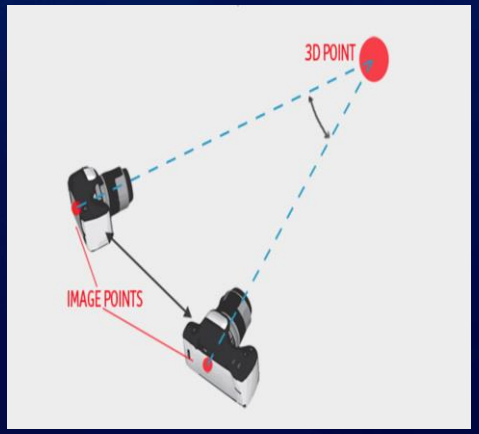
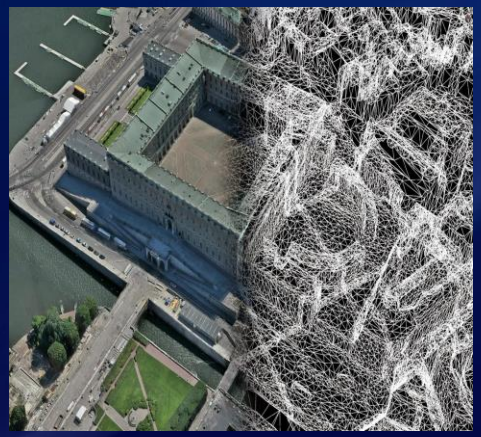
Photogrammetry

- For clinical use single camera problem is subject motion during multiple acquisitions.

- Multicamera limits use to expensive dedicated studios



http://www.photomodeler.com/products/how-it-works.html



https://www.infotechenterprises.net/image/3D-Modelling-Meshing.jpg

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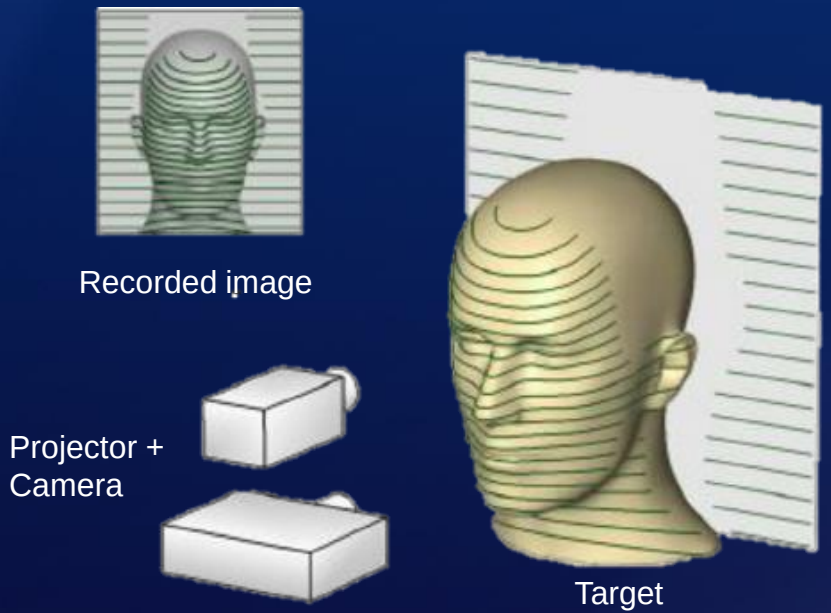
Structured Light Scanning

- Project patterns onto an object
- Calculate the distance from the scanner to the object



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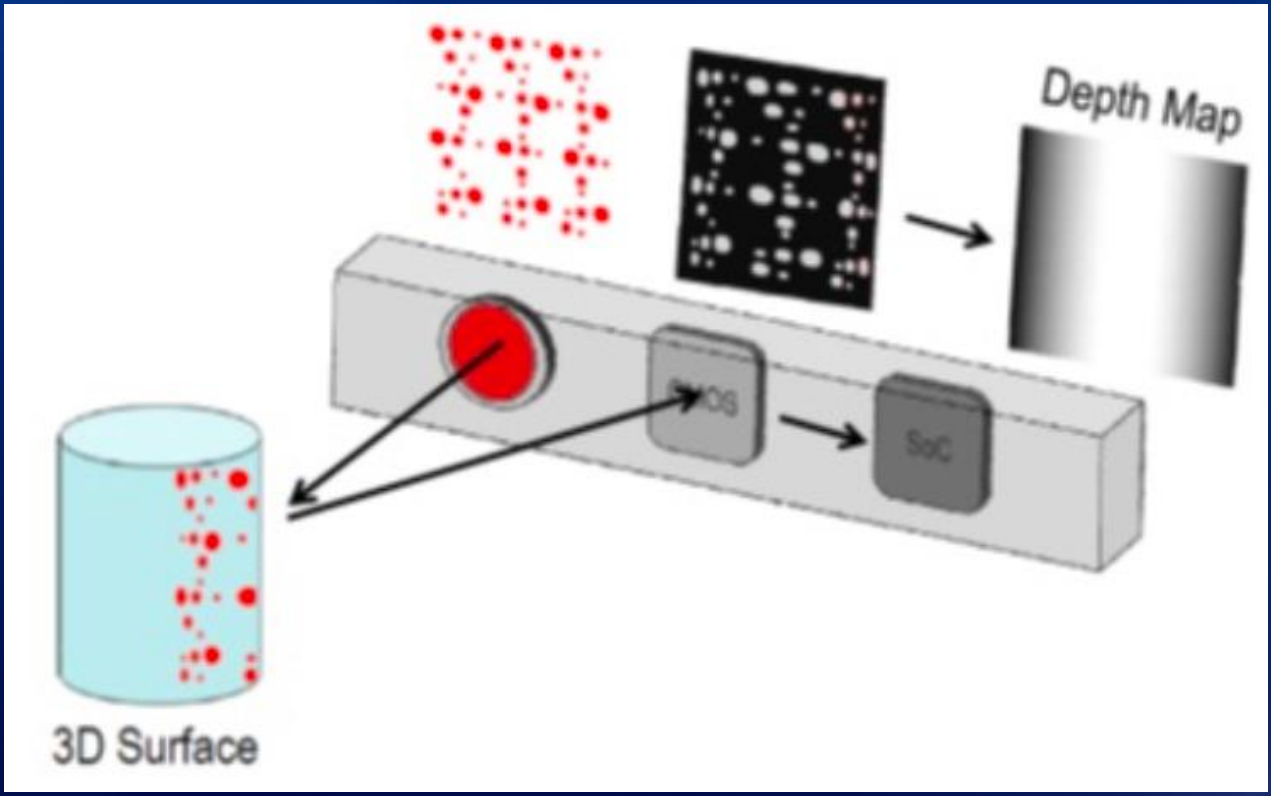
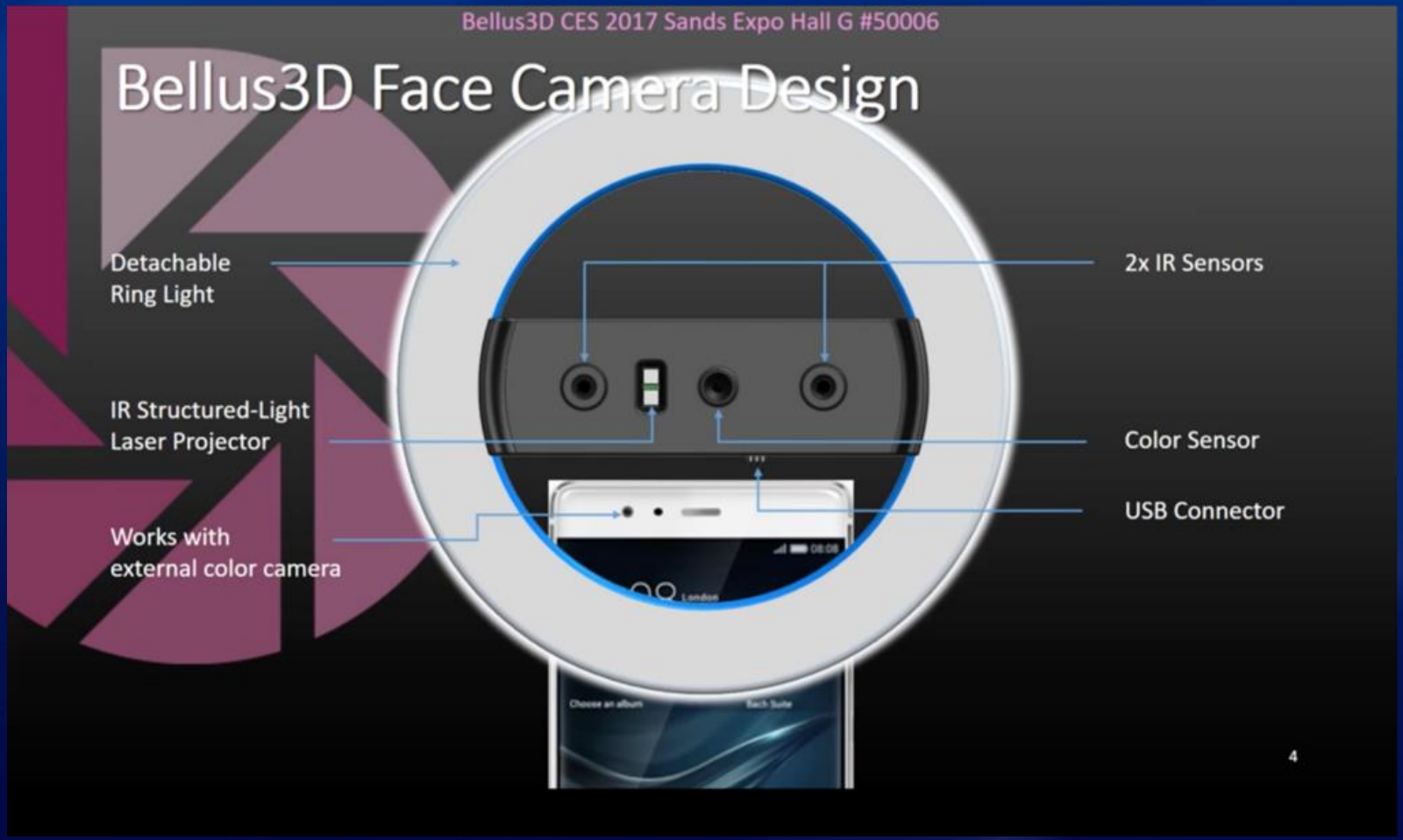
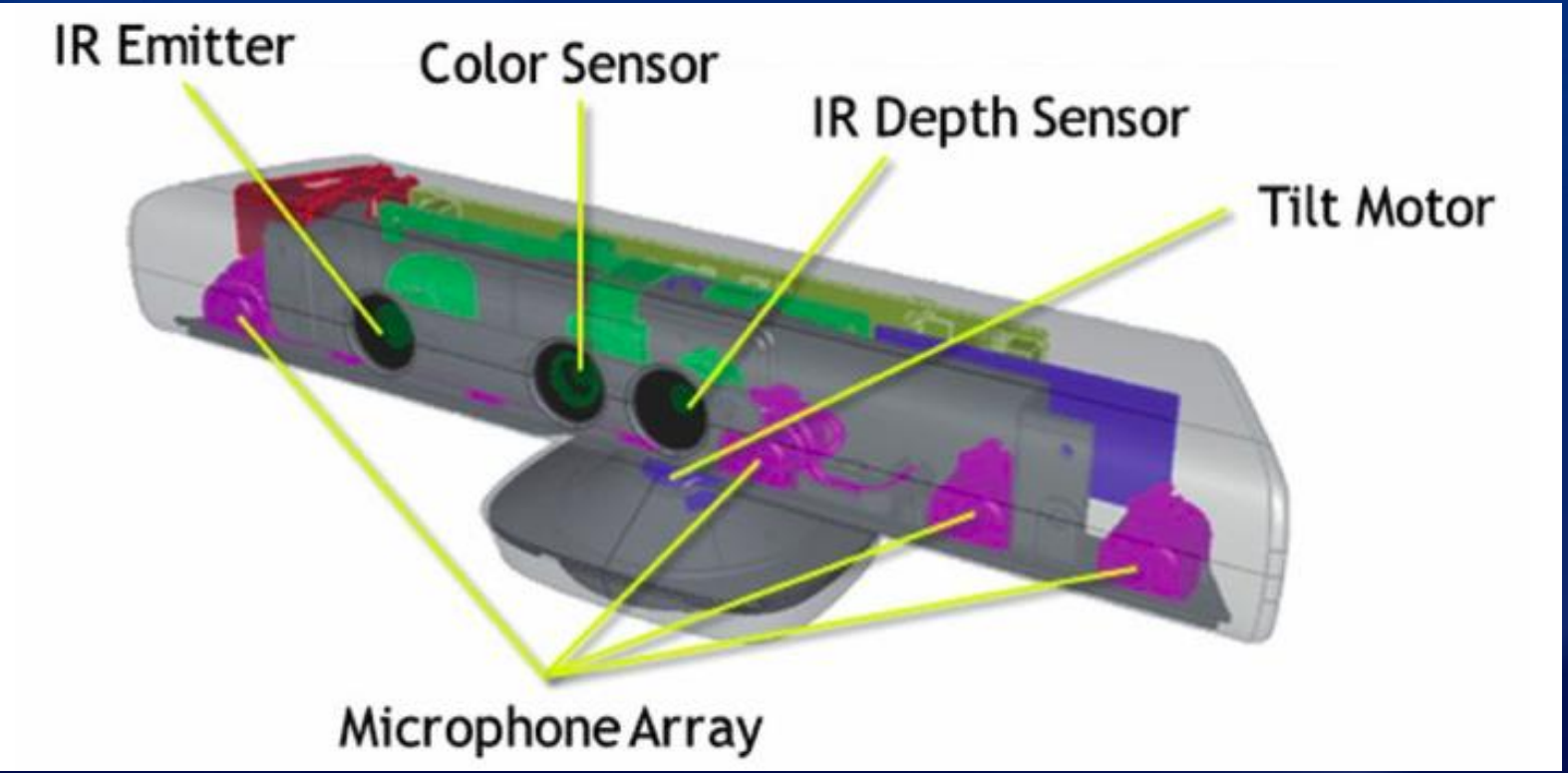
Structure Light Scanning



Bellus3D


Bellus3D CES 2017 Sands Expo Hall G #50006
Bellus3D Face Camera Design
Detachable
Ring Light
IR Structured-Light
Laser Projector
Works with
external color camera
2x IR Sensors
Color Sensor
USB Connector
4

Structure Light Scanning



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Bellus3D

1. Initial Frontal Orientation D

Orange = detecting **Green** = face detected

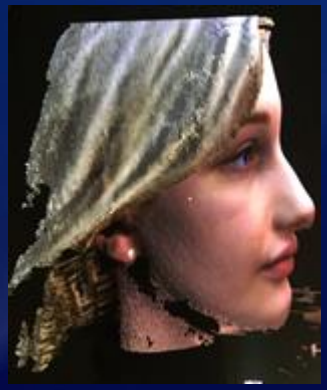
2. Initial Head Mesh: Static Frontal Sca

- Face and Eyes detected using color Imaging
- Nose Tip detected by analyzing depth data

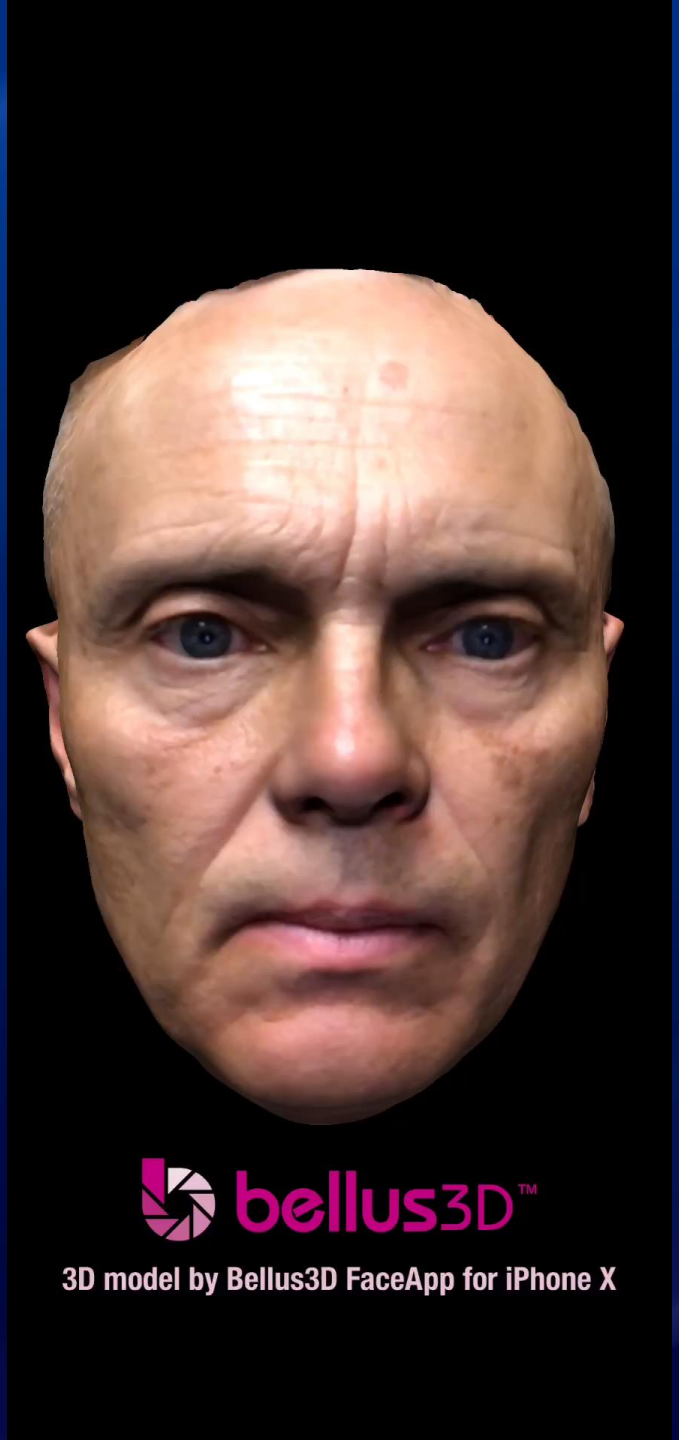
3. Second Head Mesh: Dynamic Head Tur

- Created from video frame
- Computed using transformation of 3D points

4. Final Product: OBJ with .MTL and .JPG



MAYO CLINIC



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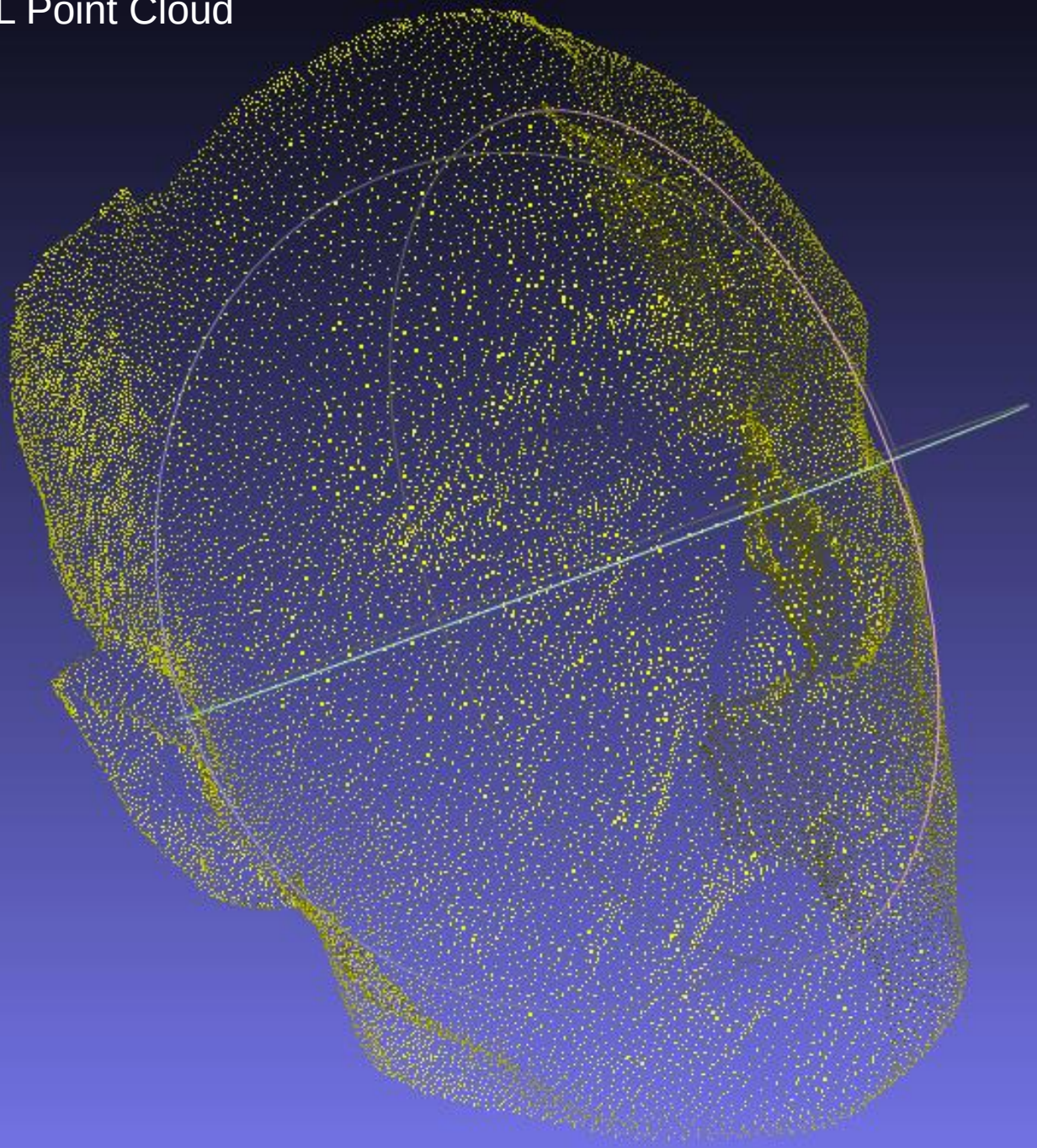
STL Point Cloud



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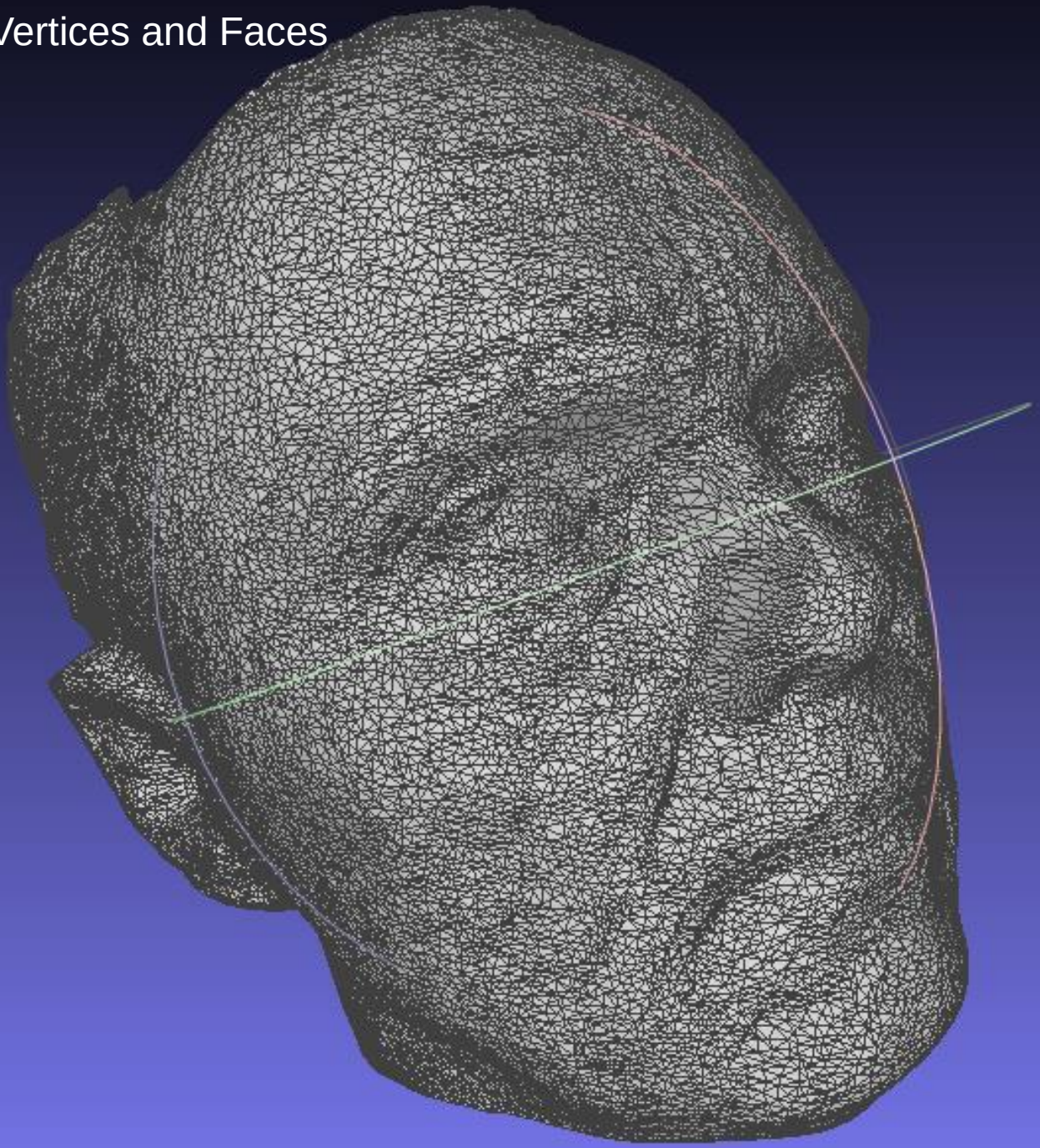
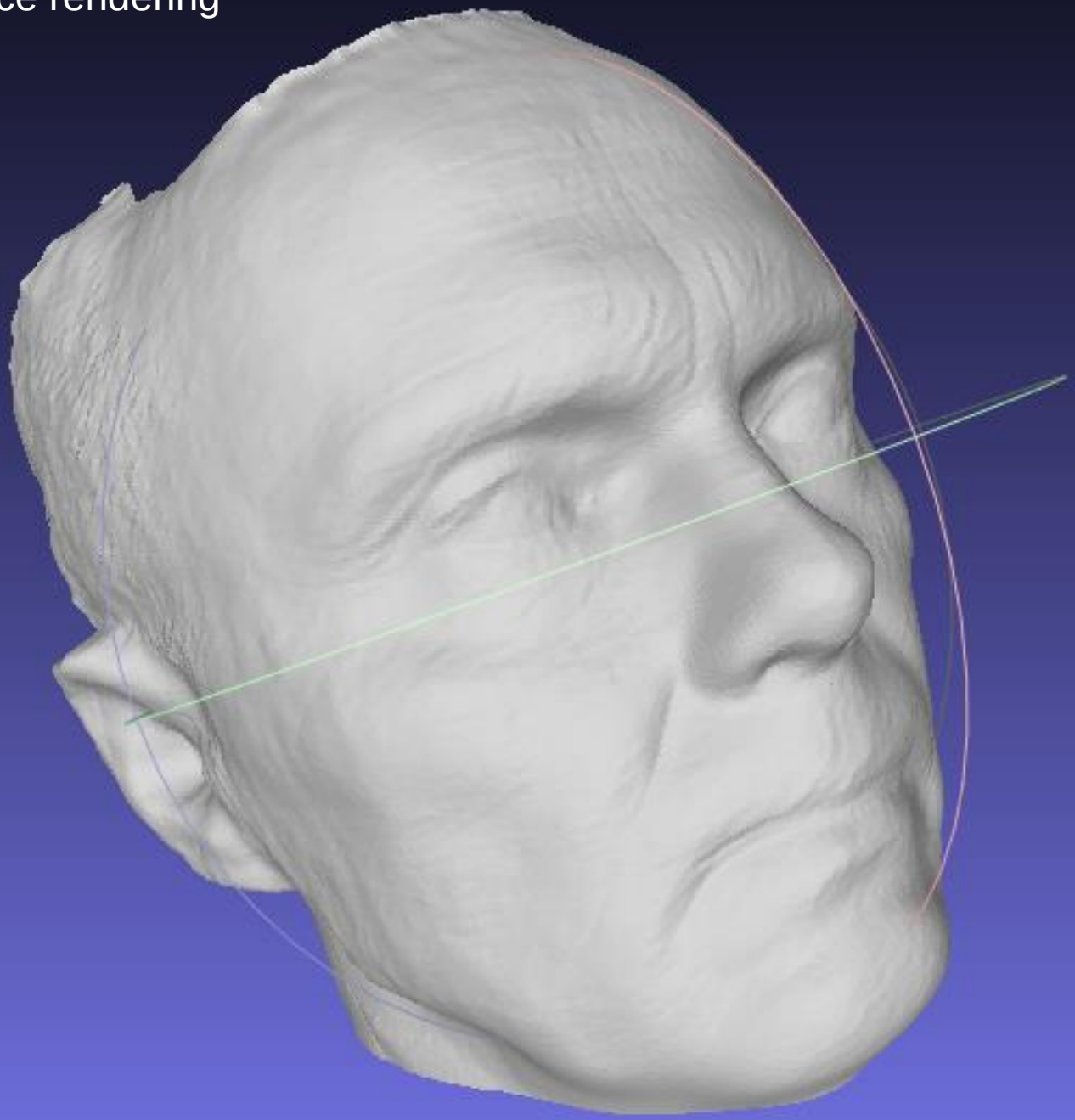
STL Vertices and Faces



MAYO CLINIC

Surface rendering



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Surface rendering

MAYO CLINIC

CPAP Test Model

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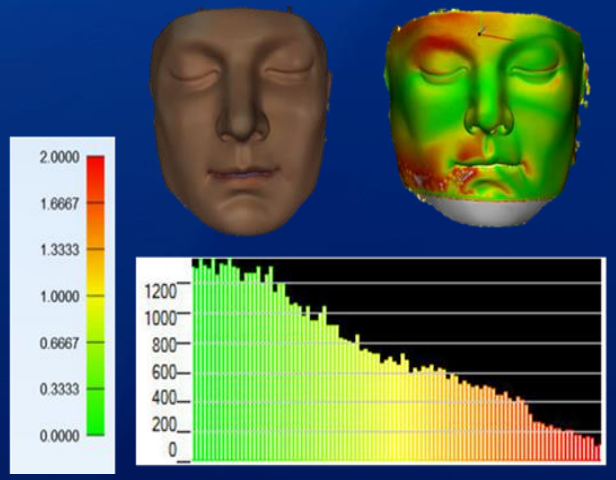
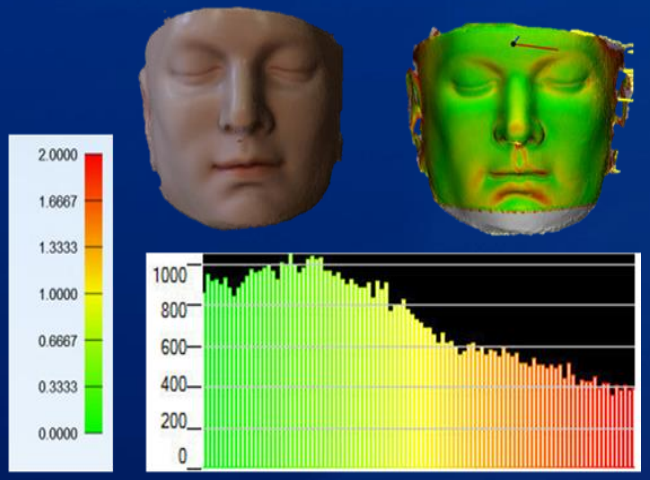
Accuracy

CT Scan

Surface Scan



Bellus3D Scan



- Green is < 1mm difference between the CT scan and the given surface scan
- Red is >1mm
- Bellus3D scan is more accurate, specifically around the nose and upper cheeks

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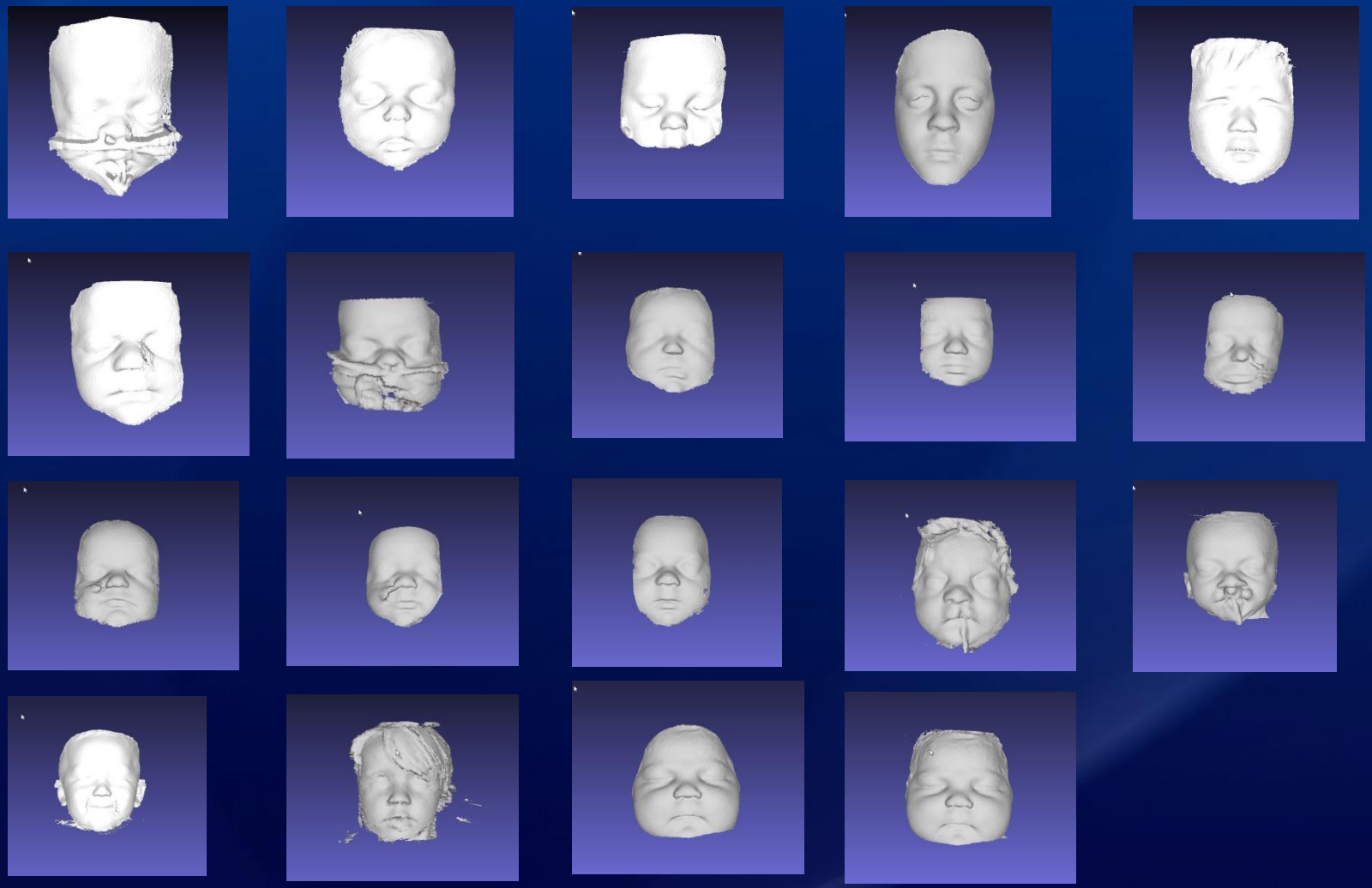
Bellus Surface Scans



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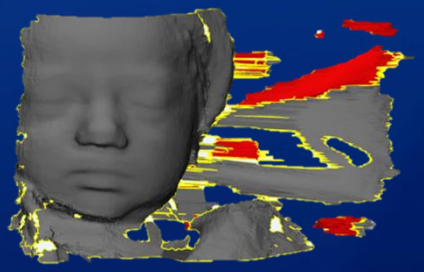
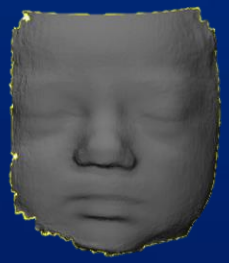
3D Model Creation

Raw STL From Bellus3D

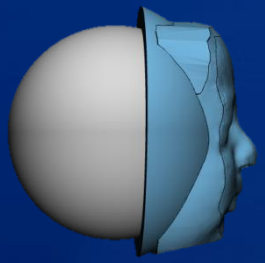


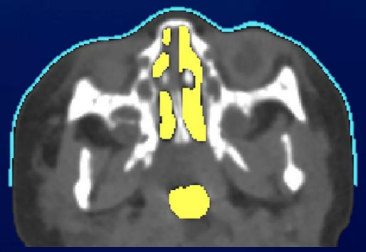
3-Matic

Trim

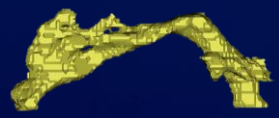


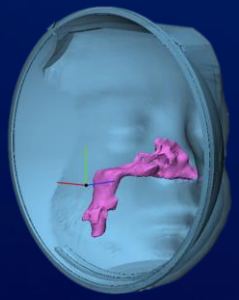
Base



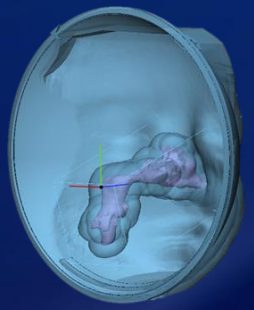


Nasal Canals

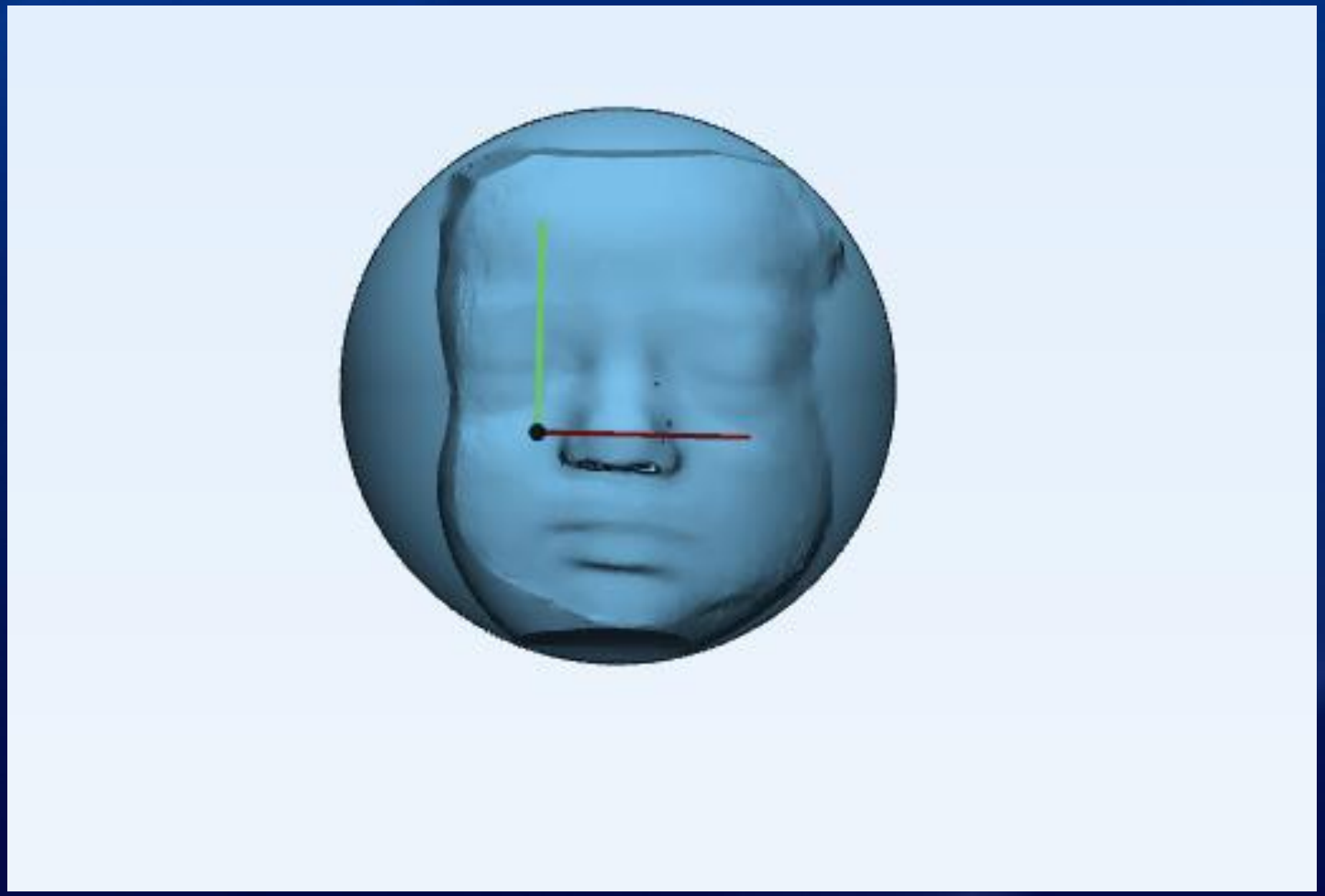




Final



Final 3D Model



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Prints






Customizable CPAP Inserts

Original CPAP Insert

(Smaller Nasal Opening)

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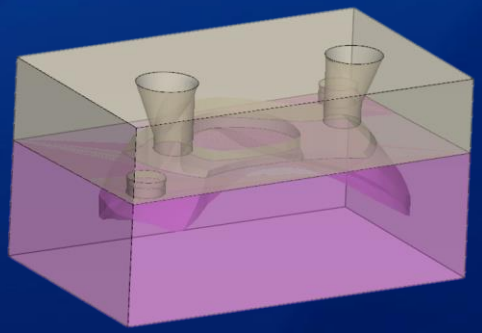
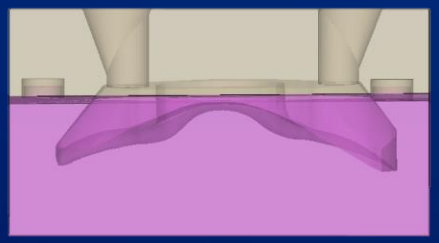
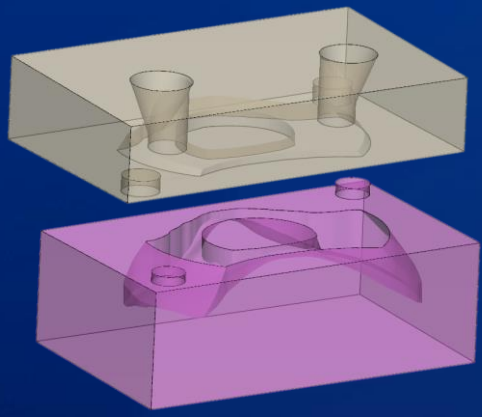
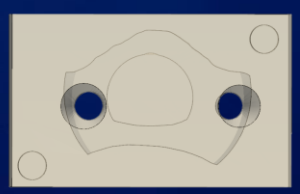
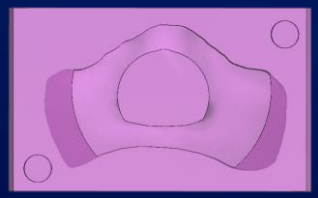
Silicone Molding Masks

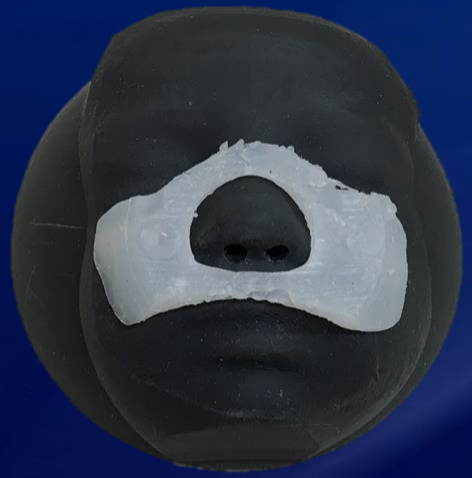








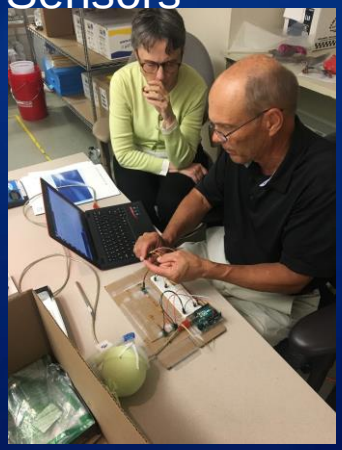


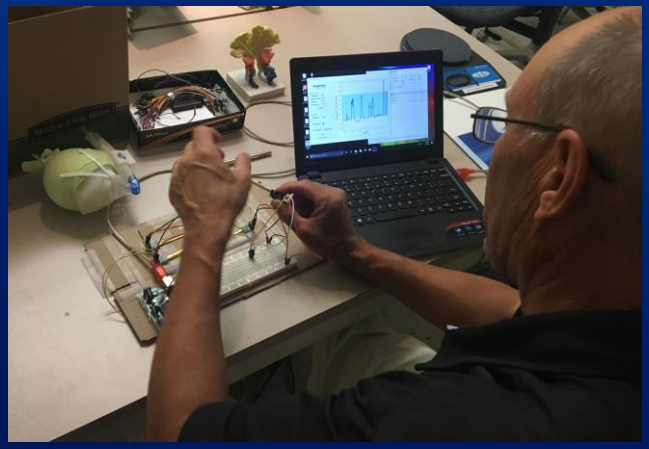


- Shore 10

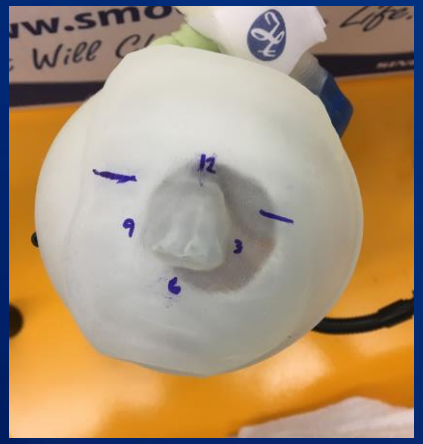
Pressure transducers: Set-up

The Arduino, Breadboard, and Sensors





Pressure Points



The Helping Hands: Soldering Tool

CPAP Mask and Bonnet

Respirator

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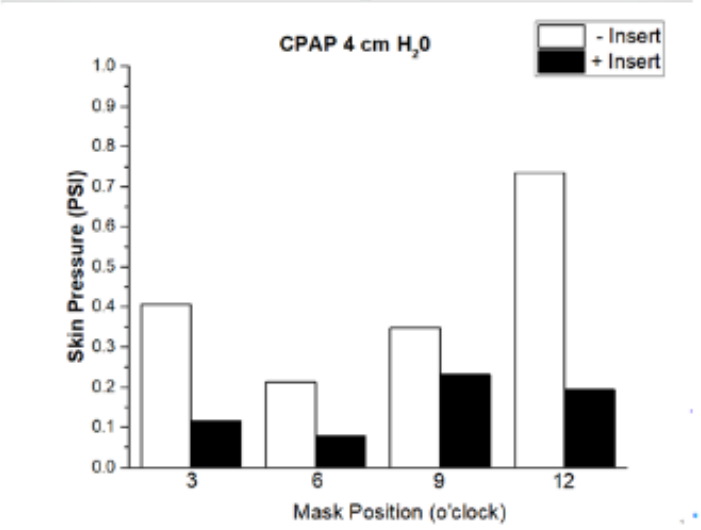
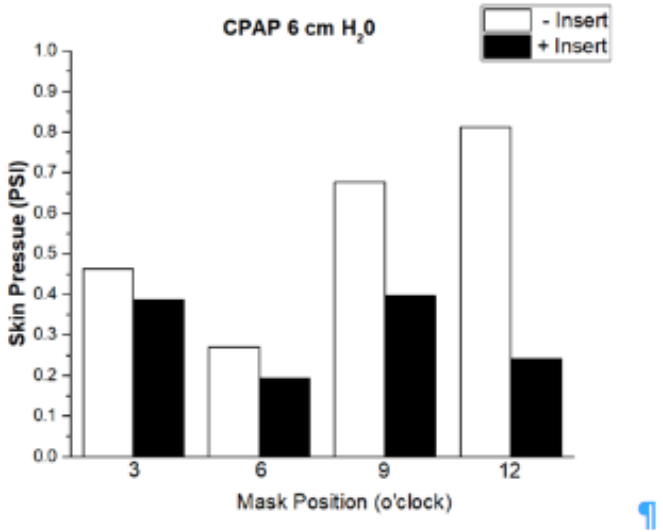
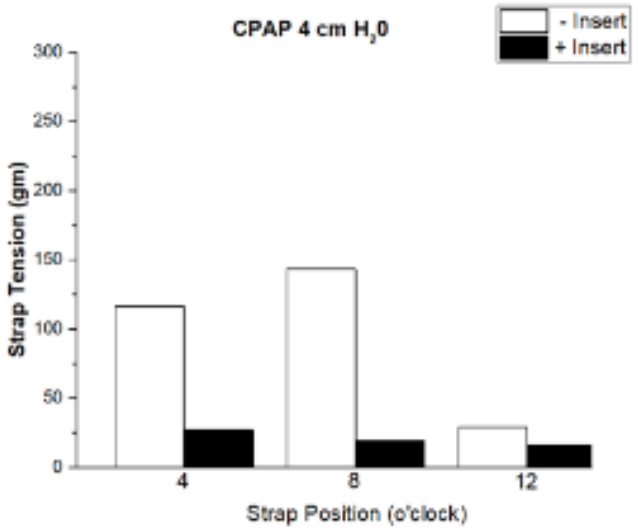
Pressure Testing

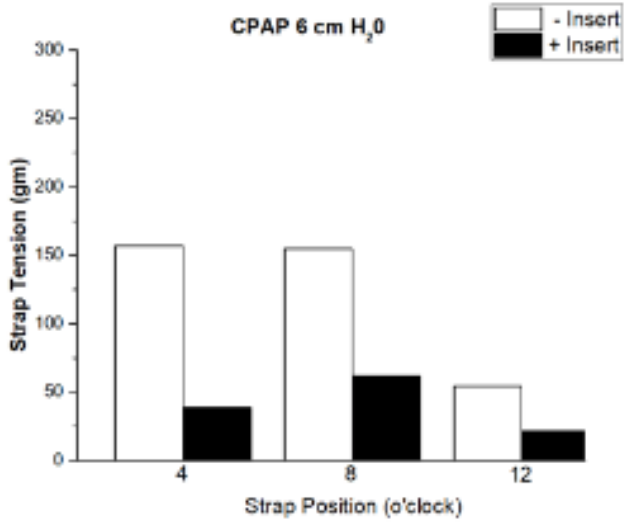
Ppeak cmH2O Output

cmH2O Set Value Input

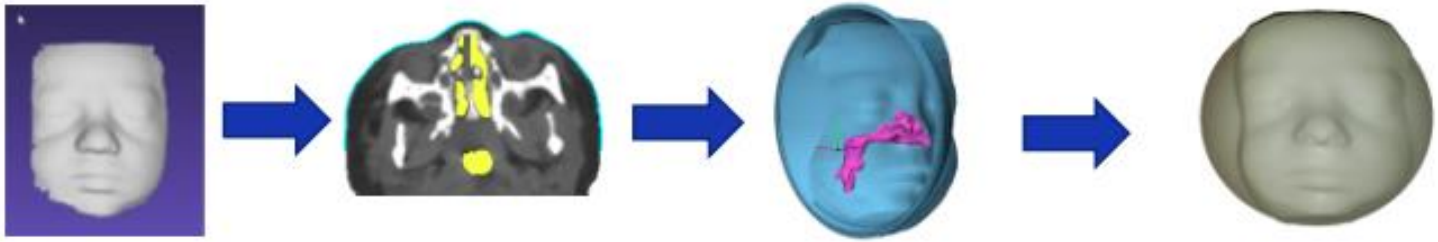

CPAP 4 cm H20
- Insert
+ Insert
Skin Pressure (PSI)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
3
6
9
12
Mask Position (o'clock)


CPAP 6 cm H20
- Insert
+ Insert
Skin Pressue (PSI)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
3
6
9
12
Mask Position (o'clock)


CPAP 4 cm H20
- Insert
+ Insert
Strap Tension (gm)
300
250
200
150
100
50
0
4
8
12
Strap Position (o'clock)


CPAP 6 cm H20
- Insert
+ Insert
Strap Tension (gm)
300
250
200
150
100
50
0
4
8
12
Strap Position (o'clock)

3D infant face model and CPAP insert design and fabrication workflow. ¶



Scanned infant face

Segment nasopharynx

CAD design: add nasopharynx to face

3D Printed facial model

Design insert to form fit face and widen contact surface area

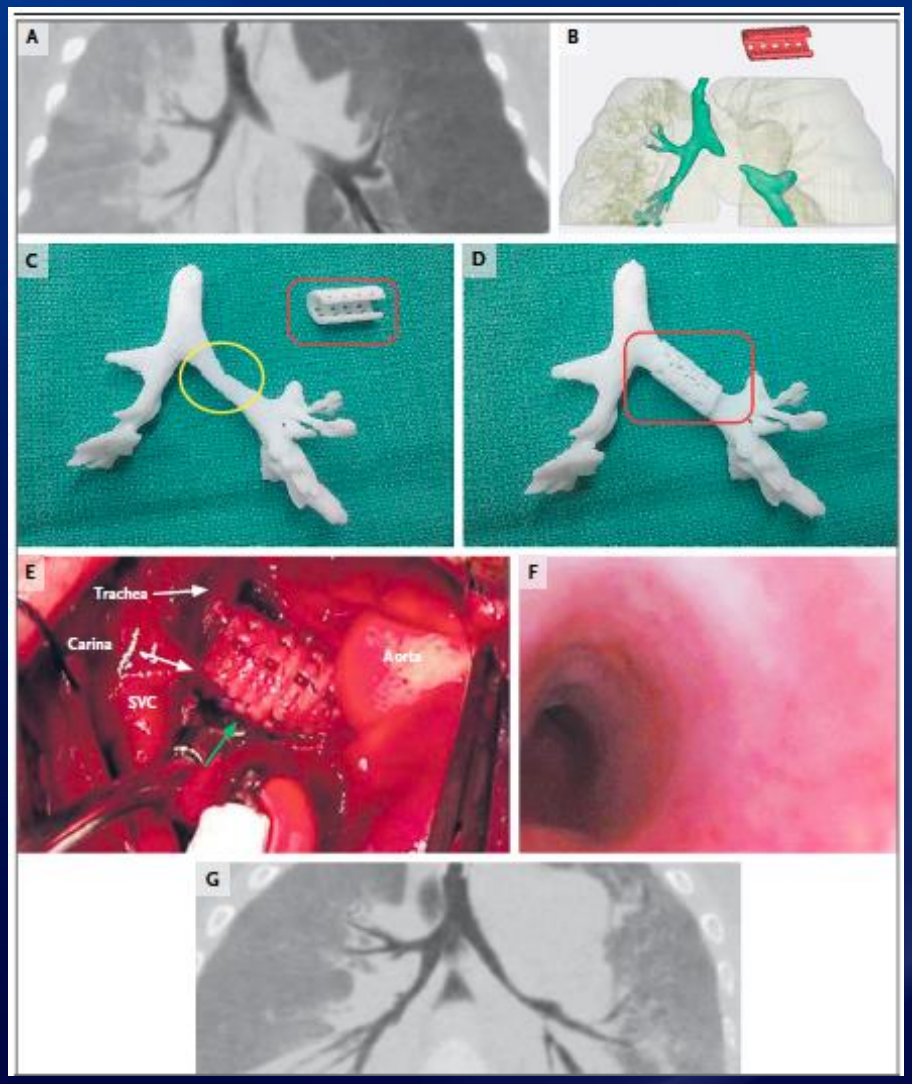
Create mold of insert and inject with silicone

Couple insert with CPAP and place on face mask of infant

Face with insert and CPAP mask for testing

¶

Polycaprolactone Splint for Tracheomalacia



NEJM 368;21 May 23, 2013

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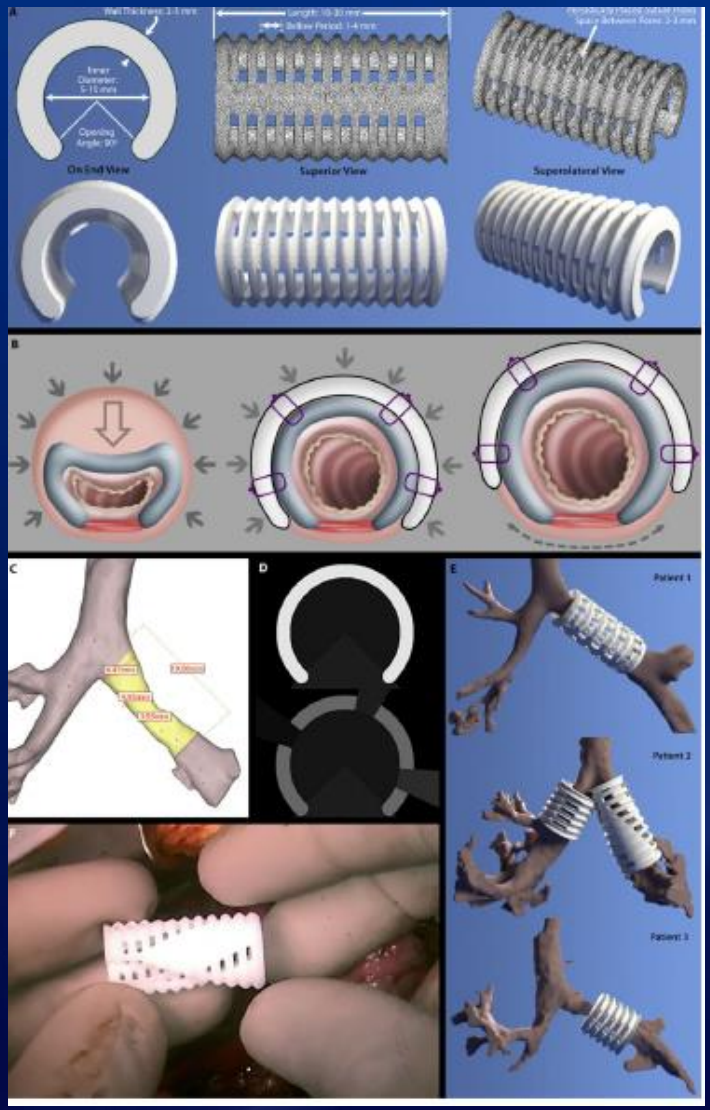
Polycaprolactone Splint for Tracheomalacia

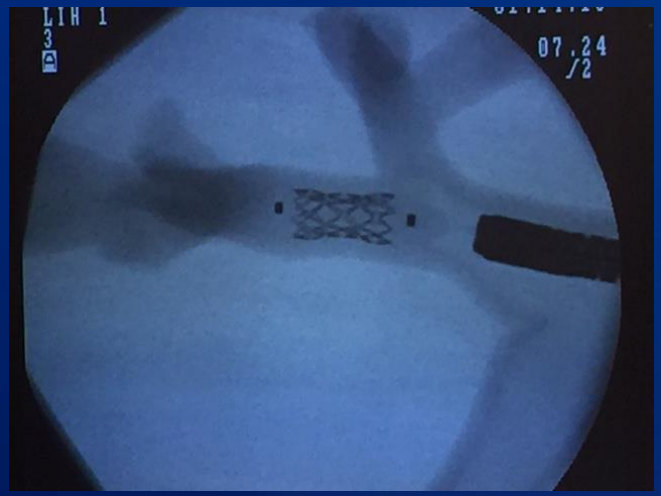
Expanded with airway growth (in the "fourth dimension").



Sci Transl Med. 2015 April 29; 7(285):

Innovation

Tracheal stent deployment



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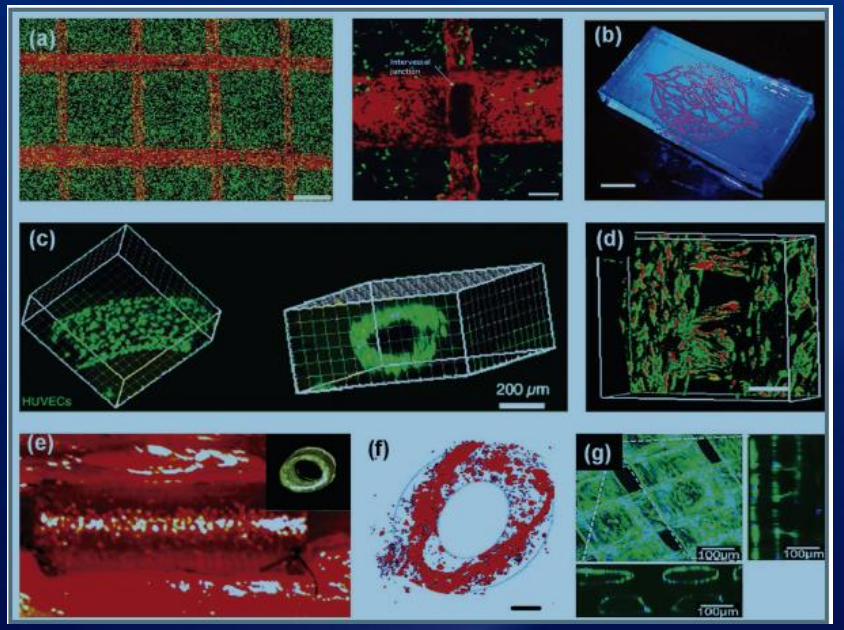
3D Bioprinting for Organ Regeneration

- Cellular Bioprinting
  - Droplet based (inkjet like cell-laden hydrogel)
  - Extrusion-based (extrudes cell-laden filament)
  - SLA-based
- Acellular Bioprinting
  - Extrusion-based scaffolds
  - Laser-based scaffolds



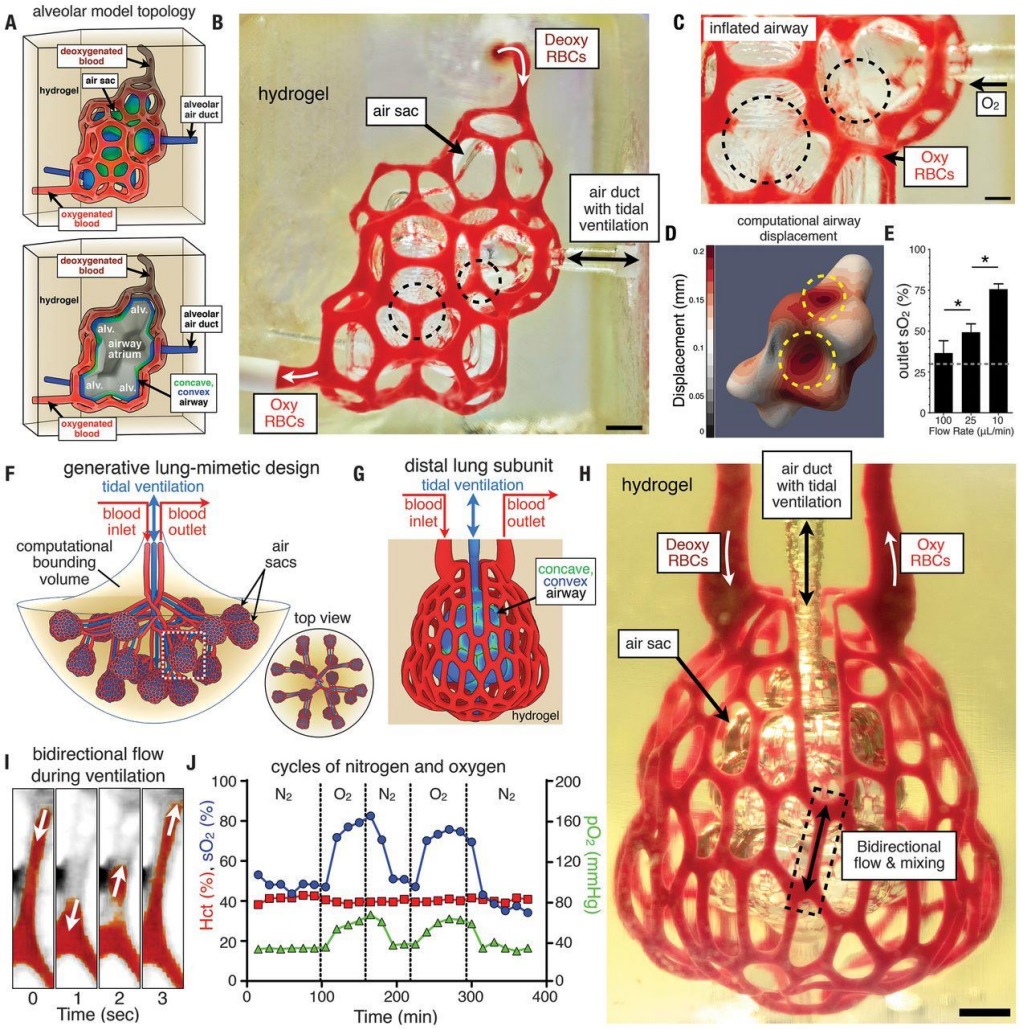
Adv Healthc Mater. 2017 January ; 6(1):

Hydrogel SLA Printing of Lung Unit

Science 03 May 2019:
Vol. 364, Issue 6439, pp. 458-464

Jordan Miller, Rice University

Fig. 3 Tidal ventilation and oxygenation in hydrogels with vascularized alveolar model topologies.



Bagrat Grigoryan et al. Science 2019;364:458-464

Science
AAAS

Reimbursement

AMA approves category III (CPT) code June 26, 2019

CPT Code	Code Description
0559T	Anatomic model 3D printed from image data set(s); first individually prepared and processed component of an anatomic structure
0560T	Each additional individually prepared and processed component of an anatomic structure (List separately in addition to code for primary procedure) (Use 0560T in conjunction with 0559T)
0561T	Anatomic guide 3D printed and designed from image data set(s); first anatomic guide
0562T	Each additional anatomic guide (List separately in addition to code for primary procedure) (Use 0562T in conjunction with 0561T)

U.S. Centers for Medicare and Medicaid may use these coding instruments for FUTURE reimbursement.

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Question 3

- The most important person in a 3D printing laboratory is the…

  - A) Radiologist
  - B) Anatomist
  - C) CAD station “segmenters”
  - C) Pulmonologists
  - D) Biomedical Engineer
  - E) Surgeons
  - F) Financial Administrator

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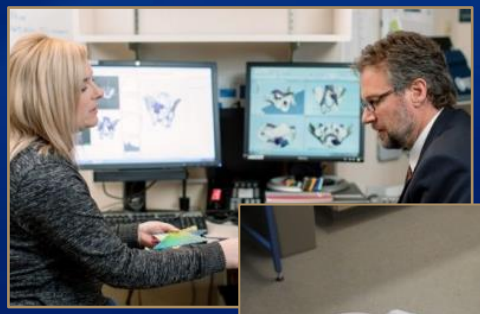
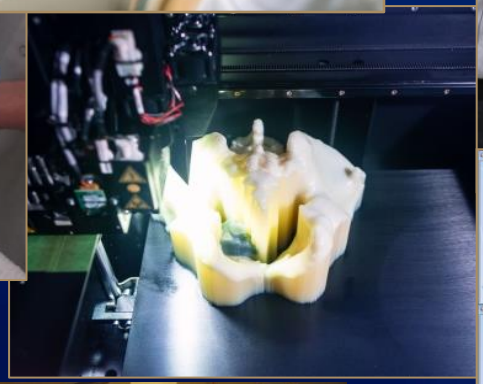
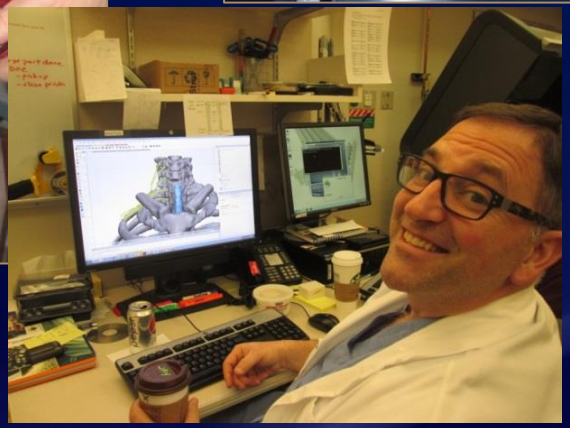
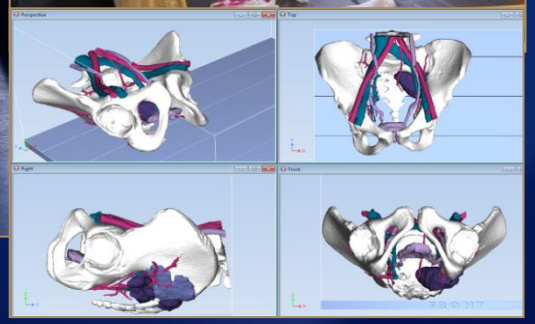
Hospital printing is like running a small shop with many moving parts……



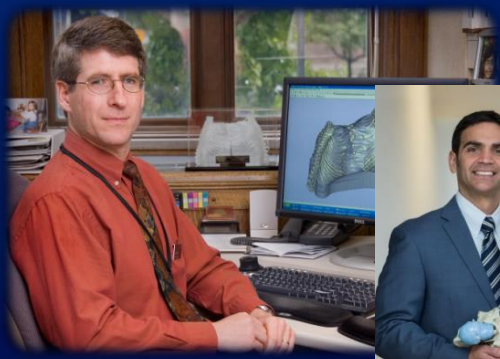




3D Modeling is a CONVERGENCE: Surgery, Radiology, Engineering……



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Questions & Discussion