

Principles, Pitfalls and Techniques of 3D Printing for Bolus and Compensators

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Learning Objectives

- Printer types
- Printing materials
- Modeling bolus/compensator
- From design to fabrication



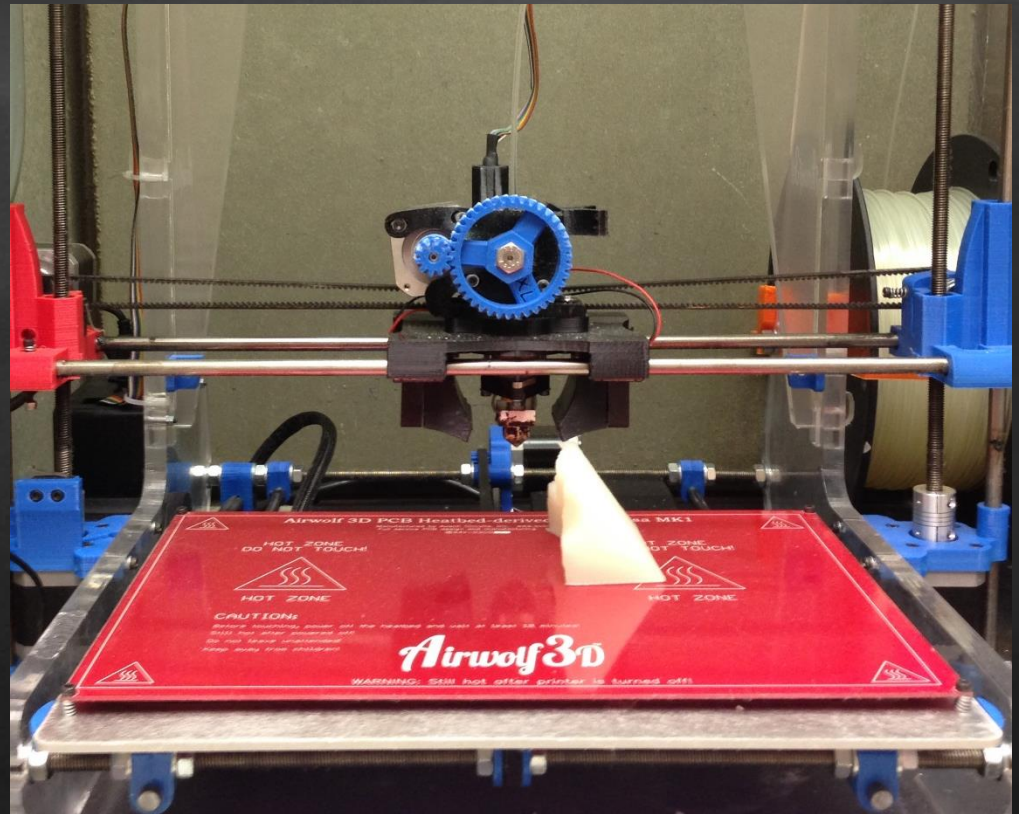
Printer Selection

Printing Method	Printer Type	Advantages	Disadvantages
Laser Fusion	(SLA) Stereolithography (SLS) Selective Laser Sintering (SLM) Selective Laser Melting	Quality Print Speed	Cost
Lamination	(LOM) Laminated Object Manufacturing	Print Cost Print Speed	Startup Cost
Molten Material Extrusion	(FDM) Fused Deposition Modeling	Cost	Print Speed

Fused Deposition Modeling

Desired Printer Specifications

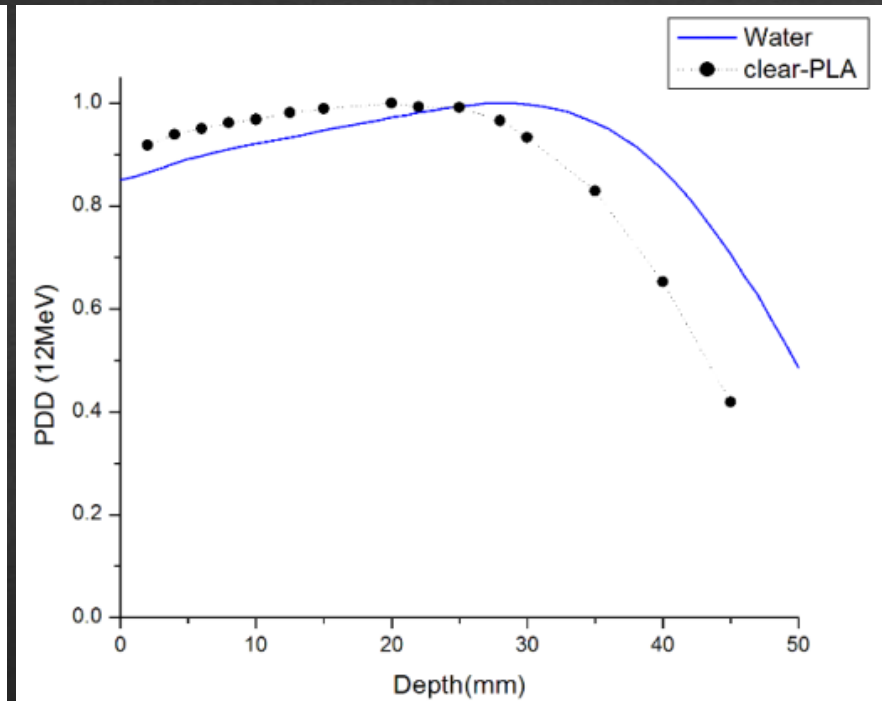
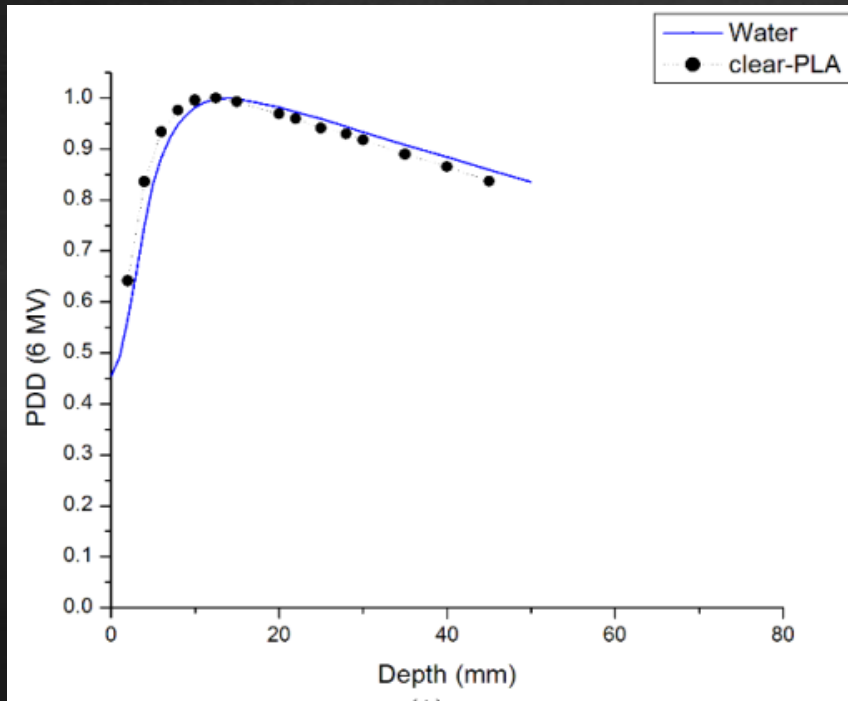
- **Dual extruders**
- Heated build platform or chamber
- Large maximum build size



Printer Materials

Material	Purpose	Advantage	Disadvantage
PLA – Polylactic Acid	Bolus	Low print failures	High electron density
ABS – Acrylonitrile Butadiene Styrene	Bolus	Electron density similar to water	Prone to layer separation
PVA – Polyvinyl Acetate	Support material	Dissolves in water	
Flexible PLA	Flexible bolus	Conforms to patient	Higher cost High print failure

Modeling Bolus or Compensator



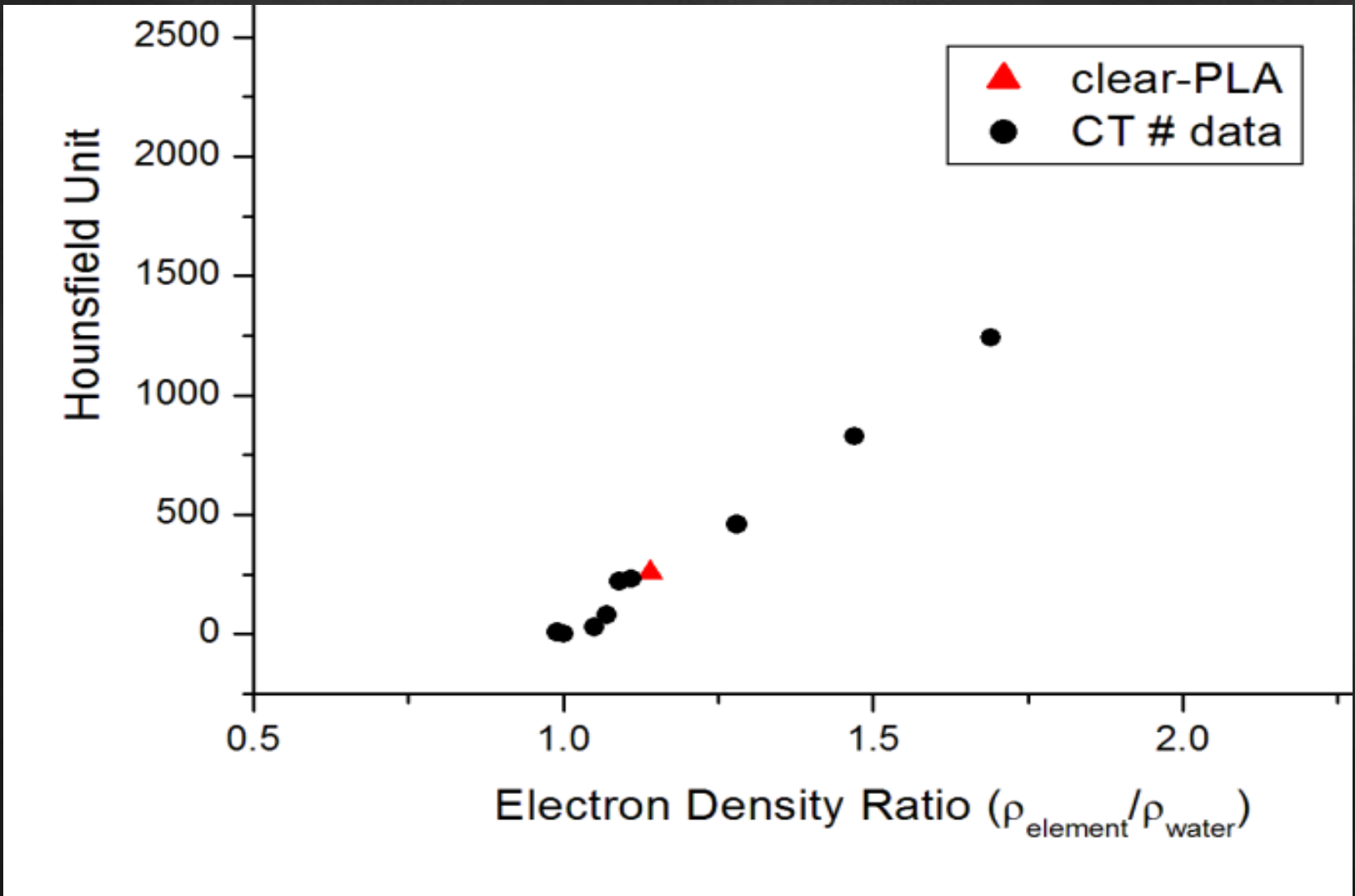
Burleson et al. Use of 3D Printers to create patient-specific 3D bolus for external beam therapy. Journal of Applied Clinical Medical Physics. 2015; 16(3):166-178

Determining Electron Density

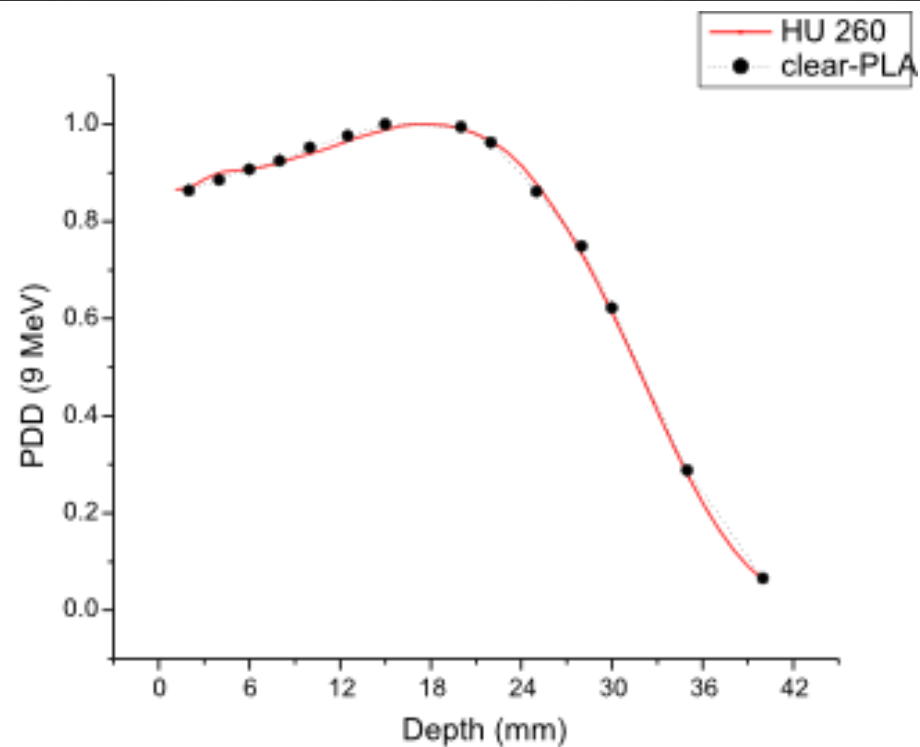
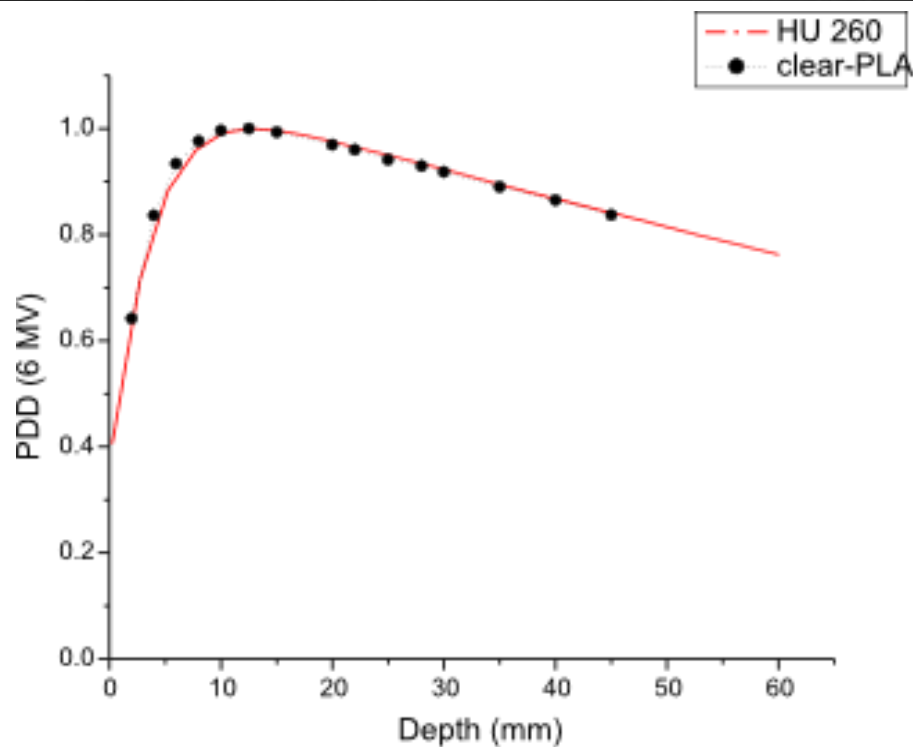
	PLA	Water
Chemical Formula	$C_3H_4O_2$	H_2O
Physical Density (g/cm ³)	1.196	1
Electron Density (e ⁻ /cm ³)	3.80E+23	3.35E+23
$\rho_e \text{ PLA} / \rho_e \text{ H}_2\text{O}$	1.14	

$$\rho_e = \frac{N_A * e^-/\text{molecule} * \rho_m}{A_{\text{tot}}}$$

- Data is site specific due to print density variations

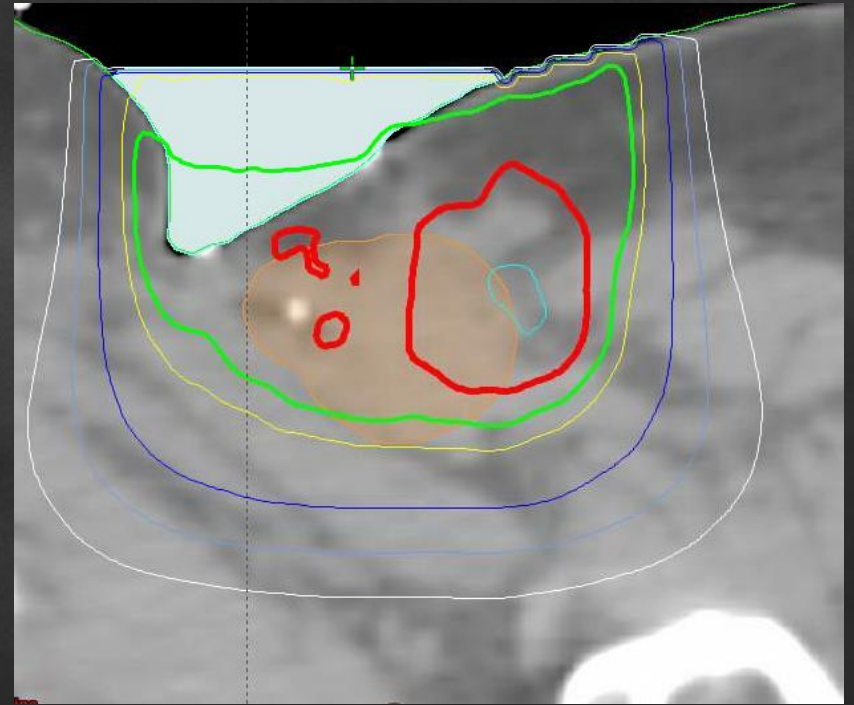
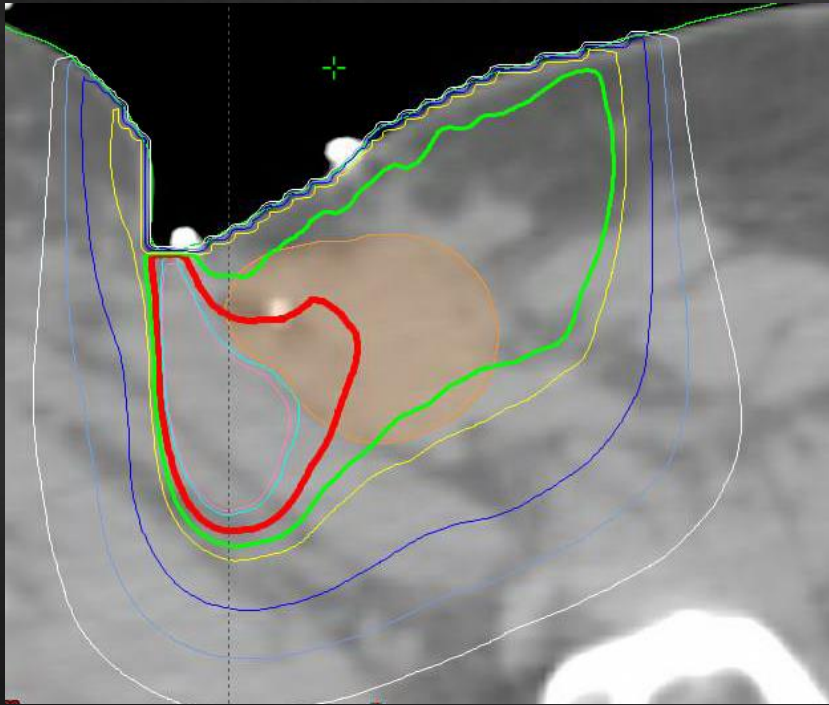


Modeled Attenuation



Burleson et al. Use of 3D Printers to create patient-specific 3D bolus for external beam therapy. Journal of Applied Clinical Medical Physics. 2015; 16(3):166-178

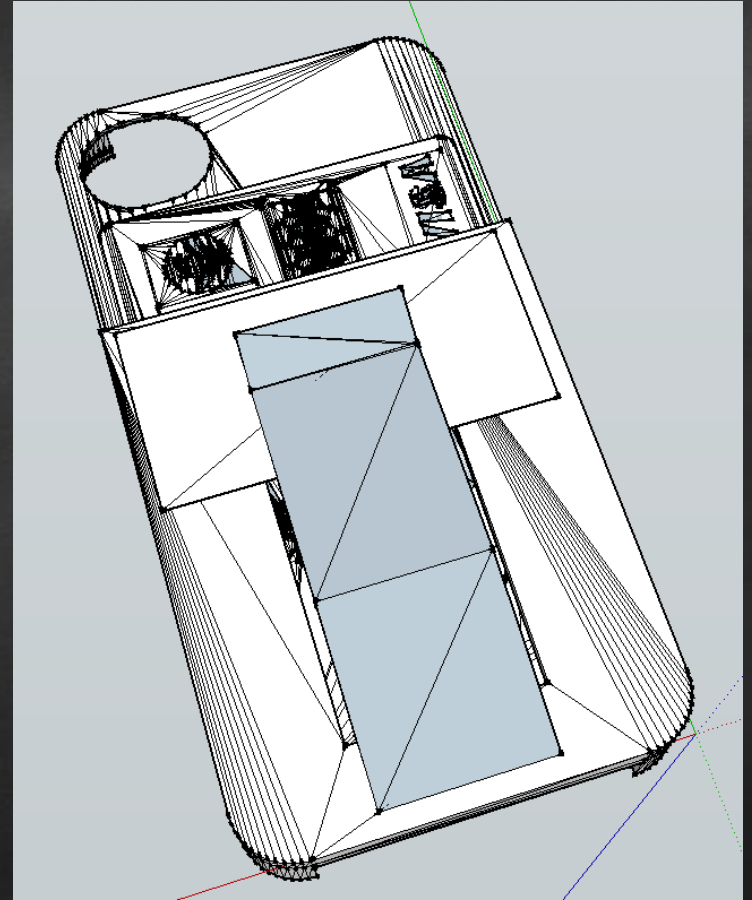
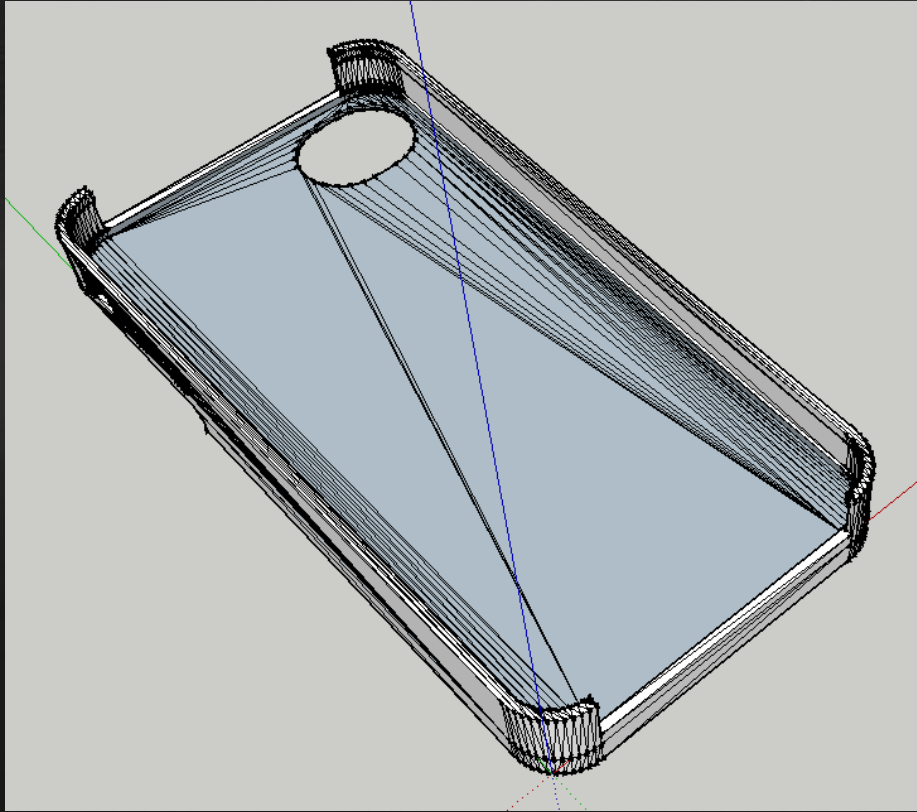
Compensator Design



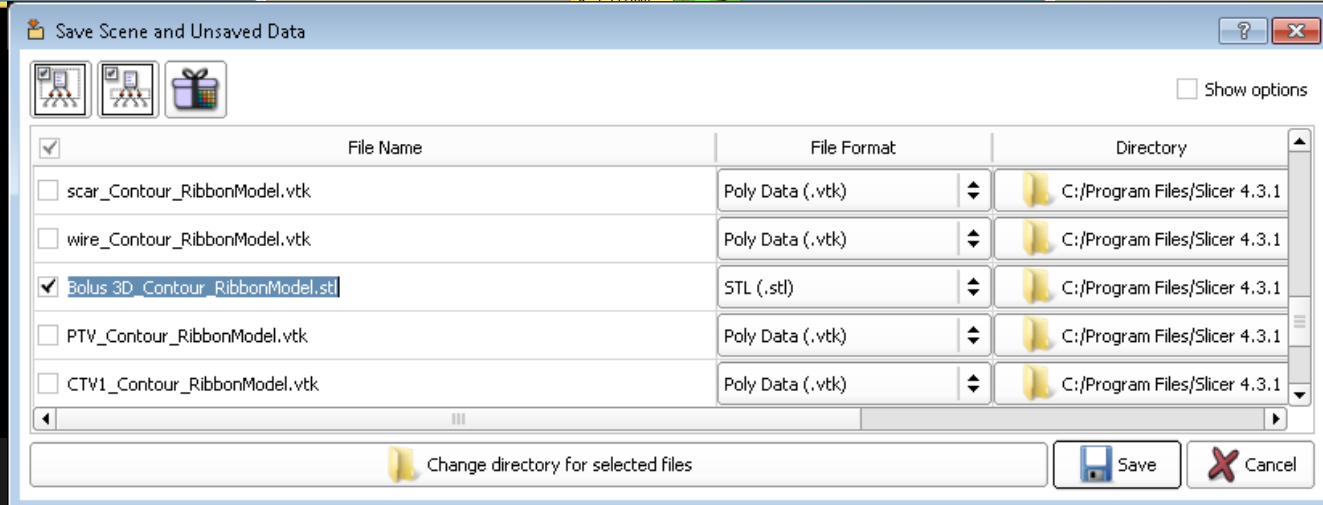
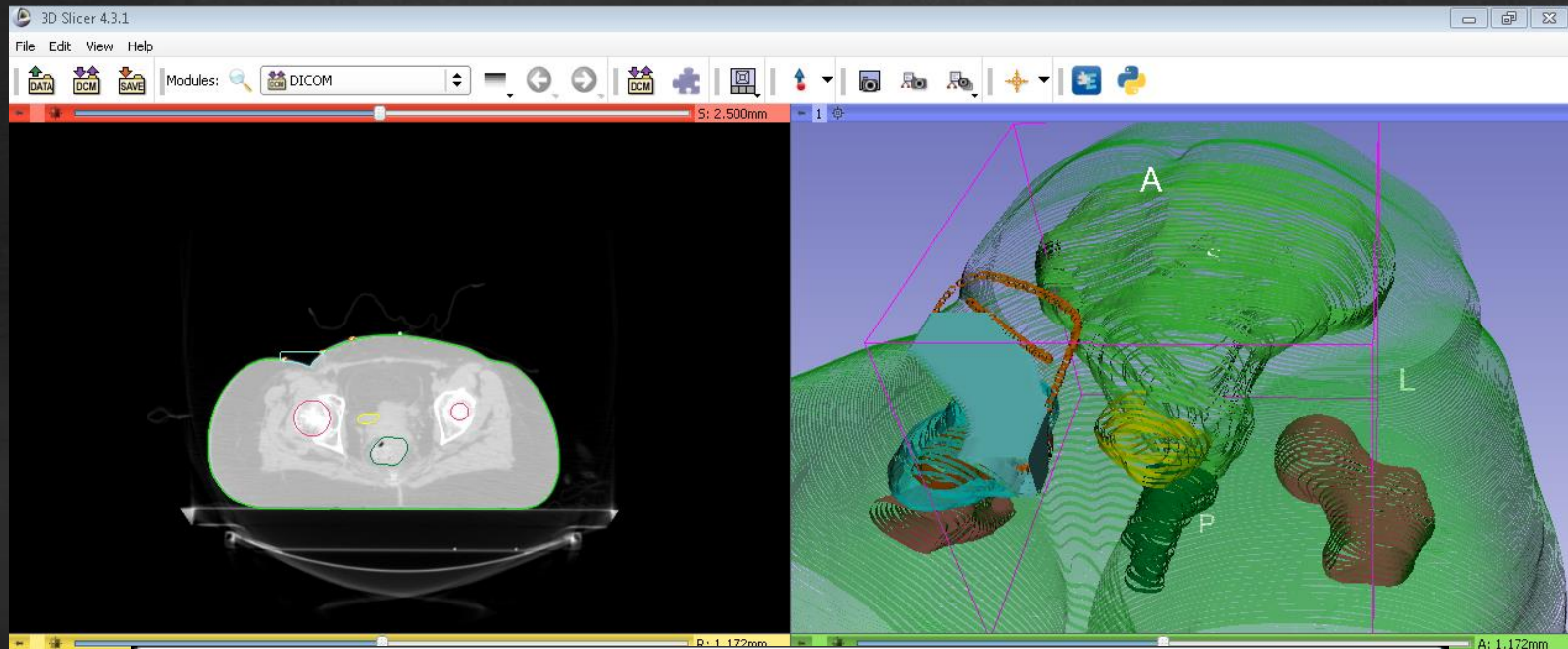
Dicom to Stereolithography (STL)

- 3D Slicer
 - <http://www.slicer.org>
 - BSD-style open source license
- SlicerRT Extension
 - From extension manager in 3D Slicer
- Collaborative Groups
 - **SPL**: Ron Kikinis, Nicole Aucoin, Wendy Plesniak, Demian Wassermann, Isaiah Norton, Sonia Pujol, Nobuy Hata, Junichi Tokuda
 - **Isomics**: Steve Pieper, Alex Yarmarkovich
 - **Kitware**: Julien Finet, Jean-Christophe Fillion-Robin, Will Schroeder, Stephen Aylward
 - **U Iowa**: Hans Johnson
 - **U Penn**: Kilian Pohl, Daniel Haehn
 - **GE**: Jim Miller
 - **Perk Lab, Queen's University**: Andras Lasso, Tamas Ungi, Csaba Pinter, Gabor Fichtinger

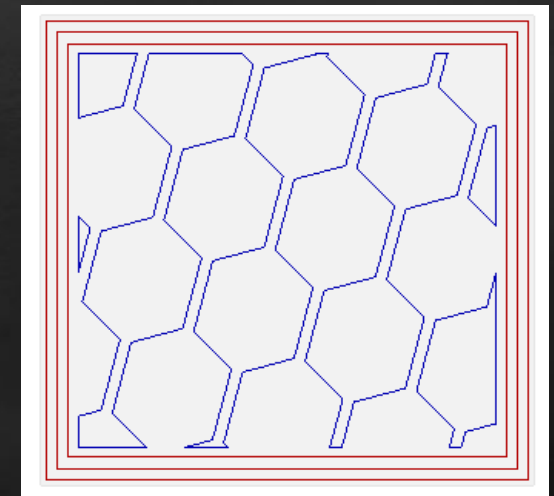
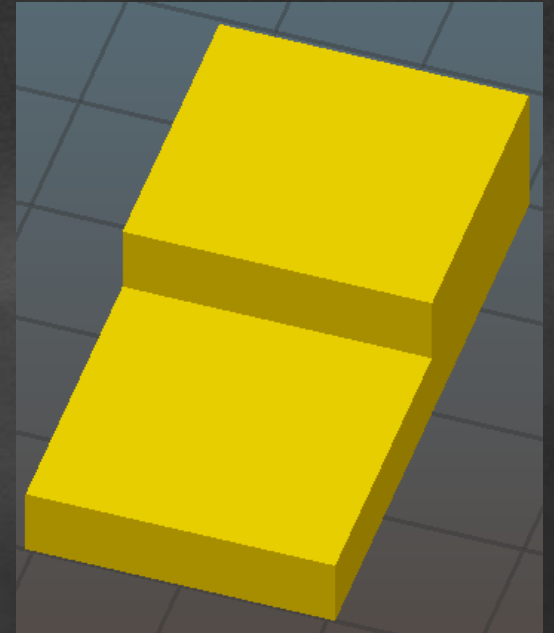
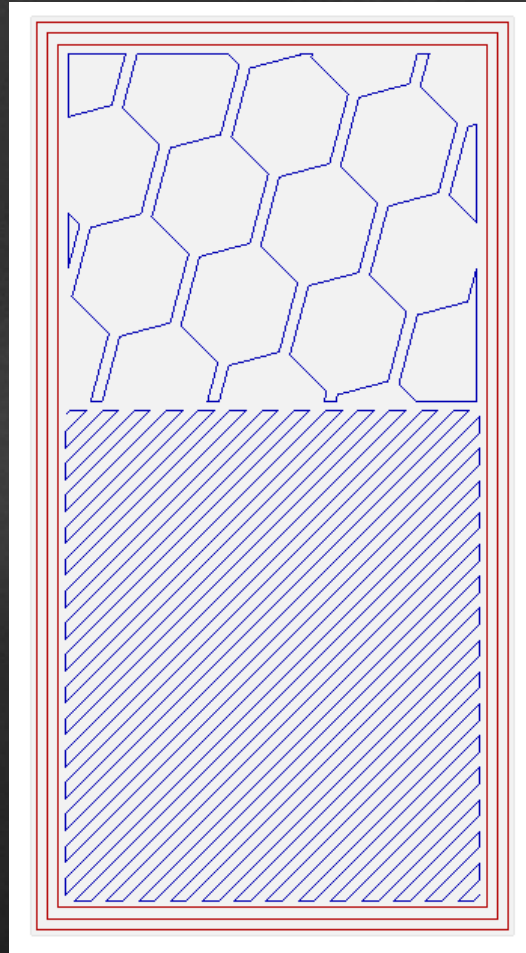
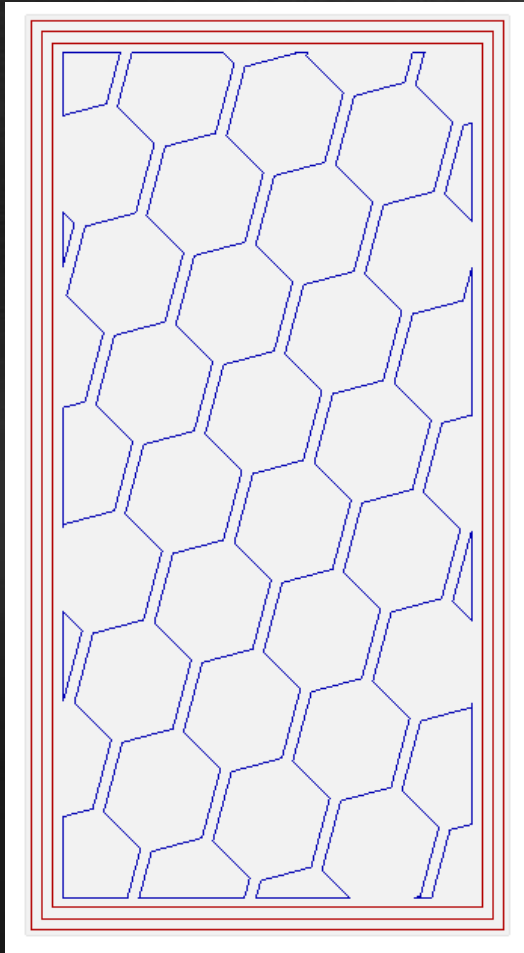
STL File?



Exporting STL file



G-code



Preparing Build Platform

- PVA
 - 25% solution white PVA glue and water
 - Blue painters tape
- ABS
 - 25% solution white PVA glue and water
 - PET tape on build platform
 - Coat tape with
 - 5% solution ABS and acetone
 - hairspray

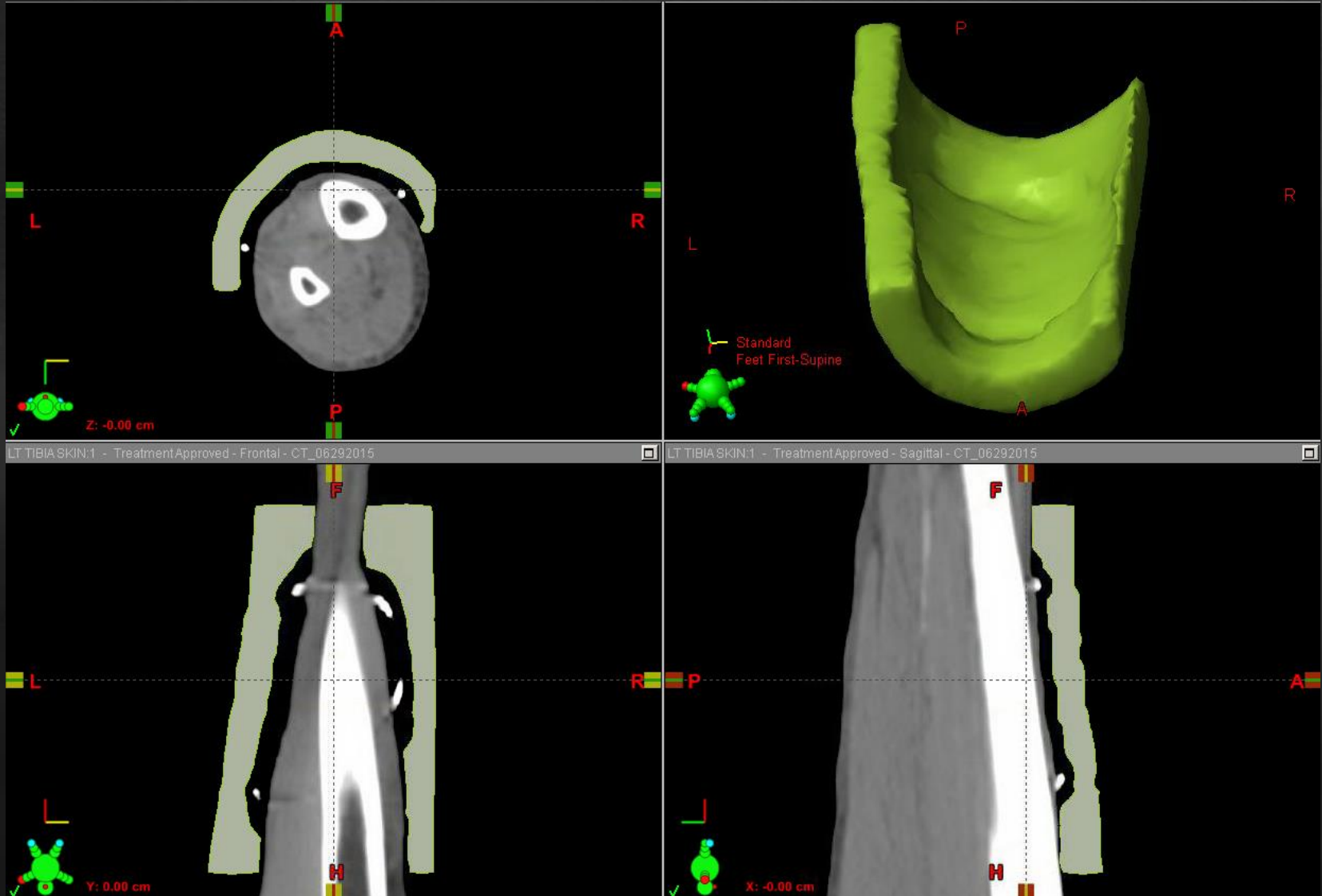
Printing Considerations

- Desire solid prints
 - $w_{\text{line}} * h_{\text{layer}} * l_{\text{line}} = \pi r_{\text{filament}}^2 * l_{\text{filament}}$
- Prints must be supported
 - 45° from horizontal minimum no support
 - Design breakaway supports
 - Use PVA filament
- CT slice thickness effects quality
- Locate where fumes and noise will not be irritating

Print Fail Mechanisms

- Layer separation and curling
 - Print cooling unevenly
- Nozzle jamming
 - Filament speed too high
 - Nozzle temperature low
- Loss of adhesion to build platform
 - Clean
 - Try different adhesion method
- Poor 3D model design

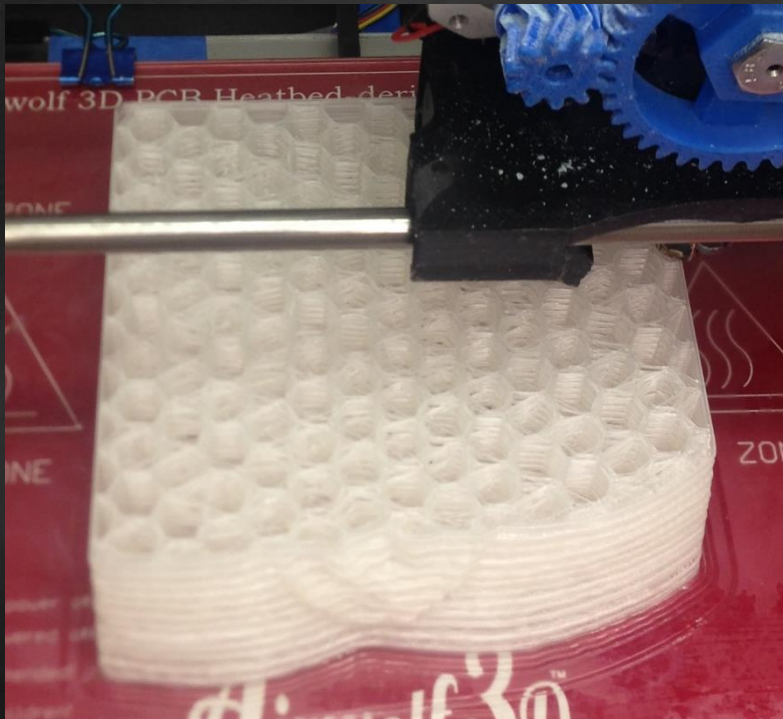
Custom Bolus



Bolus Mold



Bolus Mold



Thanks To

- Sarah Burleson, MS
- Josh Xu, PhD, DABR
- An Ting Hsia, MS, DABR