How to 3D Print Custom Bolus and Compensators for Radiotherapy
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1. Design custom bolus (or compensator) in MIM, Monaco, or XiO:
   a. <u>MIM</u>: To create simple bolus, run workflow "FH Create Simple Bolus." To create compensator, run workflow "FH Create Compensator".
   b. <u>Monaco</u>: Add bolus structure and shape like usual. When finished, DICOM export structure set (including bolus structure to MIM Clinical).
   c. <u>XiO</u>: Add bolus and shape like usual. When finished, add a new structure labeled Bolus and trace the bolus manually. When finished, DICOM export structure set (including bolus structure to MIM Clinical).
   d. <u>In all cases:</u> Try to design such that the inferior footprint of the bolus or compensator falls under the bolus center of mass.
2. Determine the volume of the bolus structure in MIM. Double click on the bolus structure and record the volume in cc.
3. Export bolus structure as STL file in MIM. Open the CT and structure set in MIM. Turn off all structures other than custom bolus. On top left toolbar, click >> icon and select "Export STL File". Give the STL file a unique name and save to the desktop. Transfer the STL file to the 3D printer laptop using a flash drive.
4. On the 3D printer laptop, launch Meshlab. Click File → Import Mesh → STL. Navigate to the STL file and click the OK button. Click Filter → Smooth → Laplacian. Enter step size of 5 and click OK. Click File → Export Mesh → STL. Enter a filename for the smoothed bolus and click the OK button.
5. On the 3D printer laptop, launch Cura. Click the Load Model icon. Navigate to the smoothed STL file and select Open.
   a. If necessary, rotate the model on the virtual build platform to improve printing efficiency and/or prevent the bolus from falling over during printing. Do this by clicking on the model, then clicking the Rotate icon.
   b. If the bolus' center of mass is not positioned over its base, select the "Print Support Structure" checkbox in the toolbar on the left of the Cura application to add supporting structures to the bolus (this will prevent the bolus from falling over during printing).
6. In Cura, confirm the "Fill Density" parameter is set to 100% in the left toolbar.
7. Determine whether you have enough filament to complete the print. Subtract the volume of the current bolus from the volume of filament remaining (denoted by the printer). Record the estimated filament volume remaining by the printer.
8. Turn on the 3D printer power supply. Press the silver knob on the 3D printer in and rotate to select "Movement". Press to select and rotate to select "Move Axis". Press to select and rotate to select "Move 1mm". Press to select and rotate to select "Move Z". Press to select and rotate until print head is moved vertically several inches off of the PEI print surface.
9. Confirm the PEI print surface on the 3D printer is clean (use wet paper towel to clean if required). Then, **apply a thin layer of PVA-based glue** to the PEI print surface using the Elmer's glue stick.
10. In Cura, click the Control icon. In the graphical control panel (see Figure 1 below), enter 225 for the nozzle temperature, then click the Set button. Enter 0 for the bed temperature, then click the Set button.
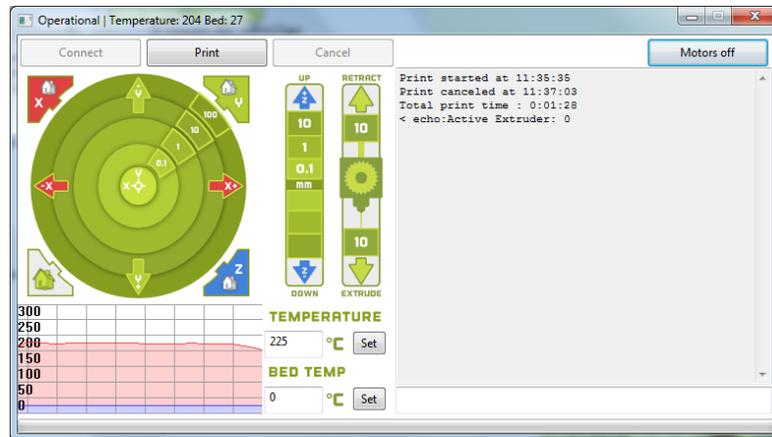

Figure 1. Cura graphical control panel

11. When the nozzle temperature has reached 225 degrees (see 3D printer LCD screen), the NinjaFlex filament will start draining from the nozzle. Clean the nozzle with a clean paper towel.
12. Press the silver knob on the 3D printer in and rotate to select "Movement". Press to select and rotate to select "Auto Home". Press to select. The printer head will move to the home position.
13. Click the Print button on the Cura graphical control panel (see Figure 1). The printer will begin printing.
14. When the printer has finished, use a flexible metal spatula to gently pry the printed bolus off of the PEI build platform. If necessary, use a knife to clean any stray filament from the printed bolus. <u>Verify the dimensionality of the printed bolus or compensator</u> and confirm it matches what was planned (e.g., 0.5 cm thick).
15. In the treatment planning system (TPS), use external contour and force electron or mass density as described in Table 1:

Table 1: Specific treatment planning system settings for 3D printing

TPS	External Contour	Electron Density	Mass Density	Notes
Monaco	patient_Monaco	1.072		Set as Bolus type; Attach bolus to treatment fields
XiO	patient	1.072		
RadiXact	patient		0.976	