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Use of 3D Printers in Proton Therapy

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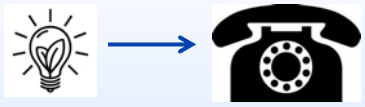
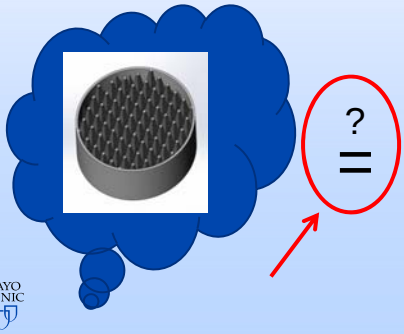
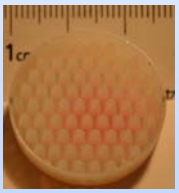
Disclosures/Confessions

My 3D Printing Process



Stephen Corner
Mayo Engineer
3D printing guru





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Disclosures – Limited Printer Experience

Printer	Dimension Elite*	Fortus 400 mc*	Objet Connex 350*
3D Build Process	Fused Deposition Modeling (Plastic Extrusion)	Fused Deposition Modeling (Plastic Extrusion)	PolyJet (Liquid Printing, UV Curing)
Material	ABS	Polycarbonate	Liquid acrylic photopolymer
Layer Thickness	0.178 mm	0.178 mm	0.016 mm
Nozzle Size	0.254 mm	0.178 mm	NA

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3D Printer Use in Proton Therapy

- Beam Filters
  - Not generally patient specific
  - Nozzle-based
  - Used almost exclusively in scanning beam systems
- Compensators
  - Patient and beam specific
  - Nozzle-based
  - Used almost exclusively in double scatter systems
  - Design is created in the treatment planning system

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Scanning Beam Problem – Narrow Low Energy Bragg Peaks

- Narrow Bragg peak equires more energy layers to construct a spread-out Bragg peak and longer treatment times
- Due to reduced volume covered by spot, treatment plans can suffer from minimum MU delivery limitations (low MU spots are eliminated).

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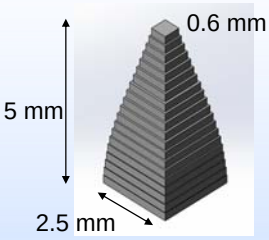
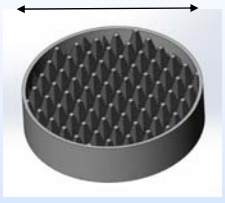
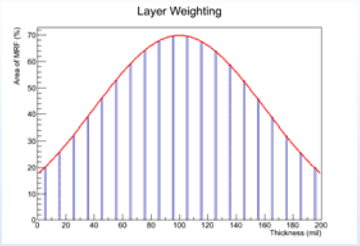
* L. Courneyea, C. Beltran, H.S. Wan Chan Tseung, J. Yu, M.G. Herman. Optimizing mini-ridge filter thickness to reduce proton treatment times in a spot-scanning synchrotron system. Med Phys. 41, 061713 (2014)

Pyramid Filter Design Prototype







- Low Z to minimize scatter (and resulting increase in spot size)
- Step height fixed by 3D printer layer thickness
- Step width tuned to give Gaussian depth profile – critical for robust planning
- Seemingly perfect application of 3D printing

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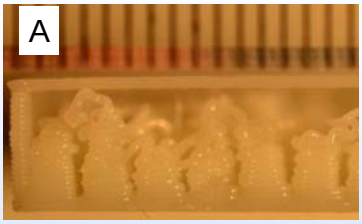
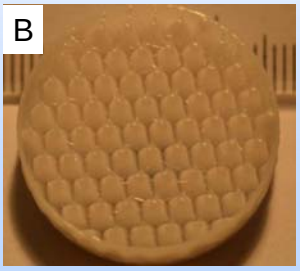
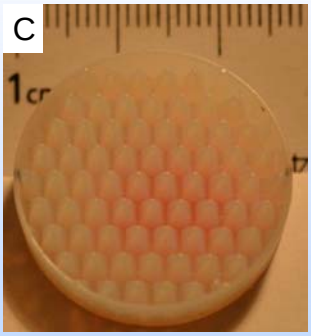
Visual Inspection



Note: Filter A used an earlier “sandwich” design.





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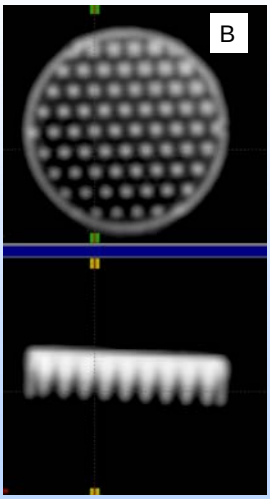
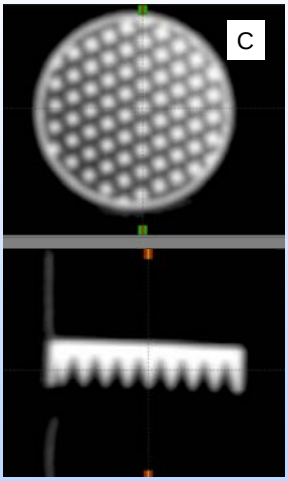
Inspection with CT Imaging





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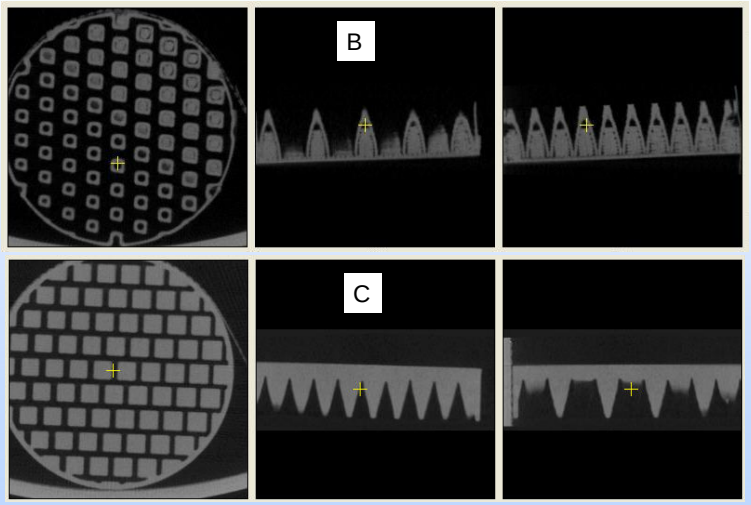
Inspection with Micro CT Imaging



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Reality Check: QA for Full Size Filter

- MicroCT is clearly not a practical go-to tool for QA
- QA should focus on functionality of device for intended purpose
- To the extent possible, QA should utilize tools already available.

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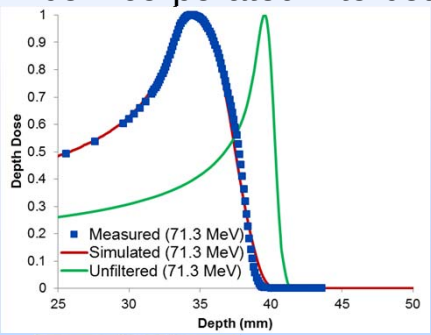
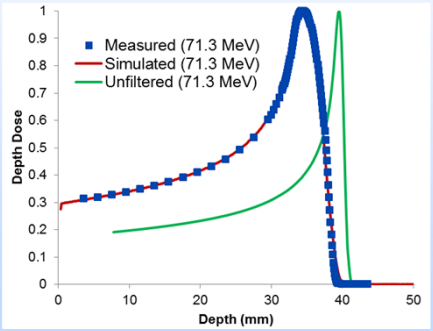
Depth Dose Curve

- Monte Carlo simulation vs Measurement is appropriate for a beam filtering device that will be incorporated into beam data





Perl J, Shin J, Schumann J, Faddegon B, Paganetti H, TOPAS: an innovative proton Monte Carlo platform for research and clinical applications. Med Phys. 39(11) Nov 2012

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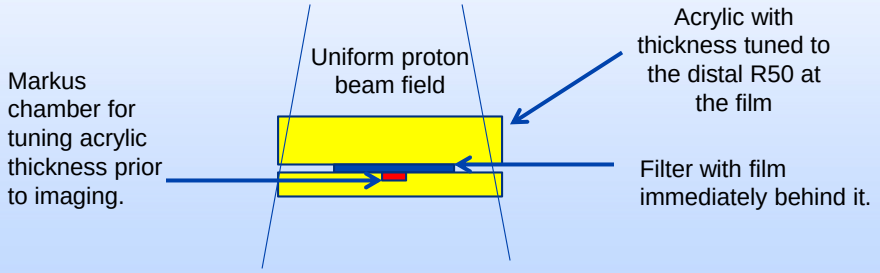
Proton Radiograph

- Image with radiochromic film at distal edge of proton range
- Filter is in direct contact with film



Quick and easy to setup (<1hr) using equipment readily available in most proton centers

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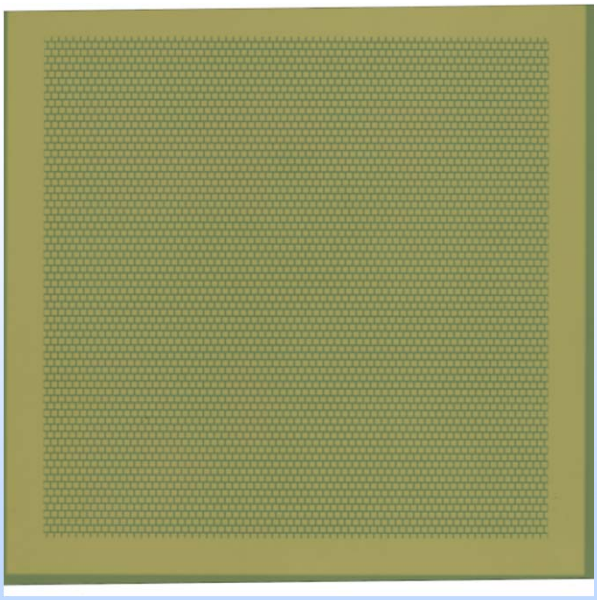
37 mm of acrylic



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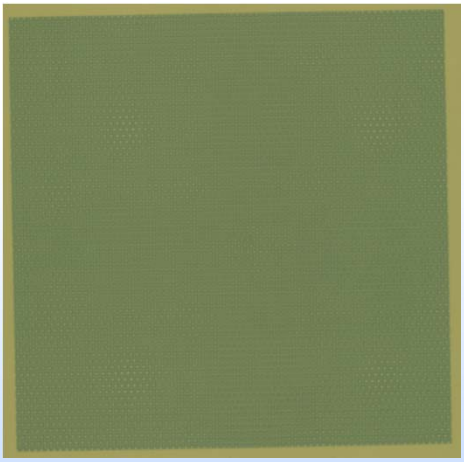
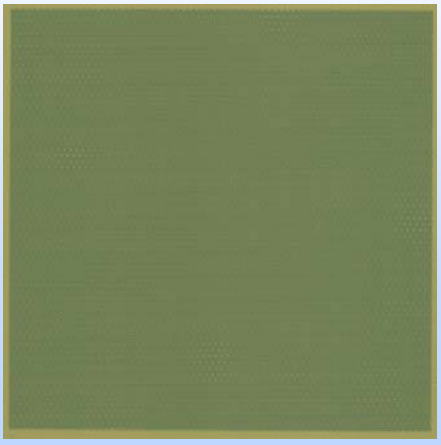


34 mm of acrylic: note variation that causes Moiré Pattern



Pattern changes when acrylic is rotated.

1mm sheets of acrylic have thickness variation of about 10%.

A very precise method of testing our acrylic slabs!

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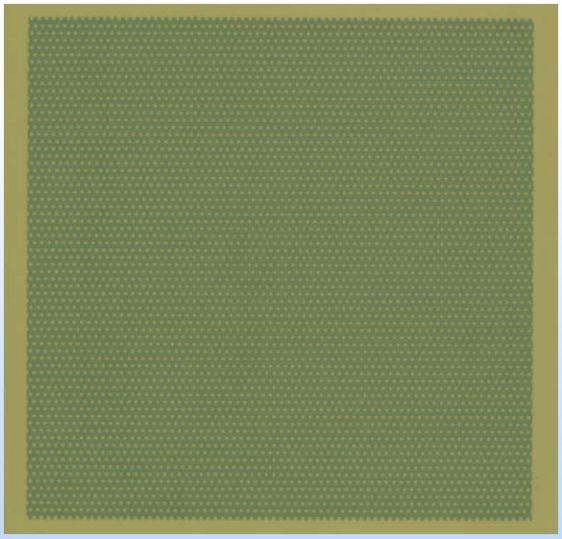
35 mm of acrylic

(no 1mm slices of acrylic)



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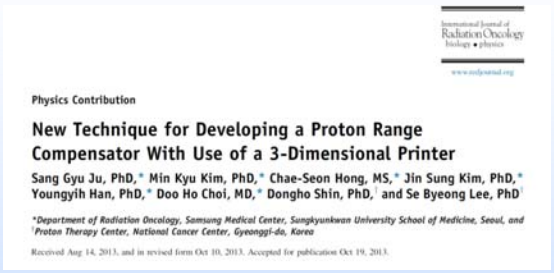
3D Compensators



Physics Contribution

New Technique for Developing a Proton Range Compensator With Use of a 3-Dimensional Printer

Sang Gyu Ju, PhD,* Min Kyu Kim, PhD,* Chae-Seon Hong, MS,* Jin Sung Kim, PhD,* Youngyih Han, PhD,* Doo Ho Choi, MD,* Dongho Shin, PhD,† and Se Byeong Lee, PhD†

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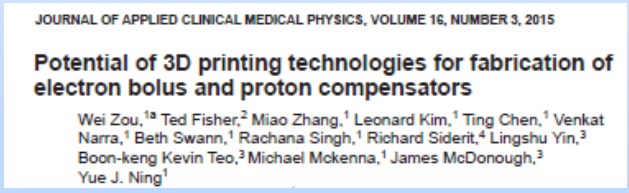
IJROBP, 88:2, pp 453-458, 2014



JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 16, NUMBER 3, 2015

Potential of 3D printing technologies for fabrication of electron bolus and proton compensators

Wei Zou,[1a] Ted Fisher,[2] Miao Zhang,[1] Leonard Kim,[1] Ting Chen,[1] Venkat Narra,[1] Beth Swann,[1] Rachana Singh,[1] Richard Siderit,[4] Lingshu Yin,[3] Boon-keng Kevin Teo,[3] Michael Mckenna,[1] James McDonough,[3] Yue J. Ning[1]

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Comments on work by Sang Gyu Ju et al.

- Milled compensators vs 3D printed compensators (ultraviolet curable acrylic plastic)
- Measured surface dimensions with 3D scanning technique
- Imaged with CT scanner
- Measured central axis PDD
- Measured selected dose planes
- Results indicate very good agreement between both compensators and TPS doses.

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Sang Gyu Ju et al., IJROBP, 88:2, pp 453-458, 2014

Comments on work by Zou et al.

- Fused Deposition Modeling (FDM) vs Selective Laser Sintering (SLS)
- Checked dimensions with calipers
- Imaged with CT scanner
- Measured depth dose curves with a Bragg peak chamber
- Measured dose distributions in an anthropomorphic phantom

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Zou et al, JACMP, 16:3, p 90-98, 2015

Warnings about FDM printing:

- From Zou et al: "…due to the random slight inhomogeneity in the FDM printing, the properties of the printed object should be understood before being applied to proton therapy."
- Note how proton therapy is singled out!

Zou et al, JACMP, 16:3, p 90-98, 2015

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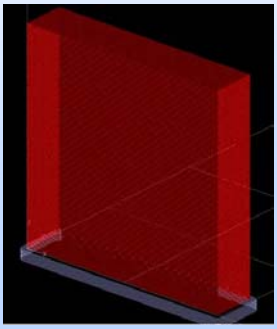
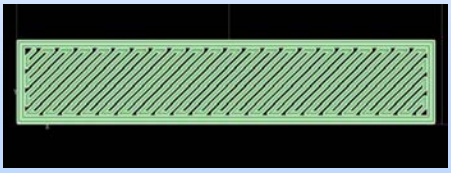
A quick experiment

- Two "solid" 5cm x 5cm x 1cm blocks printed on two different FDM printers with two different materials (ABS and polycarbonate)
- Measure central depth dose, CT, and radiograph
- Both blocks pass visual inspection and dimension measurements.





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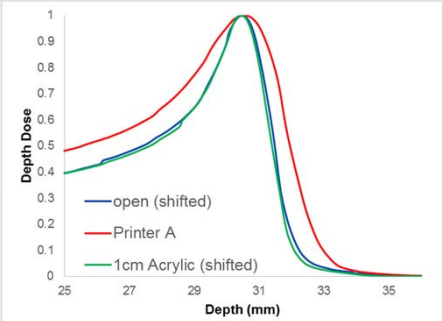
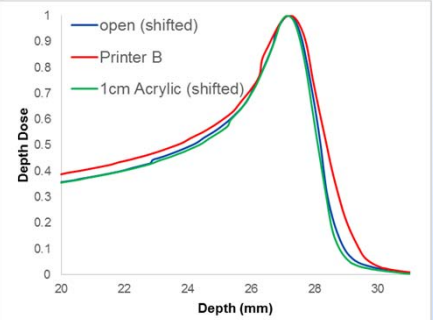
Depth Dose





- Open field depth dose is shifted for purpose of comparison
- Some discrete “jumps” due to MLIC electronics

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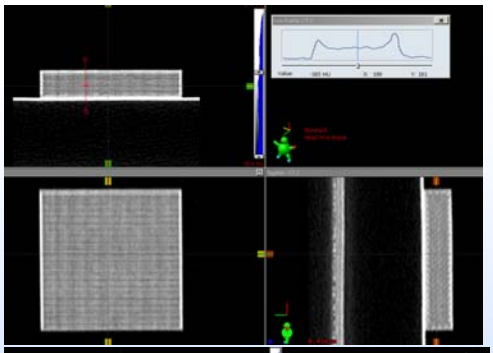
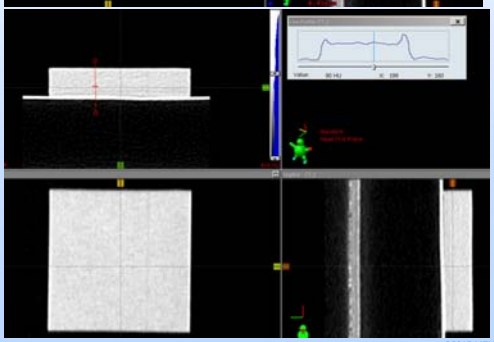
Printer A



Printer B



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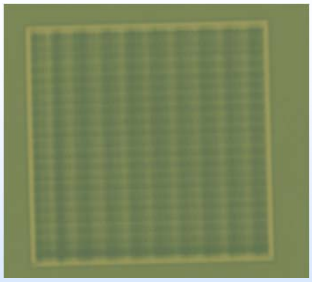
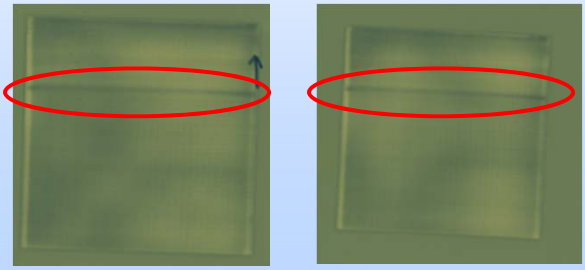
Proton Radiographs

Printer A



Printer B with acrylic rotated 45 degrees between images



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Conclusions

- 3D printing has been shown to be a useful tool in proton therapy.
- Quality assurance is key: expect imperfections unless demonstrated otherwise
- Surface measurements are not very useful for quality assurance
- Dose measurements in the middle of the SOBP are probably not sufficient QA either.
- CT scans of each device should be considered at a minimum.
- Proton radiographs and depth dose measurements are also recommended.

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- Lorraine Courneyea
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- Jon Kruse
- Josh Stoker
- Michael Herman

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