Department of Medical Physics and Biomedical Engineering

Characterisation of 3D-printable thermoplastics for proton therapy

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Background and Motivation

- Cancer treatments evolved alongside with advancements in technology
- More complex treatment techniques come with new sources of uncertainties
- Quality Assurance (QA) techniques are required to ensure treatments are delivered in a safe and accurate manner

Seo *et. al.*, 2019

With the **new advances** in treatment delivery systems, **new appropriate QA tools** need to be developed

Background and Motivation
Treatment Planning Pathway

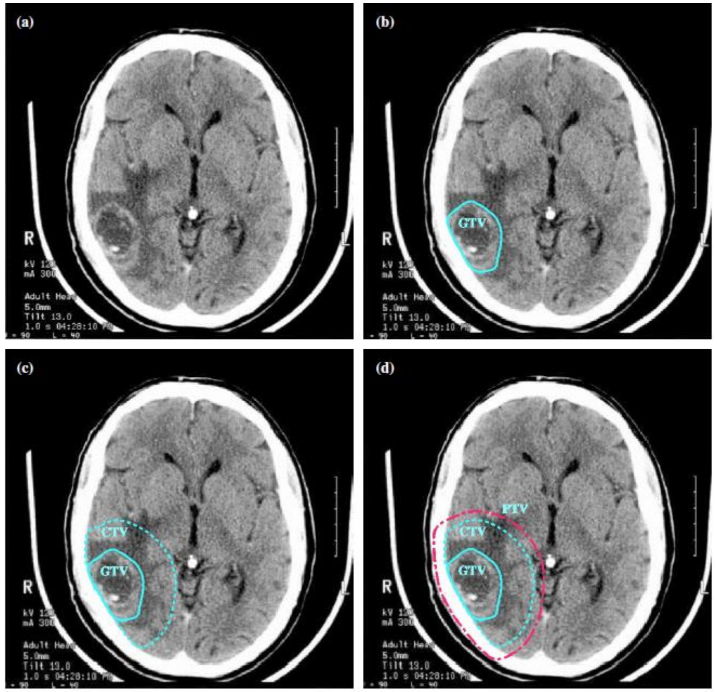
Plan CT scan

- Tumour contours
- Tissues radiological properties

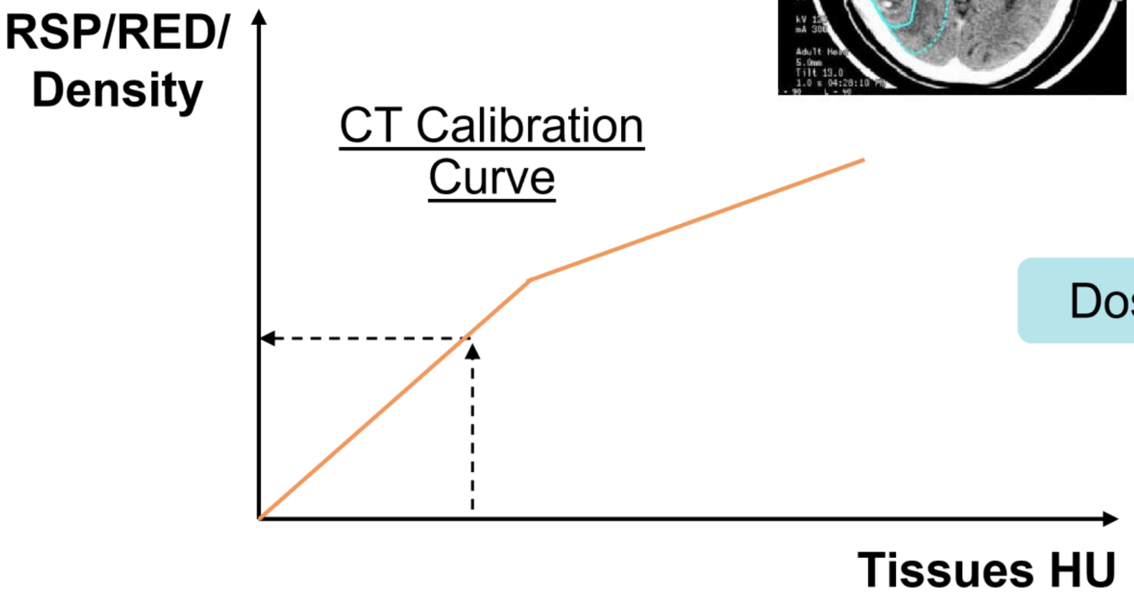
➢ HU – density

➢ HU – relative electron density (RED)

➢ HU – relative stopping power (RSP)



Burnet *et. al.*, 2004



Dose calculations

Background and Motivation
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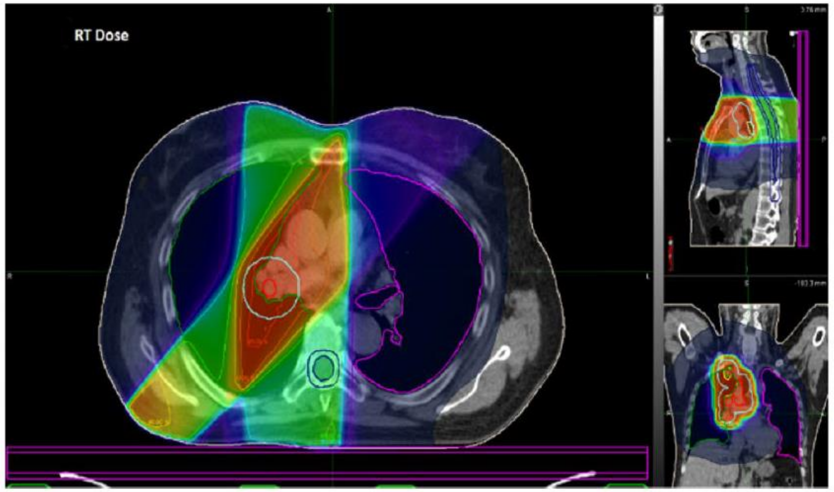
Dose distribution calculations

- Treatment Planning System (TPS)

➢ RED for photons

➢ RSP for protons



Albarakati *et. al.*, 2022

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Treatment Planning Pathway

Plan CT scan

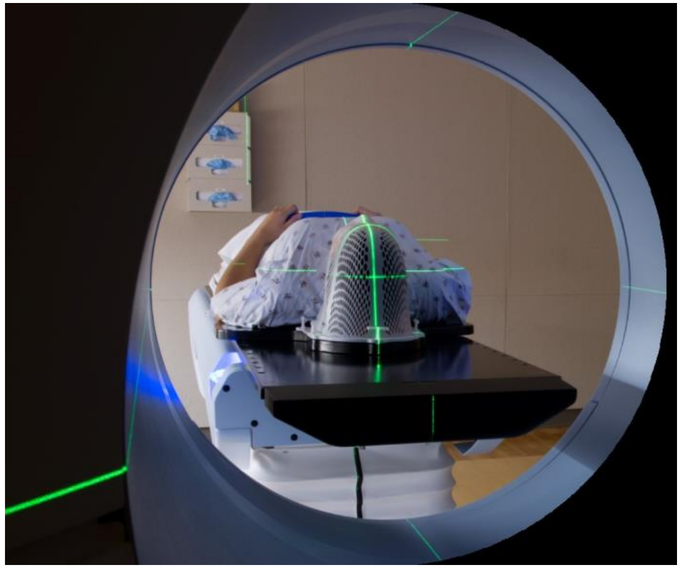
- Tumour contours
- Tissues radiological properties
  - HU – density
  - HU – relative electron density (RED)
  - HU – relative stopping power (RSP)

Dose distribution calculations

- Treatment Planning System (TPS)
  - RED for photons
  - RSP for protons

Dose delivery

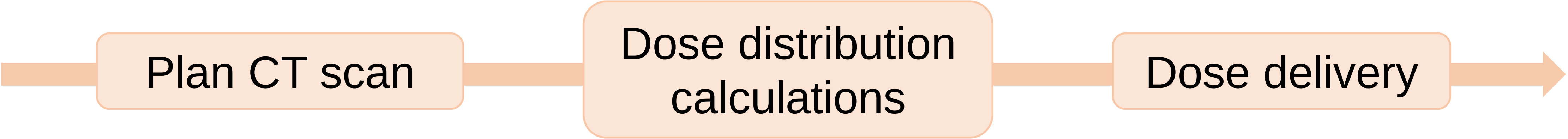
- Patient positioning

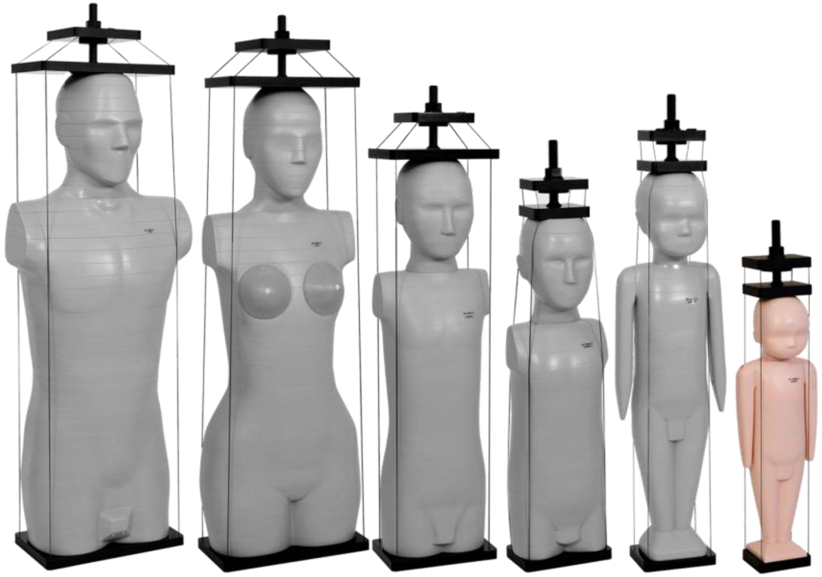


https://alphaxrt.com/radiotherapy-equipment/radiation-treatment-delivery/

Background and Motivation

End-to-end QA





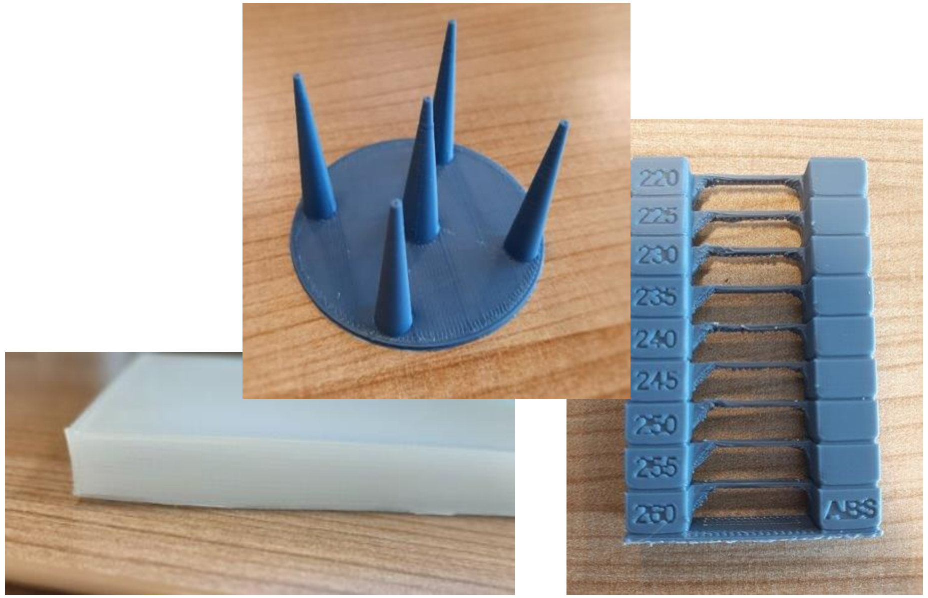
https://www.cirsinc.com/products/radiation-therapy/atom-phantom-family/

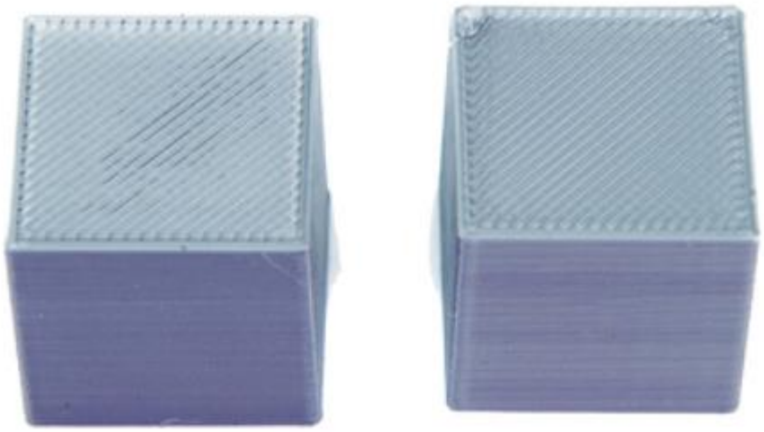
- Most of the existing tools for QA are not well-suited for proton beams
- The rising number of proton beam delivery facilities demands the development of proton specific end-to-end QA tools

Additive Manufacturing for Radiotherapy Applications

- There has been an increased interest in using additive manufacturing for creating quality assurance tools in radiotherapy
- ➢ Easy customization, high accuracy, lower production costs

- 3D-printing parameters need to be tuned to optimize the printing process of thermoplastics for end-to-end QA applications
- ➢ Layer Height
- ➢ Printing Speed
- ➢ Extruder Temperature
- ➢ Retraction Distance
- ➢ Printing Speed
- ➢ Extrusion Multiplier





Aim

- Provide guidelines on the use of 3D-printing technology – optimisation of 3D-printing settings - for end-to-end QA applications in radiotherapy

- Under these guidelines, evaluate the radiological properties of thermoplastic materials and their suitability to be used in end-to-end QA for proton therapy

Materials and Methods

- Six thermoplastic materials were selected: PLA, ABS, PETG, PMMA, HIPS and Stonefil (PLA mixed with stone powder)
- The Raise3D pro2 plus 3D-printer was used
- 3D-printing parameters were optimised
- 10x10x1 cm^3 and 10x10x2 cm^3 slabs were printed for each thermoplastic

Table 1: Vendor density and selected printing parameters for each thermoplastic under investigation.

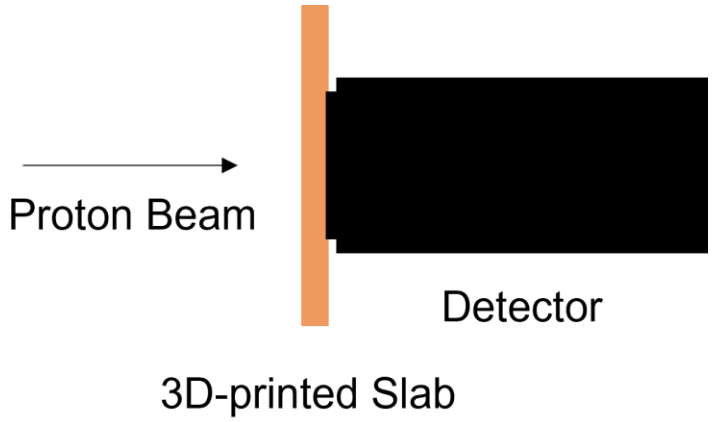
	Vendor	Density (g/cm^3)	Extrusion Multiplier	Retraction Distance (mm)	Extruder Temperature (˚C)	Heated Bed Temperature (˚C)
PLA	Raise3D Premium	1.20	0.90	1.5	210	60
ABS	Fillamentum Extrafill	1.04	0.90	1.5	230	100
PETG	3DJAKE	1.27	0.85	3.0	235	70
PMMA	Mitsubishi Chemicals 3Diakon	1.14	0.95	1.5	255	107
HIPS	Spectrum HIPS-X	1.05	0.95	1.5	240	95
Stonefil	FormFutura	1.70	1.05	2.0	230	60

Materials and Methods

- Average RSP values were acquired for each material via two different methods:

1. Range Measurements

- Girrafe Detector, Ion Beam Applications SA
- 210 MeV proton pencil-beam (ProBeam, Varian Medical Systems)



Materials and Methods

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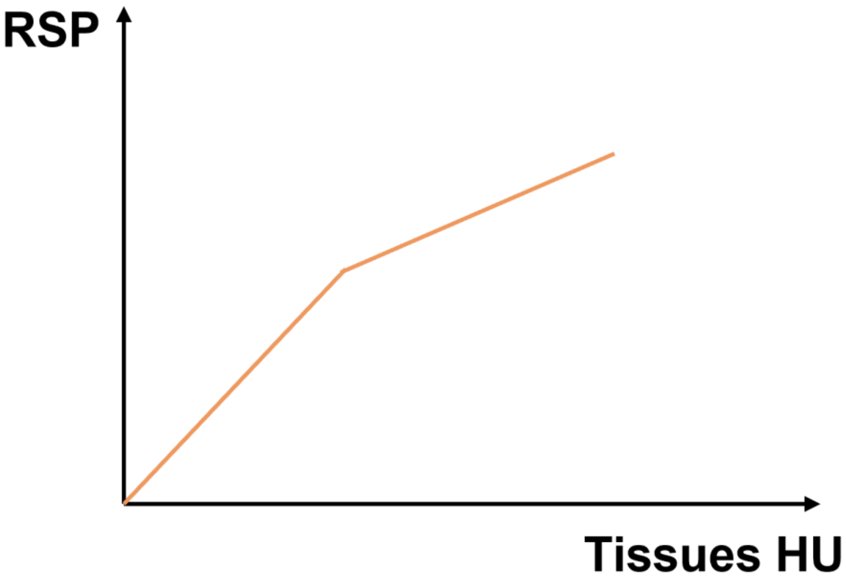
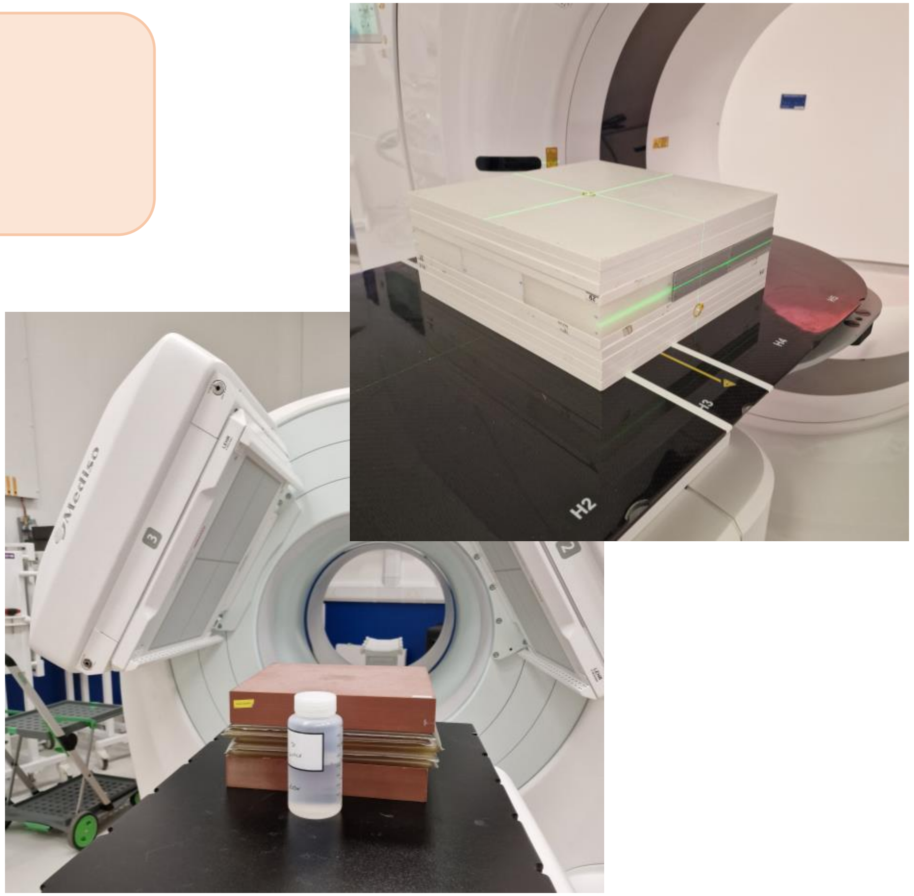
2. CT-scan prediction with calibration curves

- AnyScan TRIO®
- Philips 7500

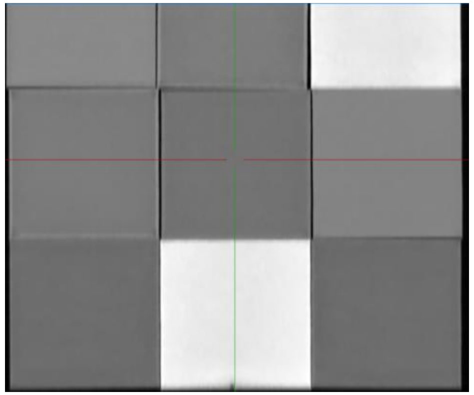


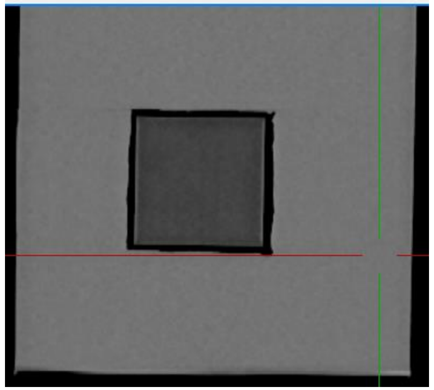


Results

Table 2: Average Hounsfield Unit (HU) values, and standard deviations, derived for each material through CT-scans, considering the different slab thicknesses.

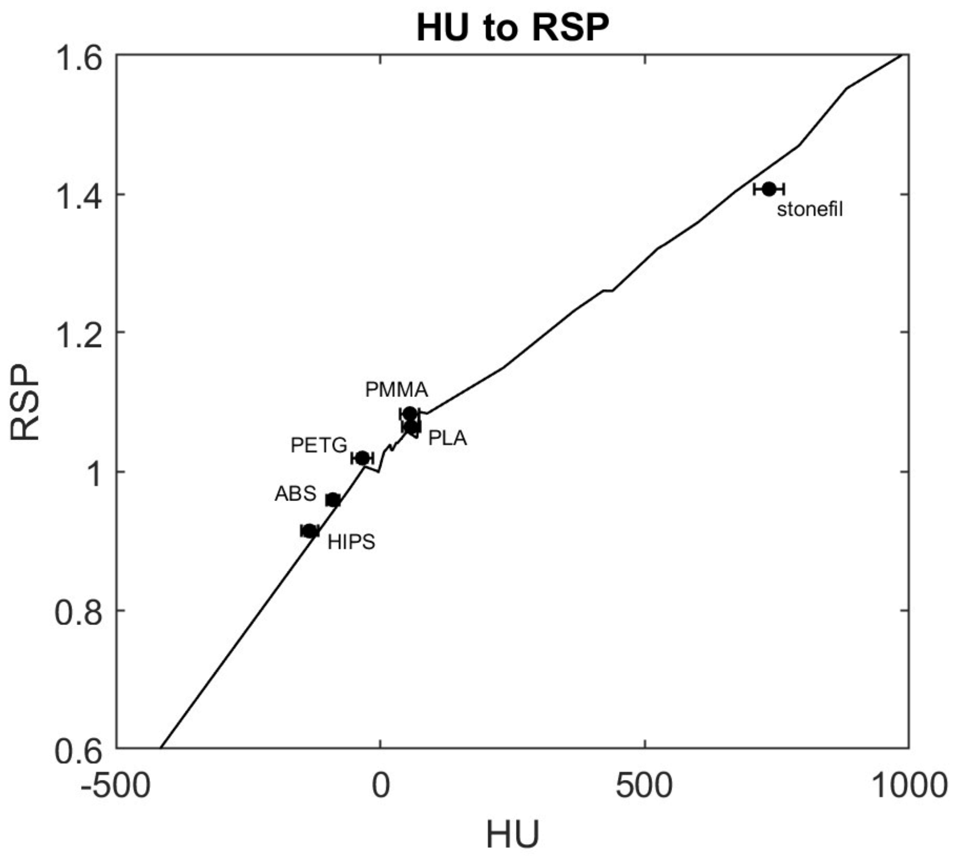
	HU					
	PLA	ABS	PETG	PMMA	HIPS	Granite
AnyScan TRIO®	58 ± 17	-90 ± 12	-34 ± 19	56 ± 18	-134 ± 16	735 ± 28
Philips Spectral 7500	48 ± 14	-107 ± 10	-58 ± 23	33 ± 22	-157 ± 14	836 ± 28



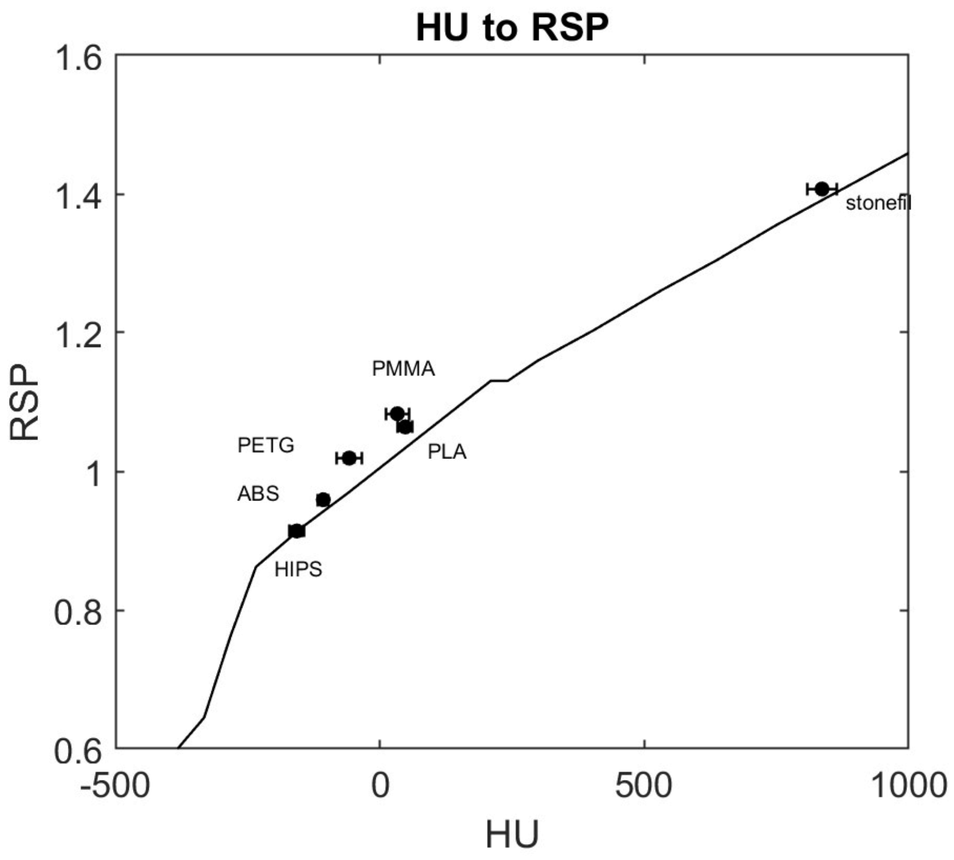


Results

AnyScan TRIO®



Philips 7500



Results

Table 3: Relative Stopping Power (RSP) values obtained experimentally via range and CT-based measurements.

Material	RSP				
	Measured	Predicted AnyScan TRIO®	Diff (%)	Predicted Philips 7500	Diff (%)
PLA	1.064 ± 0.005	1.056 ± 0.013	0.75	1.034 ± 0.008	2.91
ABS	0.959 ± 0.002	0.941 ± 0.013	1.88	0.942 ± 0.006	1.77
PETG	1.019 ± 0.006	0.996 ± 0.014	2.26	0.970 ± 0.013	4.81
PMMA	1.083 ± 0.004	1.058 ± 0.015	2.31	1.025 ± 0.013	5.36
HIPS	0.914 ± 0.007	0.896 ± 0.016	1.97	0.913 ± 0.009	0.11
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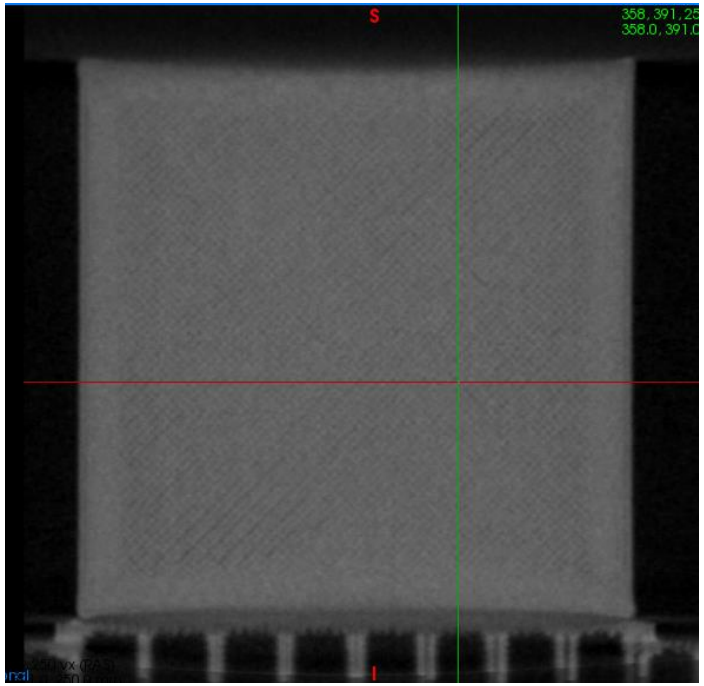
Discussion and Conclusions

- Most filaments were below the 5% difference between measured and calibration-curve predicted values
- 3D-printable thermoplastics are promising tissue equivalents for proton therapy applications, specifically for end-to-end QA techniques
- **ABS and HIPS are good candidates to be used as soft tissue equivalents**
- **Stonefil is a good candidate to be used as bone substitute**
- 3D-printing shows to be a very suitable manufacturing technique for end-to-end QA applications in radiotherapy

Limitations

- Additive manufacturing is associated with limitations in the model construction, which includes:
  - The presence of air gaps within the model's infill
  - Infill density not perfectly homogeneous
  - Surface finishing may be of lower quality
  - Variation in printing accuracy



- Limited choice of commercially available filaments of thermoplastic materials
- Plastic waste and long-term deterioration from radiation exposure

Thank you !

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