“Integrate range shifter in immobilization for proton therapy: 3D printed materials characterization”

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3D printing is investigated for application in patient immobilization during proton therapy (PT). It potentially enables a merge of immobilization, range shifting and other functionality into one patient-specific structure. Beside minimizing the lateral beam spread due to the removal of air gap it could also reduce the collision risk and the treatment time compared to movable nozzle snouts. In this first study, 9 different 3D printed materials were characterized in detail. The resulting data (Table 1) will serve as input for the design of a printed immobilization structure. The printed test objects showed reduced geometric printing accuracy for 3 materials. Compression testing yielded Young’s moduli from 0.6 MPa to 3445 MPa, without deterioration after exposure to 100 Gy in a MV photon beam. Dual-energy CT methods were used to estimate the effective atomic number Z_{eff}, the relative electron density ρ_e and the stopping power ratio SPR. Z_{eff} ranged from 5.91 to 10.43. The SPR and ρ_e both ranged from 0.6 to 1.22. The measured photon attenuation coefficients at therapeutic energies scaled linearly with ρ_e. In a 62 MeV proton beam, good agreement was seen between the DECT estimated SPR and the measured range shift, except for the higher Z_{eff}. As opposed to the photon attenuation, the proton range shifting was printing orientation dependent for certain materials. In conclusion printed materials exhibit a wide variation in structural and radiological properties. The quantification of these characteristics enables optimal material selection for the design of a multifunctional 3D printed immobilization structure for PT.

Table 1: Overview of the different 3D printed materials in terms of their mechanical and radiological properties and proton range shifting & photon attenuation capabilities.

Material	3D-printing method	Dimensional measurement		Compression test	DE-CT derived properties			62 MeV proton range shift measurements		Photon linear attenuation measurements	
		Average thickness [mm]	Standard deviation [mm]	Young's modulus [MPa]	ρ_e [#/cc]	Z_{eff} [-]	SPR [-]	Error in prediction [mm]	Diff. between orientations [mm]	μ_{tr} at 6MV [% of $\mu_{tr,water}$]	μ_{tr} at 10MV [% of $\mu_{tr,water}$]
ABS	Fused Deposition Modeling	20.18	0.19	655	0.60	6.51	0.61	0.26	0.60	62	62
Tusk	Stereolithography	19.88	0.10	2200	1.14	10.10	1.14	-1.18	-0.34	113	113
HPFlex	Polyjet digital	19.68	0.39	0.64	1.10	6.47	1.12	-0.18	0.82	109	109
TangoPlus	Polyjet digital	19.39	0.25	0.61	1.10	6.48	1.12	0.58	0.05	108	109
VeroWhite	Polyjet digital	20.05	0.08	2450	1.15	6.52	1.17	-0.05	1.10	114	115
PA-12	Laser sintering	20.03	0.06	1800	0.98	5.91	1.01	0.37	1.29	99	97
PA-Alu	Laser sintering	20.12	0.06	3445	1.18	10.43	1.16	-0.66	0.18	125	128
PA-GF	Laser sintering	20.09	0.14	3017	1.22	9.56	1.22	-0.75	0.20	120	123
TPU	Laser sintering	20.63	0.16	34	1.09	6.25	1.11	-0.06	0.36	109	109