OC-0567 Reconstructing the 3-D proton dose distribution from the modelled iono-acoustic wave field

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automated filtering approach had removed most relevant spots in this region.

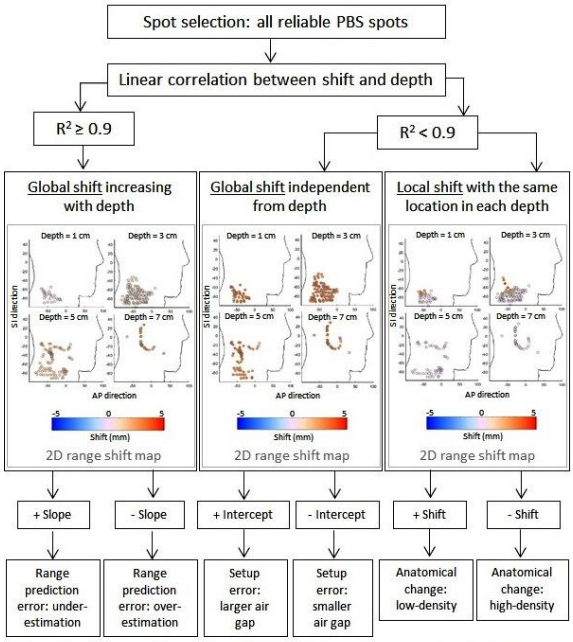

Figure 2: Decision tree to identify the source of range deviation based on PGI information.

Conclusion

An automated classification approach was introduced to identify the source for range deviation solely from prompt-gamma information. Based on phantom data, including simulation of realistic anatomical variation, the results are promising. Further refinement of this initial approach might be beneficial. An extension of the validation with patient CT data is in preparation. In the future, an application of the approach on clinically measured PGI data is planned. Also other classification methods could be evaluated.

[1] Smeets et al., PMB, 2012
[2] Sterpin et al., PMB, 2015
[3] Nenoff et al., Radiother Oncol, 2017

OC-0567 Reconstructing the 3-D proton dose distribution from the modelled iono-acoustic wave field

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Purpose or Objective

Real-time range verification during proton therapy is paramount to ensure patient safety as well as treatment effectiveness, but remains a major challenge. Here, we investigate if the iono-acoustic wave field generated by the protons can be used to reconstruct the 3-D dose distribution during treatment.

Material and Methods

We developed a new numerical method to model the pressure field generated by a clinical proton pencil beam. To compute the field, we convolved a 3-D Green's function, representing the impulse response of the medium, with a volume density of injection rate source. This source describes the expansion of the medium due to a local temperature increase caused by the energy deposited by the protons. An analytical model is used to describe the spatial and temporal shape of the proton dose distribution. Next, we used this method to compute the pressure field as would be measured by a 2-D transducer array consisting of 900 point-receivers. During a measurement the pressure field resulting from a number of proton spills is detected, this set of proton spills is defined as a proton pulse (Table).

For the model-based reconstruction of the proton dose distribution, we assumed prior knowledge of the temporal behaviour of the proton beam. To solve the resulting linear inverse problem, we used a conjugate gradient minimization scheme.

Results

To validate our method, we modelled the acoustic wave field generated by a 100 MeV clinical proton therapy beam in water. All selected beam parameters such as beam width, beam current and proton pulse duration were selected such as to reflect clinical values based on an isochronous cyclotron (Table). A cross section of the original proton dose distribution used to model the pressure field is shown in the figure (top row). Next, the figure illustrates a snapshot of the resulting pressure field (middle row). The bottom row shows the reconstructed dose distribution using the proposed method.

The simulated measured wave-field had a centre frequency around 30 kHz and an amplitude of approximately 55 mPa. It also showed all the characteristics typical for the iono-acoustic wave field with a clear pulsed behaviour, corresponding to the field generated by the protons at the Bragg-peak location. The resulting reconstructed dose is similar to the original dose distribution and the error in the location of the Bragg peak is 3.9 mm.

Conclusion

The iono-acoustic wave field resulting from a proton beam with clinically relevant parameters has been modelled using Green's functions. Imaging the proton dose distribution is feasible by solving the linear inverse problem, while taking the temporal profile of the proton dose distribution as prior knowledge. It is expected that the error can be reduced significantly, e.g. by optimizing the positions of the receivers or by taking more prior knowledge about the beam properties into account.

Table: Parameters used for the simulation

Parameter	Value	Parameter	Value
σ_t	1 ns	R	63 mm
τ	13 ns	σ_r	4.5 mm
τ_{pulse}	6.4 µs	c_0	1520 m/s
N_{spill}	492	ρ_0	996 kg/m^3
N_{proton}	1.2×10^6	Γ_0	0.8
I_{proton}	30 nA		

σ_t = Gaussian temporal width of a proton spill
τ = Temporal spacing between proton pulses
τ_{pulse} = Duration of a proton pulse
N_{spill} = Number of proton spills in a proton pulse
N_{proton} = Total number of protons
I_{proton} = Proton beam current
R = Proton range
σ_r = Initial proton beam Gaussian spatial width
c_0 = Speed of sound in the medium
ρ_0 = Mass density of the medium
Γ_0 = Grüneiser parameter of the medium

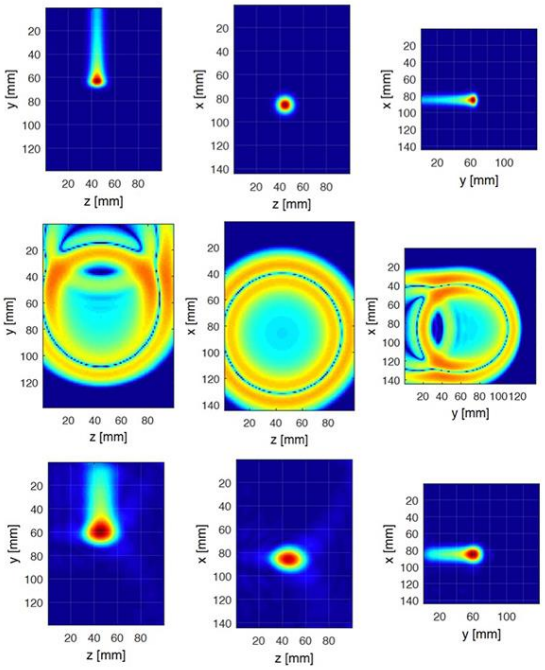

Figure: original proton pencil beam dose distribution (top row), Snap shot of the iono-acoustic pressure field at t = 0.35 µs (middle row) and reconstructed dose distribution (bottom row).

OC-0568 Experimental dosimetric characterization of a proton beam in the presence of a magnetic field

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Purpose or Objective

Advancements in Magnetic Resonance Image guided photon therapy have recently stimulated research towards MR guided proton therapy. From a physics point of view, magnetic fields induce dose distortions due to proton beam deflections and thus challenge dose measurements and dose calculations. This work aims to study the response of conventional detectors used for absolute dose verification in proton therapy in the presence of external magnetic fields up to 1T.

Material and Methods

Measurements were performed using a proton research beam line in the clinical energy range of 62.4 – 252.7 MeV. A resistive dipole magnet was positioned in the isocenter, thus allowing to apply magnetic fields between 0 – 1T perpendicular to the beam incidence plane. An in-house built PMMA phantom (200 × 120 × 300 mm^3) was carefully placed in the center of the magnet, assuring homogeneous irradiations within the entire phantom volume.

To evaluate the effect of the magnetic fields on different dosimetric methods, calibrations curves were determined for EBT3 films and measurements using a Roos chamber were performed. Film calibration was conducted using 148.2 MeV protons at 20 mm depth in PMMA, for dose levels between 0.2-10 Gy, see Fig. 1. Afterwards, dose verification measurements were performed for different targets sizes using the same batch of calibrated films and the Roos chamber. Detectors were placed transverse to the beam, at depths between 20-150 mm covering the plateau and Bragg peak region. Results were compared for B=0T and B=1T. Monte Carlo simulations using the GATE/Geant4 toolkit were used to predict the effect of magnetic fields on dose distributions.

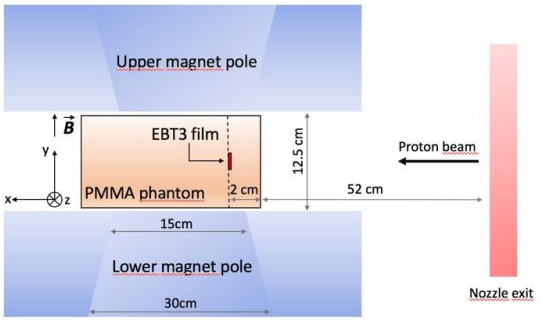

Fig. 1 Sketch view of the experimental setup used for the EBT3 films calibration.

Results

Net optical density calibration curves for EBT3 films up to 10 Gy showed no significant differences (p-value=0.05) between the different applied magnetic fields (B = 0, 0.5, 1T). Relative differences in the Roos ionization chamber response at 20 mm depth in PMMA with/without magnetic fields were below 0.3%. Figure 2 summarizes measured and calculated proton depth dose distributions reaching a box target placed in the center of the magnet, for field strengths of B=0T, B=1T. Absolute dose measurements with films showed an under-response up to -8% in the Bragg peak region, exhibiting a similar quenching effect as already observed without magnetic field.

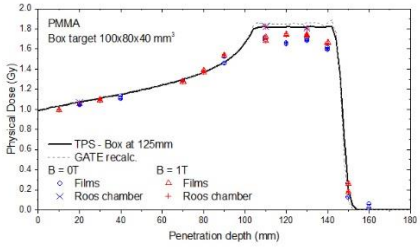

Fig. 2 Spread out Bragg peak measured without/within a magnetic field region. The continue and dash lines correspond to the planned and MC-recalculated dose distributions respectively.

Conclusion

For the first time the effect of magnetic fields on the dose response function was investigated for different detectors in the context of protons dosimetry. The proposed calibration and experimental method offer a viable solution for dose measurements within magnetic fields, considering the neglectable field influence observed. Further investigations using different detectors and irradiation geometries are foreseen.

OC-0569 A framework for variance-based sensitivity analysis of uncertainties in proton therapy

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Purpose or Objective

Due to the physical properties of proton beams, treatment outcomes in particle therapy are more sensitive to uncertainties than conventional X-ray therapy. Sources of