Novel method to quantify physical dose enhancement due to gold nanoparticles in proton therapy

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Introduction

- Gold nanoparticles (GNPs) increase dose deposition when localised to the tumour
- Studies have demonstrated this in cell and animal studies through an increase in survival rates [1,2]
- Monte Carlo studies have modelled physical dose enhancement [3]
- Many biological studies have been performed demonstrating dose enhancement, however these do not quantify physical dose enhancement
- The present study demonstrates a novel method to quantify physical dose enhancement using Gafchromic films and a custom made phantom

Aim

- To quantify the physical dose enhancement of GNPs through Gafchromic film measurements

Method

- The phantom (figure 1) contained slits at 1 mm intervals to hold film sheets at various depths
- Phantom was comprised of PMMA as this is commonly used in proton therapy for its water equivalence

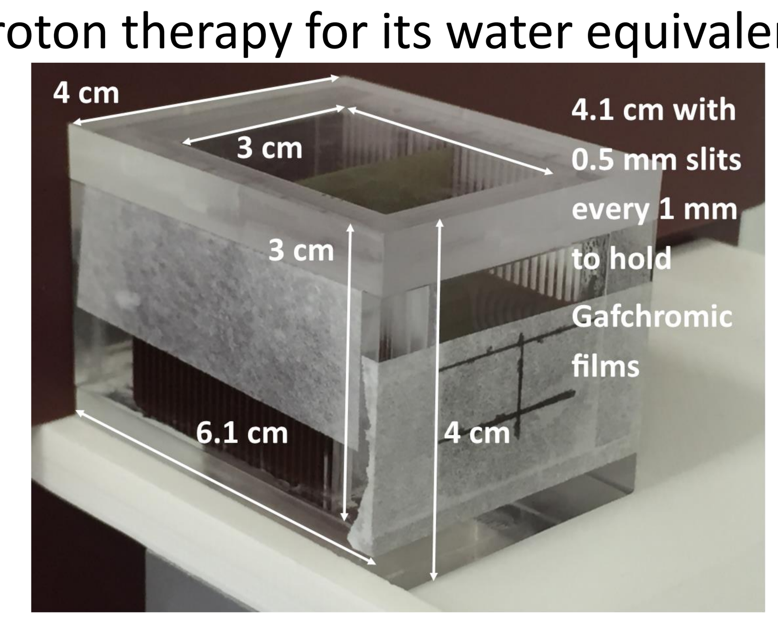

Figure 1: Custom made film phantom containing GNPs and a Gafchromic film. Phantom allows for measurements to be taken at 1 mm intervals

- The phantom was positioned within the width of the Bragg peak to allow for a high resolution depth dose plot
- EBT3 Gafchromic films (Ashland, USA) were used for the measurements
- Solid water slabs (Gammex, Middleton, WI) were used to create sufficient build up (29.1 cm) in front of the phantom to tune Bragg peak position to within the phantom (figure 2)

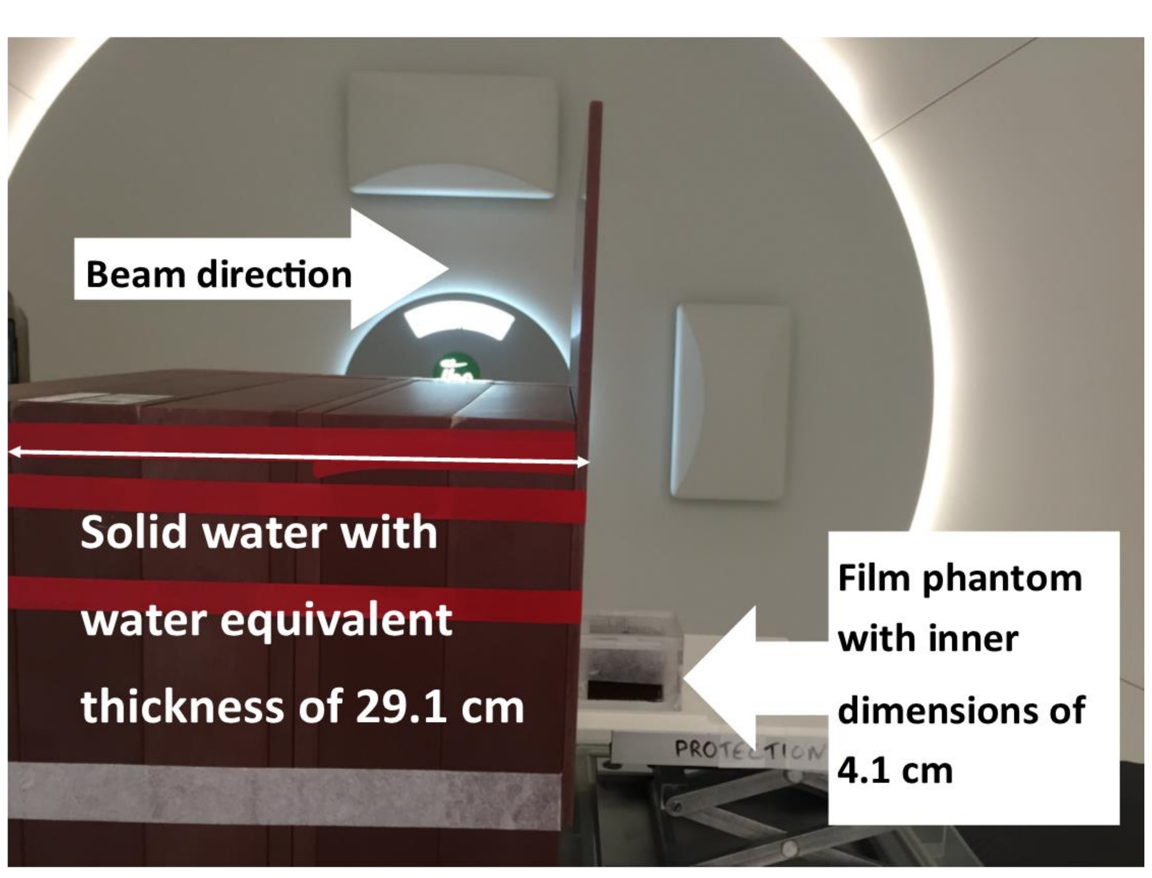

Figure 2: Experimental setup with solid water equivalent to 29.1 cm of water followed by the film phantom with inner dimensions of 4.1 cm. Phantom was filled with either water or a water + GNP solution of a known concentration

- Measurements were carried out at the Trento proton therapy centre using a 226 MeV proton beam
- Measurements were taken for both water and water + GNP solution
- Concentrations of GNPs used were 5.5 and 1.1 mgAu/ml
- Each depth was irradiated with 20 MU corresponding to a dose range of 6-37 cGy
- Films were calibrated covering a dose range from 0-250 cGy, using a clinically used procedure
- Films were scanned after 24 hours using an EPSON desktop scanner
- Depth dose plots were used to determine the level of dose enhancement
- Dose enhancement is defined as the ratio of the dose with and without GNPs for the depth being considered

Results

- Considering the depth dose plot (figure 3) it can be seen that there is an increase in dose deposition with the introduction of GNPs
- Dose deposition increases by 26%±0.53 with 1.1 mg/ml and 21%±0.53 with 5.5 mg/ml

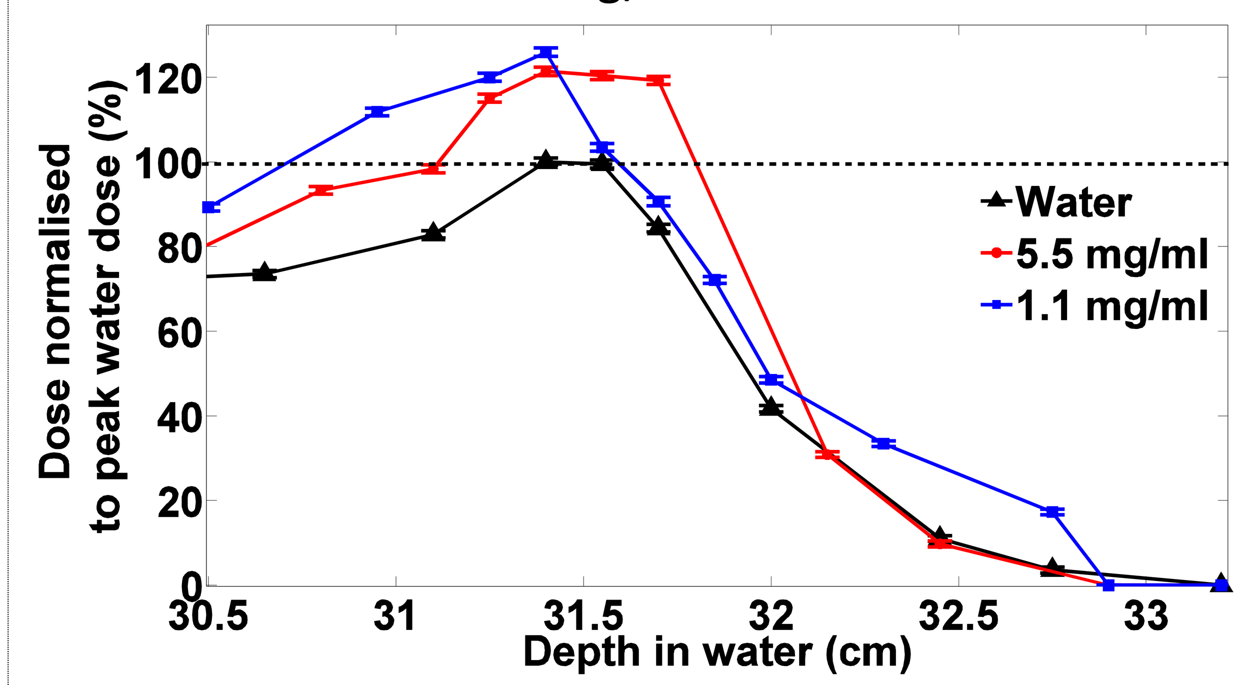

Figure 3: Depth dose plot normalized to peak water dose to show the level of enhancement with GNP concentrations of 1.1 and 5.5 mg/ml. Errors correspond to two standard deviations.

- It was expected that dose enhancement would increase with concentration, whereas these results showed a higher enhancement with the lower concentration
- Other studies have shown Gafchromic films to be prone to quenching effects which could have had a greater effect at higher concentrations, leading to the lower enhancement observed [4]

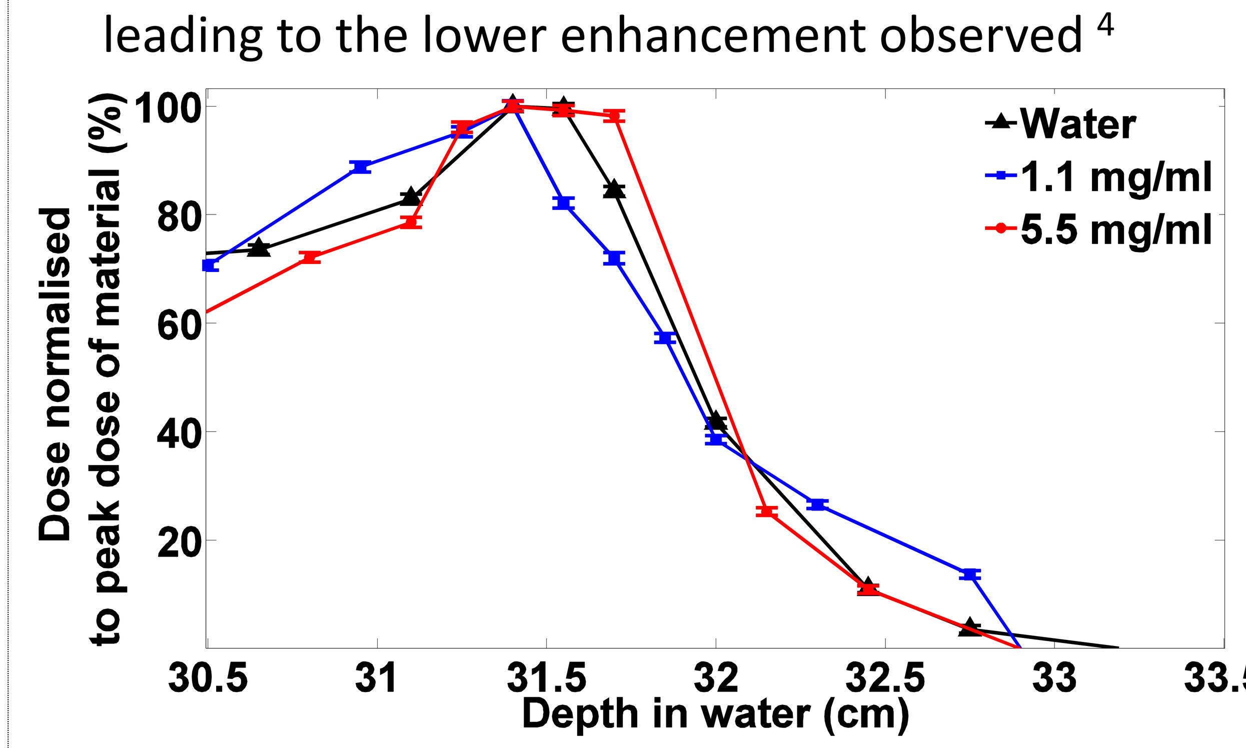

Figure 4: Depth dose plot normalized to peak dose of the material to show the changes caused to the shape of the Bragg peak with GNP concentrations of 1.1 and 5.5 mg/ml. Errors correspond to two standard deviations.

- As well as dose enhancement a 2.2 mm longitudinal shift of the distal edge was shown with 5.5 mg/ml of GNPs
- Shape changes must be taken into account to ensure the entire tumour is irradiated and there are no under dosed regions

Conclusions

- GNP concentration of 1.1 mg/ml showed a higher dose enhancement of 26% compared to 21% for 1.1 mg/ml
- Longitudinal shift was shown only with 5.5 mg/ml and was found to be 2.2 mm
- Effects of GNP concentrations were shown through measurement of physical dose enhancement
- Reasons for not having an increase in dose deposition with increasing concentration could be due to quenching effects
- Changes to the Bragg peak shape due to the presence of GNPs needs to be accounted for in future studies to ensure full tumour coverage
- These results demonstrate physical dose enhancement alone
- Cellular studies should be performed to determine how physical dose enhancement by GNPs translates to biological systems

Future work

- Investigate the effects of GNP enhancement on treatment plans, assessing any changes that need to be made
- Parallel cell studies to determine biological effect resulting from physical dose enhancement

References

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