# Proton Radiography for Pre-Treatment Range Verification in Proton Beam Therapy

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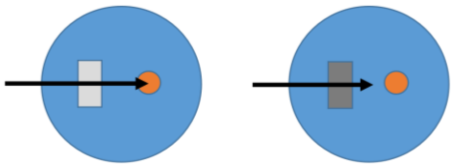
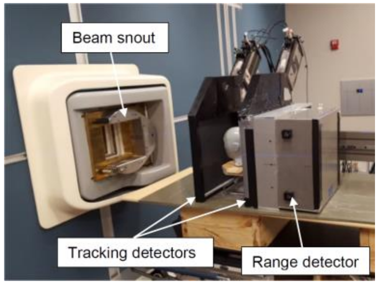
## Introduction:

Proton radiography yields anatomic information that x-ray radiography does not offer. Proton radiographs give a direct measure of the water equivalent path length (WEPL) across the radiation field in beam's eye view and can therefore detect daily anatomic changes prior to treatment that may affect the depth of the Bragg peak in the patient. These changes in proton range cannot be detected with x-ray radiography.



The schematic shown on the Right shows an example of a change in proton range due to an anatomical change. The black arrow represents the proton path to the orange target volume. If the grey box changes density between fractions, it may cause the proton to undershoot the orange target volume and overdose normal tissues.

## Proton Radiography:

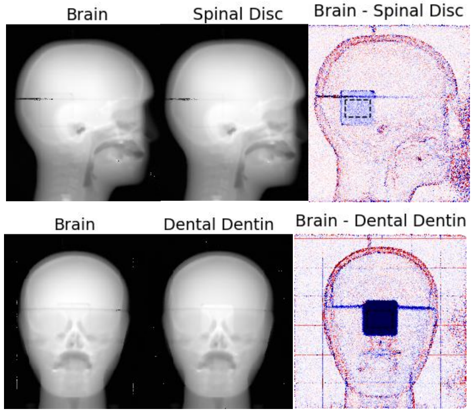



The proton radiography system mounted in a treatment room with pencil beam scanning is shown on the Left. It contains one 40x40 $cm^2$ X-Y scintillating fiber tracking plane upstream and one downstream of the phantom and a 40x40x13 $cm^3$ scintillating block to measure the residual proton energy after passing through the phantom. This system collects data that is used to calculate the water-equivalent path length in each pixel in the 2D image plane.

## Detection of Anatomical Changes:

A customized pediatric head phantom is filled with various inserts of known water-equivalent thickness ranging from 0.4 to 7.02 cm due to their different densities. A proton radiograph is taken of the phantom with each of these inserts and difference maps are created to detect the change in proton range.

Above: Customized pediatric head phantom with insert in the cavity.



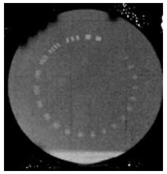

Above: Example proton radiographs with inserts of various tissue-equivalent material and the resulting difference map.

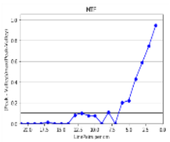
| Insert | True range change (cm) | Measured range change (cm) |
|---|---|---|
| Trabecular Bone | 0.12 | 0.12 ± 0.08 |
| Dental Dentin | 0.91 | 0.94 ± 0.09 |
| Dental Enamel | 1.43 | 1.46 ± 0.11 |
| Cortical Bone | 1.03 | 1.07 ± 0.10 |
| Spinal Disc | 0.06 | 0.05 ± 0.03 |

Table of the changes in range due to a different insert. The "True range change" column is the difference in water-equivalent thickness of the inserts and the "Measured range change" is the mean and standard deviation of the pixels in an ROI on the difference map.

## Spatial Resolution:

A proton radiograph of a Catphan Line Pair phantom and calculation of the modulated transfer function shows spatial resolution of 0.83 mm.






Good spatial resolution is needed to detect WEPL variations in small regions. Proton scatter degrades spatial resolution compared to x-ray radiography. However, x-ray radiography does not have the capability to detect proton range changes.

## Conclusion:

Proton radiographic images can be used to detect anatomical changes prior to treatment. Difference maps between radiographs show changes in proton range as low as 0.6 mm can be detected. Calculation of the modulated transfer function shows spatial resolution of 0.83 mm.

## Acknowledgements

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