Study of water equivalence of the PRESAGE dosimeter for 3D proton beam dosimetry

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History of Proton Therapy

› Dr Robert Wilson (1914-2000)
  - A Harvard University physicist who played a central role on the development of the atomic bomb
  - Published a paper in 1946 that first proposed the medical use of protons for cancer therapy

› In 1954
  - The University of Berkeley began using proton technology after the construction of a cyclotron to treat cancer patient
Proton therapy

A Comparison of the Dose Distribution for Proton and X-ray Beams

- Additional Dose Outside the Target Delivered with Photons
- 10 MeV X-rays (Photons)
- Protons Spread Out Bragg Peak (SOBP)
- Protons Bragg Peak

http://procure.com/media/factsheets/science
http://www.medical.siemens.com/webapp/wcs/stores/servlet/
Dosimetry in proton therapy

According to IAEA recommendations, the dosimetry of proton beams can be performed with an ionization chamber dosimeter.

However, because of the steep dose gradients, dose measurements are difficult close to the Bragg peak.

In addition, the ion chambers only provide point dose information and would require a large number of them to provide two or three dimensional dosimetric information.

Therefore, 3D dosimetry techniques such as polymer gel dosimetry has potential to be used as dosimeters to improve spatial resolution in proton therapy dosimetry.
Gel Dosimetry

a) 

b) 

c) 

d) 

e) 

f)
What is PRESAGE?

› The PRESAGE dosimeter is composed of radiochromic components (leuco dyes) and halogen-containing free radical initiators.

› It undergoes a color change when exposed to ionizing radiation.
Advantages of PRESAGE as a dosimeter

› Being able to provide three-dimensional dose information.

› Insensitivity to oxygen contamination.

› Being machinable and molded to variety of shapes and sizes.

› Absorbing rather than scattering light which facilitates high accuracy readout by optical CT.
## Different formulations of PRESAGE

<table>
<thead>
<tr>
<th>Material</th>
<th>Effective atomic number</th>
<th>Density (g/cm³)</th>
<th>w_H</th>
<th>w_C</th>
<th>w_N</th>
<th>w_O</th>
<th>w_S</th>
<th>w_Cl</th>
<th>w_Br</th>
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</thead>
<tbody>
<tr>
<td>PRESAGE® Formulation A</td>
<td>7.69</td>
<td>1.050</td>
<td>0.089</td>
<td>0.62</td>
<td>0.050</td>
<td>0.21</td>
<td>0.0038</td>
<td>0.031</td>
<td>0.0023</td>
</tr>
<tr>
<td>PRESAGE® Formulation B</td>
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<td>1.050</td>
<td>0.091</td>
<td>0.62</td>
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<td>0.21</td>
<td>0.019</td>
<td>0.0021</td>
<td>0.0047</td>
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<tr>
<td>PRESAGE® Formulation C</td>
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<td>1.101</td>
<td>0.089</td>
<td>0.61</td>
<td>0.045</td>
<td>0.22</td>
<td>-</td>
<td>0.033</td>
<td>0.0084</td>
</tr>
<tr>
<td>PRESAGE™</td>
<td>9.70</td>
<td>1.112</td>
<td>0.090</td>
<td>0.61</td>
<td>0.045</td>
<td>0.22</td>
<td>-</td>
<td>0.023</td>
<td>0.018</td>
</tr>
<tr>
<td>Water</td>
<td>7.42</td>
<td>1.000</td>
<td>0.11</td>
<td>-</td>
<td>-</td>
<td>0.89</td>
<td>-</td>
<td>-</td>
<td>-</td>
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Investigation of radiological properties and water equivalency of PRESAGE® dosimeters

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**Purpose:** PRESAGE® is a dosimeter made of polyurethane, which is suitable for 3D dosimetry in modern radiation treatment techniques. Since an ideal dosimeter is radiologically water equivalent, the authors investigated water equivalency and the radiological properties of three different PRESAGE® formulations that differ primarily in their elemental compositions. Two of the formulations are new and have lower halogen content than the original formulation.

**Methods:** The radiological water equivalence was assessed by comparing the densities, interaction probabilities, and radiation dosimetry properties of the three different PRESAGE® formulations to
Since Monte Carlo simulations can provide accurate predictions of dose (GOLD STANDARD), in this work, we have calculated the relative dose response of the four PRESAGE dosimeters to proton beam and compared it with dose response of water.
Method

› The GEANT4 Hadrontherapy example was modified accordingly to calculate depth doses in the PRESAGE® Formulation A, PRESAGE® Formulation B, PRESAGE® Formulation C, PRESAGE™ and water.

› Mean energy of proton beam was set to 62 MeV.
Method

40 cm

40 cm

40 cm
To compare the depth doses in each dosimeter, the water equivalent thickness (WET) was calculated according to IAEA technical report 398 for each dosimeter using the following formula:

\[
WET \approx t_m \frac{R_w}{R_m}
\]

\(t_m\) is thickness of dosimeters and \(R_w\) and \(R_m\) are the proton range in water and PRESAGE dosimeter, respectively.
Results

![Graph showing deposited energy (MeV) vs. water equivalent thickness (cm) for different materials including PRESAGE® A, B, and C, and Water.](image)
Results

![Graph showing relative dose vs. water equivalent thickness for different materials: PRESAGE® A, PRESAGE® B, PRESAGE® C, PRESAGE™, and Water. The graph illustrates the dosimetric properties of these materials in a radiation therapy context.]
Results
Results

Water

Relative dose at 50% dose to Bragg peak

Entries: 40000
Mean x: -0.01518
Mean y: -0.01951
RMS x: 4.073
RMS y: 4.093

PRESAGE® A

Relative dose at 50% dose to Bragg peak

Entries: 40000
Mean x: 0.0202
Mean y: 0.02755
RMS x: 4.055
RMS y: 4.084
Results

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<th>RMS x</th>
<th>RMS y</th>
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<tbody>
<tr>
<td>40000</td>
<td>-0.01057</td>
<td>-0.02286</td>
<td>3.999</td>
<td>4.012</td>
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### PRESAGE® A

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</thead>
<tbody>
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<td>40000</td>
<td>0.02697</td>
<td>0.03669</td>
<td>3.982</td>
<td>4.005</td>
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Results

**Water**

**PRESAGE® A**

Relative dose at Bragg peak

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</tbody>
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Results

Water

Relative dose at 10% dose to Bragg peak

Entries: 40000
Mean x: 0.006691
Mean y: -0.03004
RMS x: 3.992
RMS y: 3.996

PRESAGE® A

Relative dose at 10% dose to Bragg peak

Entries: 40000
Mean x: 0.02271
Mean y: 0.05056
RMS x: 3.981
RMS y: 3.99
Results

Water

PRESAGE® A

Relative dose at 10% dose to Bragg peak

- Entries: 40000
- Mean x: 0.006691
- Mean y: -0.03004
- RMS x: 3.992
- RMS y: 3.966

Relative dose at 10% dose to Bragg peak

- Entries: 40000
- Mean x: 0.02271
- Mean y: 0.05056
- RMS x: 3.981
- RMS y: 3.99
Results

Secendary protons

Deposited energy (MeV) vs. Water equivalent thickness (cm)

- PRESAGE® Formulation A
- Water
Results

Secondary Neutrons

- PRESAGE® Formulation A
- Water

Deposited energy (MeV)

Water equivalent thickness (cm)
Results

Secondary electrons

![Graph showing deposited energy versus water equivalent thickness for PRESAGE® Formulation A and Water.](image-url)
PRESAGE® dosimeters with new formulas, specially formulation A, are more water equivalent than the currently available PRESAGE dosimeter.

Thus more suitable for accurate 3D dosimetry of proton beams.

Further experimental studies are planned to investigate possible saturation in PRESAGE for high LET radiation fields.
Thanks!