INVESTIGATION OF NESTED VOLUME-OF-INTEREST CONE-BEAM CT IMAGING WITH A LOW ATOMIC NUMBER LINEAR ACCELERATOR TARGET

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Outline

- Low Z target
- VOI
- Workflow and Utility (multiple and nested VOIs)
- Normalization and dosimetry
- Applications and future work
Low-Z target CBCT

- **Carbon, beryllium or aluminum target** in linac beam line
- Replaces flattening filtration
- Allows improvement of CNR by 2-5x
PDD

6 MV

\[ d_{\text{max}} = 1.5 \text{ cm} \]

Rel dose = 65% at 10 cm

2.35 MV

\[ d_{\text{max}} = 0.3 \text{ cm} \]

Rel dose = 45% at 10 cm
Compare energy spectra

Diagnostic imaging energy range
Low-Z CBCT: Contrast-to-noise

Decrease of dose with 3.5 MeV/Al beam compared to 6MV by a factor of ~5–8 depending on tissue and CNR

Robar et al. Med. Phys. 36, pp.3955
CBCT versus VOI CBCT

Full-Field (FF)  Volume-of-Interest (VOI)

**Costs:**
1. Imaging dose to entire volume of patient
2. Reduction of image quality due to scatter

**Benefits:**
1. Localization of imaging dose to VOI
2. Improved scatter-to-primary characteristics
Low-Z VOI CBCT workflow

1. Delineate VOI for imaging on planning CT
   - Define CBCT arc geometry and beam shaping – export MLC sequence file

2. Processing of MLC files using Matlab

3. Acquire 2.35 MV / Carbon target VOI CBCT

4. FDK reconstruction
   - Normalization

Eclipse 10.0

Matlab

Clinac with carbon target

Reconstruction
Apparatus
Example VOI configurations
Multiple VOIs
Multiple VOIs
Nested VOIs

Two separate MLC sequences merged together

Define inner VOI
e.g. PTV
Define outer VOI
e.g. surrounding OARs or body contour
Acquire inner VOI at higher dose and CNR
Nested VOIs
Pixel intensities between the two VOIs now have different relative radiodensities.

For this reason we normalize inner and outer VOI after the reconstruction that can later be converted into Hounsfield units.
Normalize - masking

A) Input image
B) Inner mask
C) Outer mask
D) Ring mask
E) Inner mask
F) Outer mask
G) Ring mask
Normalize - masking

In

Out

Ring
Normalized reconstruction

Position along profile

Raw

Normalized
Zoomed images

2:1  6:1
Radiochromic Film Dosimetry
Find dose and CNR

Repeat the VOI sequences on a water phantom with cortical bone $\rho_e=1.69$ contrast tissue

With bone inserts

With ion chamber

2:1
3:1
4:1
5:1
6:1
Control of dose and CNR in nested VOIs

\[ CNR = \frac{|P_{\text{bone}} - P_{\text{water}}|}{\sqrt{\sigma_{\text{bone}}^2 + \sigma_{\text{water}}^2}} \]

\[ CNR \propto \sqrt{\text{dose}} \]
Low-Z CBCT dose AAA distributions

Nested VOI, 2:1

Nested VOI, 6:1
Case scenarios

Prostate cancer treatment
Based on QUANTEC review
For Rectum \( V75 < 15\% \)
For Bladder \( V75 \leq 25\% \)
Summary

- Lowered dose and/or improved CNR by combining low-Z target beam with dose localization VOI approach
- Versatile MLC approach – multiple or nested VOIs possible as defined at planning step
- With VOI inner/outer ratio sequencing, dose reduction can be tuned to threshold CNR for outer VOI
- Dose can be calculated in Eclipse and subtracted from treatment dose
Future directions

**Cho, S. (2005)**

Based on the results of Hainfeld et al. (2004) simulated the dose enhancing using a modified phantom and tumor composition defined by ICRU to incorporate different concentrations of GNPs and compared 3 radiation sources.

<table>
<thead>
<tr>
<th>Concentration (per gram of tumor)</th>
<th>140 kVp</th>
<th>6 MV FF</th>
<th>6 MV NFF</th>
<th>4 MV FF</th>
<th>4 MV NFF</th>
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</thead>
<tbody>
<tr>
<td>7 mg Au</td>
<td>2.114</td>
<td>1.007</td>
<td>1.014</td>
<td>1.009</td>
<td>1.019</td>
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<tr>
<td>18 mg Au</td>
<td>3.811</td>
<td>1.015</td>
<td>1.032</td>
<td>1.019</td>
<td>1.044</td>
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<tr>
<td>30 mg Au</td>
<td>5.601</td>
<td>1.025</td>
<td>1.053</td>
<td>1.032</td>
<td>1.074</td>
</tr>
</tbody>
</table>

FF: flattening filter, NFF: no flattening filter.
Future directions
Thank you!