The Use of PCXMC in the Optimisation of Pelvic CBCT in Radiotherapy

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Overview

• **Objective**
  - Create size-specific pelvic CBCT protocols for OBIs on both Varian Clinac and TrueBeam linear accelerators, in order to reduce imaging dose for smaller patients.

• **Motivation**
  - Under IR(ME)R legislation have to ensure imaging doses are both justified and optimised.
  - Imaging dose can no longer be considered negligible in comparison to treatment dose.
  - Pelvic CBCT scans currently performed using Varian default protocols.
Overview

• **Issues**
  - Currently no standard approach for CBCT dosimetry or image quality assessment.
  - Pelvic CBCT acquisition differs between Varian Clinac and Varian TrueBeam accelerators

• **Goals**
  - Determine patient size categories for patients receiving pelvic CBCTs in NHS Tayside.
  - Establish method of assessing CBCT dose, for all size categories, using PCXMC.
  - Determine effect of changing exposure parameters on CBCT image quality, for all size categories.
Varian OBI

Varian Clinac iX Linear Accelerator with On-Board Imager (OBI)
CBCT Theory

**Full-Fan = Small FOV**

**Half-Fan = Large FOV**

**Symmetric field**

**Asymmetric field**
CT Patient Audit

- Retrospective audit of prostate planning CTs (n=90)
- Information recorded:
  - Patient age at time of scan
  - Total scan mAs
  - Max CTDI$_{vol}$ for scan
  - Scan DLP
  - Max Lateral and A-P dimensions at position of prostate

- Due to replacement of current CT scanner, decision was made to calculate patient ‘size’ based on measurements of lateral and anterior-posterior (A-P) dimensions on the CT slice at the prostate with largest body cross-section. This will change to scan mAs or CTDI once enough data is collected for the new scanner.

‘size’ = Lateral x A-P
Patient Size Categories

Patient Number vs. Size = Lat x AP (cm²)

<table>
<thead>
<tr>
<th>Patient size Category</th>
<th>Calculated ‘size’</th>
<th>Scan mAs</th>
<th>Scan CTDI_{vol}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>&lt; 750 cm²</td>
<td>&lt; 4780 mAs</td>
<td>&lt; 45 mGy</td>
</tr>
<tr>
<td>Medium</td>
<td>750 – 875 cm²</td>
<td>4780 – 6830 mAs</td>
<td>45 – 70 mGy</td>
</tr>
<tr>
<td>Large</td>
<td>&gt; 875 cm²</td>
<td>&gt; 6830 mAs</td>
<td>&gt; 70 mGy</td>
</tr>
</tbody>
</table>
Image Quality Assessment

- Imaging radiographers reviewed 14 pelvic CBCT scans of patients representing a spread of patient sizes (5 small, 6 medium, 3 large)

- CBCTs were scored according to image quality, focusing on suitability for image matching

- Found to have ‘acceptable’ image quality for all patient size groups
  - **Large** patient size category assigned to Varian default pelvic CBCT protocols
  - Can reduce current imaging dose for smaller patients by adjusting kV and/or mAs of default pelvic CBCT protocols
PCXMC2.0 Rotation

PCXMC = PC program for X-ray Monte Carlo
Input Height and Weight

PCXMC Phantom Height
• Decided to set a phantom height of **175 cm** for all patient size categories

PCXMC Phantom Weight
• Increased phantom weight from 58kg to 95kg
• Measured phantom lateral and A-P dimensions for each input weight
• Calculated a ‘size’ for each input weight
• From range of weights for each size category, **median** weight was decided on for PCXMC input

<table>
<thead>
<tr>
<th>Size Category</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>175</td>
<td>63</td>
</tr>
<tr>
<td>Medium</td>
<td>175</td>
<td>78</td>
</tr>
<tr>
<td>Large</td>
<td>175</td>
<td>90</td>
</tr>
</tbody>
</table>
Number of Projections

- For 360° pelvis CBCT scan the OBI acquires 655 projections (Clinac) or 900 projections (TrueBeam)
  - Not practical to model this as computation time too long

- Previous project within department recommended using 8 equally spaced projection angles for modelling effective dose in the pelvic region
  - No additional benefit found from using 16 or 32 projections
Reference Co-ordinates

- Pelvic CBCT acquired with asymmetric beam and the detector off-set
- PCXMC models symmetric beams, therefore reference co-ordinates were determined in order to model an asymmetric beam

\[ X_{\text{ref}} \text{ and } Y_{\text{ref}} \] - Off-set direction changes depending on projection angle

\[ Z_{\text{ref}} \] - Same for all projections. Positioned at level of prostate based on organs in FOV
Number of Sub-Fields

- PCXMC assumes a uniform x-ray spectra; however due to half-fan bow-tie filter, pelvic CBCT beam is not uniform
- Due to the half-fan bow-tie filter used for pelvic CBCT scans, it was decided to split the beam into sub-fields, each of which will be considered ‘uniform’
- An investigation determined that the optimal number of sub-fields to use is 4
- Using more than 4 sub-fields resulted in no change of effective dose, but increased computational complexity
DAP vs. Air Kerma

- 5 input dose quantities available in PCXMC
- Decided to compare:
  - Air Kerma at reference distance (i.e. isocentre) in mGy
  - Dose-Area Product (DAP) in mGy.cm²
Air Kerma Measurements

Set-Up
- Gantry at 90°
- Half-fan bow-tie filter inserted into kVs
- kVs at 0° and positioned at +100cm
- kVd at 180° and positioned offset at -50cm
- Treatment couch within OBI field of view
- Asymmetric field as used in CBCT protocol

Successful Method
- RadCal 10X6-6 ionisation chamber with traceable kV calibration
- Detector positioned in air at isocentre
- Air kerma recorded in centre of all 4 sub-fields
- Measurements taken for both 110kV and 125kV
Air Kerma Results (Clinac)

### 110kV

**Air Kerma vs. Lateral Position**

<table>
<thead>
<tr>
<th>Sub-Field</th>
<th>Lateral Position (cm)</th>
<th>Air Kerma for 110kV</th>
<th>Air Kerma for 125kV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>μGy/mAs</td>
<td>mGy</td>
</tr>
<tr>
<td>1</td>
<td>-2</td>
<td>75.9</td>
<td>6.46</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>56.9</td>
<td>4.84</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>25.9</td>
<td>2.21</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>18.7</td>
<td>1.59</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>7.1</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>6.7</td>
<td>0.57</td>
</tr>
</tbody>
</table>

### 125kV

**Air Kerma vs. Lateral Position**
DAP Measurements (Clinac)

Set-Up
– Same as for air kerma measurements

Method
– PTW Diamentor M2 DAP meter attached to half-fan bow-tie filter
– Filter and DAP meter assembly inserted into kVs
– RadCal Patient Dose Calibrator, traceable to National standard, positioned on treatment couch
– RadCal used to calibrate PTW DAP meter
– PTW DAP meter used to record full-field DAP for 100mAs exposure
– Measurements taken for both 110kV and 125kV
DAP Results (Clinac)

- To get correction for field non-uniformity due to half-fan bow-tie filter, XR-QA2 Gafchromic film was irradiated using the same set-up
- Film was processed and dose profile for filter obtained
- Dose profile used to get percentage of total DAP per sub-field
- DAP per sub-field then determined for PCXMC input

<table>
<thead>
<tr>
<th>Sub-Field</th>
<th>Lateral Position (cm)</th>
<th>% of Full Field DAP</th>
<th>DAP for 110kV mGy/cm²</th>
<th>DAP for 125kV mGy/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2</td>
<td>57.09</td>
<td>75.9</td>
<td>103.6</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>23.84</td>
<td>56.9</td>
<td>79.3</td>
</tr>
<tr>
<td>3</td>
<td>9 10</td>
<td>6.52 9.77</td>
<td>25.9 18.7</td>
<td>38.9 28.4</td>
</tr>
<tr>
<td>4</td>
<td>14 18</td>
<td>1.98 6.86</td>
<td>7.1 6.7</td>
<td>11.9 10.9</td>
</tr>
</tbody>
</table>
DAP vs. Air Kerma (Clinac)

- Both inputs show the same trend with respect to patient weight and change in kV
- Effective dose calculated via DAP input is consistently higher than for Air Kerma input
  - Uncertainty in detector positioning for Air Kerma measurements taken to contribute to difference
• PCXMC simulations, using DAP as dose input, indicate patients receive an effective dose ranging from **3.87 mSv** to **5.03 mSv** for the current default protocol (125kV, 80mA, 13ms).

• Evident that the effective dose for smaller sized patients can be reduced by decreasing the tube voltage or scan mA.

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<table>
<thead>
<tr>
<th>CBCT Exposure Setting</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>125kV, 80mA, 13ms</td>
<td>5.03</td>
<td>4.30</td>
<td>3.87</td>
</tr>
<tr>
<td>125kV, 63mA, 13ms</td>
<td>3.96</td>
<td>3.39</td>
<td>3.04</td>
</tr>
<tr>
<td>125kV, 50mA, 13ms</td>
<td>3.14</td>
<td>2.69</td>
<td>2.42</td>
</tr>
<tr>
<td>125kV, 40mA, 13ms</td>
<td>2.51</td>
<td>2.15</td>
<td>1.93</td>
</tr>
<tr>
<td>110kV, 80mA, 13ms</td>
<td>3.59</td>
<td>3.06</td>
<td>2.75</td>
</tr>
<tr>
<td>110kV, 63mA, 13ms</td>
<td>2.82</td>
<td>2.41</td>
<td>2.16</td>
</tr>
<tr>
<td>110kV, 50mA, 13ms</td>
<td>2.24</td>
<td>1.91</td>
<td>1.72</td>
</tr>
<tr>
<td>110kV, 40mA, 13ms</td>
<td>1.79</td>
<td>1.53</td>
<td>1.37</td>
</tr>
</tbody>
</table>
Size-Specific Protocols (Clinac)

- Size-specific protocol settings selected with intention of all sized patients receiving equivalent CBCT dose

<table>
<thead>
<tr>
<th>Patient Size Category</th>
<th>CBCT Exposure Setting</th>
<th>Change in Dose wrt Current Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>125kV, 50mA, 13ms</td>
<td>-37.6%</td>
</tr>
<tr>
<td></td>
<td>110kV, 80mA, 13ms</td>
<td>-28.6%</td>
</tr>
<tr>
<td>Medium</td>
<td>125kV, 63mA, 13ms</td>
<td>-14.8%</td>
</tr>
<tr>
<td>Large</td>
<td>125kV, 80mA, 13ms</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Image Quality

- In-house constructed size-category specific Catphan annuli were created to verify the image quality for the new pelvic CBCT protocols.

- All annuli were designed to slip over 20cm outer diameter Catphan phantoms.

- Using data from the CT patient audit, the largest size of a patient within each category was used to define the outer dimensions of the annuli. This was in order to determine the ‘worst case’ image quality in each category.

<table>
<thead>
<tr>
<th>Annulus Size</th>
<th>Height (cm)</th>
<th>Width (cm)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>22</td>
<td>34</td>
<td>20</td>
</tr>
<tr>
<td>Medium</td>
<td>24</td>
<td>36.5</td>
<td>20</td>
</tr>
<tr>
<td>Large</td>
<td>26</td>
<td>39</td>
<td>20</td>
</tr>
</tbody>
</table>
Image Quality

Align with in-room lasers

Use soft wedges to aid positioning
Image Quality (Clinac)

- CNR (Air and BG)
- CNR (Telfon and BG)
- SNR (Large ROI)
- SNR (Small ROIs)
Summary

- PCXMC pelvic CBCT model successfully created using 8 projections and 4 sub-fields per projection.

- DAP was chosen as the optimal PCXMC dose input for pelvic CBCTs
  - Removes uncertainty with positioning associated with Air Kerma measurements.

- Based on this study, 3 size-specific pelvic CBCT protocols will be implemented in NHS Tayside for the Varian OBIs.

- The Varian default protocol will be used for the large patient size category
  - Imaging dose will be reduced for the small and medium size groups by adjusting mA.

- Image quality results using the Catphan plus annulus confirm the image quality of new protocol settings are comparable to that of the default for the large size category.

- Initial clinical implementation results indicate new protocols are clinically useable and not detrimental to clinical decision making.
  - In the future there may be scope to reduce imaging dose further.
Thanks

- Emma McIntosh, Radiotherapy Physicist
- Mark Worrall, RP/DR Physicist
- Kirsty Farnan, Treatment Advanced Practitioner
- Kirsty Muir, Treatment Advanced Practitioner
- Ian Sanders, Oncology Consultant

Key References

Thank you for listening.

Are there any Questions?