Calculation of Effective Doses for Radiotherapy Cone-Beam CT and Nuclear Medicine Hawkeye CT

Laura Sawyer

Department of Medical Physics and Bioengineering, Royal United Hospital, Bath
Overview

- **Varian Acuity ConeBeam CT**
  - ConeBeam CT option available Sept 2005
  - Aim to use for breast and pelvis treatment planning

- **GE Infinia Hawkeye SPECT / CT**
  - Installed in March 2006
  - Enables registration of CT and Nuclear Medicine Images
ConeBeam CT

• Full Fan
  – irradiates uniformly over 360°
  – Single rotation produces full image

• Partial Fan
  – for larger fields of view
  – Detector is offset
  – Centre of field of view is irradiated for whole rotation
  – Edge of field of view is irradiated for fraction of the rotation
ConeBeam CT

• System upgrade in October 2006
  – Allows images to be ‘stitched’
  – Images are acquired in 1, 2 or 3 rotations.
  – Images acquired using a single rotation can be collimated
  – Irradiated length at isocentre exceeds image length
  – For double and triple scans, irradiation at the isocentre overlaps at stitching area
    • 10cm overlap for 2.5mm slice width
    • 13.6cm overlap for 10mm slice width
  – It is not possible to collimate double and triple scans
Infinia Hawkeye CT

- All clinical scans use ‘half scan’ setting
  - 240° exposure per 360° rotation
- Rotational increment programmed between slices
  - Changes the 240° section irradiated

Doses were measured using CTDI head and body phantoms (16cm and 32cm diameters)
Effective Dose Calculations

Three calculation methods were compared:

1. IMPACT CT Patient Dosimetry Calculator

2. Combination of tissue weighting factors and fraction of organs in the beam

3. NRPB W-67 Effective dose conversion factors
IMPACT CT Patient Dosimetry Calculator

• Each scanner was matched to an existing CT scanner
  – Using ratio of dose measurements in air, to doses at centre and periphery of head and body phantoms

• Both scanners use maximum exposure parameters
  – ConeBeam CT: 125kV, 80mA, 15ms pulse, 45s rotation
  – Infinia Hawkeye: 140kV, 2.5mA, 2.6rpm, 10mm slice
IMPACT CT Patient Dosimetry Calculator for ConeBeam CT

- Assumes uniform irradiation
  - Correct for ConeBeam CT full fan
- Estimation only for partial fan
  - Assumes gradual variation in dose
  - Small high dose area at centre
  - Doses to organs between centre and periphery of body will be overestimated
    - E.g. lung, colon, stomach, liver
- For double and triple scans
  - Calculate dose for full scan length
  - Add dose at stitching overlap
IMPACT CT Patient Dosimetry Calculator for Infinia Hawkeye

• Variation in dose around periphery
  – Due to 240° irradiation
  – And couch attenuation

• Average peripheral dose used for scanner match
  – Irradiated area varies due to rotation increment between slices
  – Organs exceeding 15cm length will receive approximately uniform irradiation
  – Dose will be underestimated if small radiosensitive organ is at irradiated surface e.g. thyroid
Organ Fractions Calculation

• Estimate fraction of each radiosensitive organ in the beam for common scans
  – Using IMPACT phantom
• Multiply by measured dose in phantom
• Multiply by tissue weighting factors
• Sum results for all organs
Organ Fractions Calculation: Infinia Hawkeye

- Clinical settings, with ‘half scan’
  - Average peripheral dose: 4mGy
  - Central dose: 2mGy

<table>
<thead>
<tr>
<th>Chest scan</th>
<th>Weighting factor</th>
<th>CTDI (mGy)</th>
<th>Fraction in beam</th>
<th>Organ dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung</td>
<td>0.12</td>
<td>2</td>
<td>1</td>
<td>0.24</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.12</td>
<td>2</td>
<td>0.1</td>
<td>0.02</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.05</td>
<td>4</td>
<td>0.2</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.8</strong></td>
</tr>
</tbody>
</table>
Organ Fractions Calculation: ConeBeam CT

• Partial fan for body scans
  – Average periphery: 20mGy
  – Centre: 12mGy
  – Average mid-points: 14mGy

• Dose measurements at mid-points correspond to dose at edge of head phantom
  – Apply mid-point doses to lung, stomach, liver

• For double and triple scans
  – Calculate dose for total scan length
  – Add dose for overlap in centre of scan
NRPB W-67 Effective Dose Conversion Factors

• Calculate dose length product:
  – CTDI (mGy/mAs)
  – mAs = mA x rotation time (x pulse length x frame rate)
  – Scan length

• Effective doses per DLP (mSv (mSv cm)^{-1})
  – Head: 0.0021
  – Chest: 0.014
  – Abdo-pelvis: 0.015
## Comparison of Methods for Infinia Hawkeye

<table>
<thead>
<tr>
<th>Effective dose (mSv)</th>
<th>Chest</th>
<th>Abdo-pelvis</th>
<th>Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPACT</td>
<td>1.0</td>
<td>1.6</td>
<td>0.10</td>
</tr>
<tr>
<td>Organ fraction</td>
<td>0.8</td>
<td>1.5</td>
<td>0.12</td>
</tr>
<tr>
<td>Conversion factors</td>
<td>0.9</td>
<td>1.5</td>
<td>0.11</td>
</tr>
<tr>
<td>Standard CT</td>
<td>2.6</td>
<td>6.2</td>
<td>1.4</td>
</tr>
</tbody>
</table>

- Standard scan lengths used in CT
- Good agreement between calculation methods
- Effective doses lower than standard CT due to low mAs
Comparison of Methods for ConeBeam CT (single scan)

<table>
<thead>
<tr>
<th>Effective Dose (mGy)</th>
<th>Chest</th>
<th>Abdo-pelvis</th>
<th>Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPACT</td>
<td>9.9</td>
<td>10</td>
<td>1.7</td>
</tr>
<tr>
<td>Organ fraction</td>
<td>4.7</td>
<td>5.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Conversion factors</td>
<td>5.8</td>
<td>6.2</td>
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- **IMPACT calculation**: Overestimates doses to organs between centre and periphery of body
- **Organ fraction method**: Underestimates dose due to exclusion of scattered radiation to organs outside beam
ConeBeam CT: Stitched Images

- A single scan will produce a maximum image length of 14.4cm
- Data from 2 rotations may be stitched to produce a maximum image length of 28.8cm
  - Total image length depends on slice width selected
  - Overlap in centre of image depends on slice width
  - Total irradiated length is independent of slice width
  - Therefore, effective dose has negligible dependence on slice width
- Abdo-pelvis scans generally use double scan
Summary: Calculation Methods

- **Infinia Hawkeye CT**
  - Methods for calculating effective dose are in good agreement with one another

- **ConeBeam CT**
  - There is significant variation in doses
    - IMPACT method overestimates dose
    - Organ fraction method underestimates dose
Summary: Effective Doses

• Hawkeye doses are below diagnostic CT results
  – Half-scan setting is used for all patients
  – Scan length is determined individually for each patient
  – No option to reduce kV or mA

• ConeBeam CT doses may significantly exceed diagnostic CT doses
  – No option to reduce kV, mA
  – Recommendations:
    • Single scan should be used wherever possible
    • Longer pulse lengths only used for very low contrast details
    • Slice widths of 3-5mm compromise between data storage, reconstruction times, and prevention of double overlap
    • Double and triple scans only used where clinically justified