Characterization, Commissioning and Evaluation of Delta⁴ IMRT QA System

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Introduction

• IMRT dose distribution is complex and requires QA
• Current IMRT QA provides limited points and planes and the Gamma analysis is only 2D
• Labor intensive
• Leaves voids in the evaluation of plan and its delivery
• Field by Field and Segment by Segment analysis is typically not possible
• Does not readily extend to 4D

Question: Does the DELTA⁴ system potentially address these drawbacks?
Delta$^4$ Device Fully Assembled

Currently commercially available

Power, Synchronization and Data Cables

2D diode Arrays

Electrometers
2D Detector Arrays Units

- Main Unit
- Detection Area 20x20 cm²
- Sensitivity 5nC/Gy
- Wing Unit
Detector Arrays

- p-diodes in absolute dose mode
- High spatial resolution
- 5 mm spacing at center
- 10 mm spacing at periphery
- 1069 diodes

Area: 0.78 mm$^2$
Height: 0.05 mm
G Rikner and E Grusell


![Graph showing sensitivity vs. dose for n-type and p-type materials.](image-url)
Figure 4. Ratio between signals from a semiconductor detector and an ionisation chamber, measured in 8 MV x-rays, as a function of dose per pulse. Data for p-type detectors pre-irradiated to 25 kGy (+) and n-type detectors pre-irradiated to 10 kGy with 20 MeV electrons (⊙) are shown (from Grussell and Rikner 1984).
Power Distribution System

- Provides each detector unit with power
- Provides (external) synchronization signals to detector units
Pulse by Pulse Measurements

- All diodes readings are recorded with time stamp and reset after each pulse

- Segment by Segment and 4D measurements possible

- Approximate pulse separation is 3ms and width is 3ms

- No measurement between pulses, results in a high signal to noise ratio
Characterization Measurements

- Precision
- Stability
- Linearity
- Dose rate (pulse rate) dependence
- Dose per pulse rate dependence
- Beam directional dependence
- Energy dependence
- Interpolation at non detector location
- Sensitivity change – about 1% kGy
Results

- **Precision**
  - $1\sigma = 0.1\%$, Range from 0 to 1\% measured exposing single field 10 times in a 6 MV beam

- **Stability**
  - $1\sigma = 0.6\%$, Range from 0 to 0.5\% (Five measurements of 4 Field box distribution over a 3 month period)

*No ion chamber measurements are necessary*
Linearity

Dose response of the central detector from 50 to 1000 MU

\[ y = 0.8632 \times + 0.0556 \]

\[ R^2 = 1 \]
Dose Rate Dependence

Dose rate (Pulse rate) dependence: Negligible from 100 MU/min to 600 MU/min

$y = 86 \quad R^2 = 1$
Dose per Pulse Dependence

\[ y = 0.0174x + 0.981 \]

\[ R^2 = 0.0548 \]
Directional dependence 6 MV beam

Range ± 2.5 %

Normalization: 100 % at 60 degrees

Beam angle with respect to main detector plane (degrees)
# Response to Scatter and Leakage Radiation

<table>
<thead>
<tr>
<th>MLC FS</th>
<th>JAW FS</th>
<th>DIST. FieldEdge</th>
<th>DELTA(^4) 6 MV</th>
<th>IC CC04 6 MV</th>
<th>DELTA(^4) 18 MV</th>
<th>IC CC04 18 MV</th>
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<tbody>
<tr>
<td>2 X 2</td>
<td>3 X 3</td>
<td>1</td>
<td>0.030</td>
<td>0.020</td>
<td>0.040</td>
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<tr>
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<td>3 X 3</td>
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<td>Lo Signal</td>
<td>0.009</td>
<td>Lo Signal</td>
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<tr>
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<td>5 X 5</td>
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<td>0.060</td>
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<tr>
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<td>0.020</td>
<td>0.018</td>
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<tr>
<td>10 X 10</td>
<td>11x11</td>
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<td>0.090</td>
<td>0.100</td>
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<tr>
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<tr>
<td>MLC Leakage</td>
<td>10x10</td>
<td>-</td>
<td>0.016</td>
<td>0.013</td>
<td>0.017</td>
<td>0.013</td>
</tr>
</tbody>
</table>
Commissioning

- Absolute dose calibration against calibrated Farmer Type ion chamber in plastic-slab phantom
- Relative dose calibration in a stable beam
- Network, PC and interface with R&V system configuration (if needed)
- Configuring export (from TPS) and import (into Delta4) of DICOM RT and RTOG formatted files
Evaluation

• IMRT QA on Thirteen patient plans (HN, CNS, Thoracic, Gyn, GU and GI)
• Plans with Non coplanar beams were also measured
• All plans passed the criteria of Gamma (5% or 5mm) $\leq 1$ for more than 97% of points
• Representative analysis presented
Delta^4 Software 3D View

Software provides information on IMRT QA Statistics
Visualization of BEV MLC Deviations

Dose Comparison

3D

Interactive
Dose comparison in 2D and Interactive Statistics
Software allows for Profile Comparison – Composite Dose

Planned 90% iso dose line
Conclusions

- Accurate and Precise.
- It is an integrated 3D system with analysis software.
- Timeliness: QA prior to treatment.
- Powerful: Field by Field and Segment by Segment analysis, display of anatomical contours over the measured distribution.
- Efficiency and convenience of central database.
- Extension to 4D.

*Delta^4* system does address the drawbacks in the current QA system.
Future Work

- Research possibilities - RPC Head and Neck phantom

- Future work - Breast phantom, 4D lung phantom, Independent algorithm to verify the interpolation method used here, etc.