Review of TG-186 recommendations

Implementation of advanced brachytherapy dose calculation algorithms beyond TG-43

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Learning Objectives

• Why move beyond TG-43 for brachytherapy dose calculations?

• What are issues in adopting advanced dose calculation algorithms?

• What are the TG-186 recommendations for adoption of advanced model-based dose calculation algorithms?

Why move beyond TG-43?

• TG-43 based treatment planning systems (TPS) can fail to accurately calculate dose...
  Air, tissues ≠ water
  Intersource effects
  Shielding
  Radiation scatter

TG-43 approach versus Reality
Effect of non-water media significant

Mass energy absorption coefficients of various tissues relative to water versus energy
How large are deviations from TG-43?

• Shielded applicators (GYN, ocular ...): huge!
  - Eye plaque: up to 90%

• Breast:
  - HDR: up to 5% for skin dose
  - Low energy: 30-40% from tissue heterogeneities

• Prostate:
  - HDR: <2% (plastic catheters)
  - Permanent seed: 4 to 15%
If not TG-43, then what?

→ Model-based dose calculation algorithms (MBDCAs)
  • Collapsed-cone superposition/convolution method
  • Deterministic solutions to the linear Boltzmann transport equation
  • Monte Carlo simulations
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TG-186 charge: provide guidance for early adopters of MBDCAs for brachytherapy to ensure practice uniformity

→ Maintain inter-institution consistency and high QC/QA standards

TG-186 recommendations

Recommendations focused on three main areas:

1. Dose specification medium selection
2. CT imaging and patient modeling
3. MBDCA commissioning
TG-186 recommendations

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MBDCA model radiation transport and energy deposition in realistic patient treatment geometries

→ Adopters of MBDCA must select media for:
   – Radiation transport
   – Dose specification

Dose reporting possibilities

\( D_{x,y} \)

\( x \): dose specification medium

\( y \): radiation transport medium

\( x,y \): Local medium (m) or water (w)
Dose reporting possibilities

\[ D_{x,y} \]

\( x \): dose specification medium

\( y \): radiation transport medium

\( x, y \): Local medium (m) or water (w)

\[ D_{m,m} \]

Scoring volume / dose specification medium
Dose reporting possibilities

$x$: dose specification medium

$y$: radiation transport medium

$x,y$: Local medium (m) or water (w)
Dose reporting possibilities

\[ D_{x,y} \]

\( x \): dose specification
\( m \), \( x \): medium

\( y \): radiation transport
\( m \), \( w \): medium

\( x, y \): Local medium (m) or water (w)

\[ D_{m,m} \]
\[ D_{w,w} \]
\[ D_{w,m} \]
Adoption of MBDCA is motivated by clinical need for accurate and rigorous estimation of delivered dose distributions

Model radiation transport with most accurate tissue compositions available:

\[ D_{m,m} \quad \text{or} \quad D_{w,m} \]
Dose specification medium?

- Debate:
  - $D_{m,m}$
  - $D_{w,m}$

or

???
Dose specification medium?

- Debate:

  $D_{m,m}$

  or

  $D_{w,m}$

External Beam:

- Controversy largely academic (except for bone): differences 1-2% for all soft tissues

- AAPM TG-105 on MC dose calculations for EBRT (2007): no position on $D_{m,m}$ versus $D_{w,m}$ issue

$D_{m,m}$ versus $D_{w,m}$: brachytherapy

- Differences between $D_{m,m}$, $D_{w,m}$ and $D_{w,w}$ (TG-43) significant, especially for low energy brachytherapy

- Cannot generally motivate reporting $D_{w,m}$ to connect with previous clinical experience

- Adoption of MBDCA: potential for significant impact on dose metrics
TG-186 recommendation

- As available evidence does not directly support $D_{w,m}$, reporting $D_{m,m}$ is preferred
  - $D_{m,m}$ is a conceptually well-defined quantity whereas $D_{w,m}$ is a theoretical construct (no physical realization in a non-water medium)

→ Require only reporting $D_{m,m}$ when using MBDCAs

$D_{m,m}$  $D_{w,m}$
TG-186 recommendations

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2. CT imaging and Patient modeling

• MBDCA require assignment of interaction cross sections on a voxel-by-voxel basis

• EBRT: only need electron densities (e⁻/cm³)

• Brachytherapy (< 400 keV): importance of photoelectric effect → interaction cross sections depend on atomic number Z, in addition to density

→ Need to know tissue mass density and atomic number distribution within patient geometry
Tissue segmentation

• Human tissues ≠ water

• Need accurate tissue segmentation: identification of tissue type → density and elemental composition

• Inaccurate tissue segmentation → inaccurate dosimetry (both for cancerous tissues and organs at risk)
TG-186 recommendations

CT imaging and Patient modeling:

i. Consensus material definition

ii. Material assignment method

iii. CT artifact removal
i. Consensus material definition

- Limit # of materials to a few
- Tissue mass density derived from CT scanner image (exception: artifacts)
- Material definitions: ICRU Report 46 (Ref. 109)
  Woodard and White 1986 (Ref. 110) – Table III (TG-186)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>% mass</th>
<th>Z &gt; 8</th>
<th>Mass density g cm⁻³</th>
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<tr>
<td></td>
<td></td>
<td>H</td>
<td>C</td>
</tr>
<tr>
<td>Prostate (Ref. 110)</td>
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<td>10.5</td>
<td>8.9</td>
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<tr>
<td>Mean adipose (Ref. 110)</td>
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<td>Mean gland (Ref. 110)</td>
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<tr>
<td>Mean male soft tissue (Ref. 109)</td>
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<td>25.6</td>
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<tr>
<td>Mean female soft tissue (Ref. 109)</td>
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<td>31.5</td>
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<tr>
<td>Mean skin (Ref. 109)</td>
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<td>10.0</td>
<td>20.4</td>
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<tr>
<td>Cortical bone (Ref. 109)</td>
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<td>15.5</td>
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<tr>
<td>Eye lens (Ref. 109)</td>
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<td>19.5</td>
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<td>Lung (inflated) (Ref. 109)</td>
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<tr>
<td>Liver (Ref. 109)</td>
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<tr>
<td>Heart (Ref. 109)</td>
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</tr>
<tr>
<td>Water</td>
<td></td>
<td>11.2</td>
<td>13.9</td>
</tr>
</tbody>
</table>
i. Consensus material definition

• Clinical physicist: confirm sufficiently accurate and spatially resolved applicator and source models, including correct media assignments

• Applicators, sources should be modeled analytically or with very fine resolution meshes

• Manufacturers should disclose seed and applicator geometry, material assignments, and manufacturing tolerances to both end users and TPS vendors
ii. Material assignment method

• For a given organ, use contours to guide tissue assignment

• If CT data available:
  • Use CT-derived density with uniform tissue composition
  • Voxels outside contours: use CT densities with ‘mean soft tissue’ composition

• Other imaging modalities: use bulk tissue densities and compositions based on contoured organs
iii. CT artifact removal

• Artifacts must be removed prior to dose calculations

• Simplest: manual override of tissue composition and density

• Advanced approaches: if used, must be carefully documented

TG-186 recommendations

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3. MBDCA Commissioning

- Implementation of MBDCA for treatment planning: compromises between computational speed and accuracy

  → MBDCA TPS must be carefully benchmarked against analogue MC or experiment

- TG-186: two levels of commissioning tests in addition to TPS QC/QA already in place based on societal guidelines
Commissioning level 1

• Comparison of MBDCA-derived doses in a reference-sized homogeneous water phantom to consensus TG-43 data

→ Check dose distribution due to physical source model without consideration of surrounding environment

• Level 1 pass criterion: 2.0% tolerance for agreement with consensus TG-43 dosimetry parameters
  • Deviations > 2.0% should be carefully examined, clinical impact understood and documented prior to patient use
Commissioning level 2

• Comparison of MBDCA TPS 3D dose distributions for specific virtual phantoms mimicking clinical scenarios with benchmark dose distributions for the same phantom geometries

• Benchmarked dose distributions obtained using well-documented MC code
  - Working group on MBDCA for brachytherapy: development of test cases to be made publicly available
MBDCA commissioning workflow

Fig. 4 (TG-186 Report): MBDCA commissioning workflow for heterogeneous dose distributions calculated by a MBDCA-based TPS.

See TG-186 report for discussion.
Conclusions

• TG-43 calculations
  - Consistent formalism → important part of clinical brachytherapy
  - Use in parallel with model-based calculations → experience

• TG-186 recommendations:
  1. Dose specification medium selection
  2. CT imaging and patient modeling
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→ guide field towards greater adoption of accurate MBDCA

• Outstanding research questions...
Thanks

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