Review TG-186 and WG-MBDCA guidelines, commissioning process, and dosimetry benchmarks

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Disclosure

There are no conflicts of interest for the presenter on the topics discussed in this presentation.

Opinions contained are solely those of the presenter, not meant to be interpreted as societal guidance.

Specific equipment, instruments, and materials are mentioned to fully describe the necessary procedures. Such identification does not imply endorsement by the presenter nor imply that the items identified are necessarily the best available for these purposes.
Learning Objectives

• Background on advanced BT dose calculations
• Review TG-186 report and guidelines
• Introduction to WG-MBDCA guidelines
• Explain recommended process for advanced TPS clinical commissioning and practice integration
• Examine infrastructure and dosimetry benchmarks
Humans are not water equivalent!
Brachytherapy is a mature treatment modality that has benefited from technological advances. Treatment planning has advanced from simple lookup tables to complex, computer-based dose calculation algorithms. The current approach is based on the AAPM TG-43 formalism with recent advances in acquiring single-source dose distributions. However, this formalism has clinically relevant limitations for calculating patient dose. Dose-calculation algorithms are being developed based on Monte Carlo methods, collapsed cone, and the linear Boltzmann transport equation. In addition to improved dose-calculation tools, planning systems and brachytherapy treatment planning will account for material heterogeneities, scatter conditions, radiobiology, and image guidance. The AAPM, ESTRO, and other professional societies are coordinating clinical integration of these advancements. This Vision 20/20 article provides insight on these endeavors.
Appropriate Spatial Scale?

- organs
- voxels
- cells
- DNA
Brachytherapy Dose Calculation Methods

**TG-43**

**INPUT**
- source characterization

**“CALCULATION”**
- superposition of single-source data

**OUTPUT**
- $D_{W:TG-43}$

**MBDCA**

**INPUT**
- source characterization
- tissue+applicator information

**CALCULATION**
- Monte Carlo
- GBBS
- Collapsed Cone

**OUTPUT**
- $D_{M,M}$
- $D_{W,M}$

courtesy Å. Carlsson Tedgren
<table>
<thead>
<tr>
<th>Method</th>
<th>Characteristics</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monte Carlo</td>
<td>explicit particle transport simulation</td>
<td>standard source characterization and research tool, clinical use under</td>
</tr>
<tr>
<td></td>
<td>+ accurate</td>
<td>development</td>
</tr>
<tr>
<td></td>
<td>– noisy dose distributions</td>
<td></td>
</tr>
<tr>
<td>analytic solvers</td>
<td>solves transport equations</td>
<td>standard tool in Nuc Engin, clinical implementation (GBBS) only for HDR</td>
</tr>
<tr>
<td></td>
<td>deterministic methods</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+ accurate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– discretization effects</td>
<td></td>
</tr>
<tr>
<td>scatter kernel methods</td>
<td>implicit particle transport</td>
<td>potential for parallel hardware, e.g. GPU, clinical use under development</td>
</tr>
<tr>
<td>Collapsed Cone based on PSS data</td>
<td>+ accurate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– discretization effects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– small systematic errors</td>
<td></td>
</tr>
<tr>
<td>TG-43 hybrid methods</td>
<td>+ more accurate than TG-43</td>
<td>can serve as dose engine within optimization loops, sensitive geometry</td>
</tr>
<tr>
<td></td>
<td>+ fast, available with current TPS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– highest accuracy not obtained</td>
<td></td>
</tr>
<tr>
<td>Parameterization of Primary and Scatter Separation (PSS) data</td>
<td>no particle transport</td>
<td>same source data as advanced algorithms</td>
</tr>
<tr>
<td></td>
<td>+ fast, robust radial extrapolation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– neglect effects from shields, finite patient, heterogeneities</td>
<td></td>
</tr>
<tr>
<td>TG-43</td>
<td>no particle transport</td>
<td>current clinical workhorse</td>
</tr>
<tr>
<td></td>
<td>+ fast, familiar, permits hand calcs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– neglect effects from shields, finite patient, heterogeneities</td>
<td></td>
</tr>
</tbody>
</table>
Vision 20/20 Paper: 2010

- next-generation dose calculation algorithms
- commissioning issues
- TPS QA recommendations
- societal infrastructure
- dosimetric benchmarking
  - reference dataset and dosimetric tolerances
- clinical paradigm shift
  - dose specification, tissue segmentation, RBE

*Medical Physics*

Enhancements to commissioning techniques and QA of brachytherapy treatment planning systems that use model-based dose calculation algorithms

Mark Rivard,¹ Luc Beaulieu,² and Firas Mourtada³

¹Tufts University, Boston ²Centre Hospitalier Universitaire de Québec ³MD Anderson Cancer Center

V. NEEDED INFRASTRUCTURE

While MBDCAs are expected to produce more accurate dosimetric results than the current TG-43 formalism, the authors feel that the medical community should not immediately replace the current approach without careful consideration for widespread integration. **Assessment of the current infrastructure is needed** before assigning new resources, with opportunity for further cooperation of national and international professional societies.

### V.A. Centralized dataset management

Societal recommendations and reference data do the clinical physicist no good if they cannot be readily implemented. Having quantitative data available beyond the scientific, peer-reviewed literature may be accomplished through expansion of the joint AAPM/RPC Brachytherapy Source Registry. An independent repository such as the Registry to house the reference data would facilitate this process—especially with international accessibility.

Need Standardized MBDCA Benchmarks

- excellent reference HDR $^{192}\text{Ir}$ benchmark
  - Acuros BrachyVision

Need Standardized MBDCA Benchmarks

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Need New TPS Evaluation Criteria

1% and 1 mm

5% and 2 mm
Medical Physics

Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation


The Task Group 186 charge is to provide guidance for early adopters of model-based dose calculation algorithms (MBDCAs) for BT dose calculations to ensure practice uniformity. Contrary to external beam radiotherapy (EBRT), heterogeneity correction algorithms have only recently been made available to the BT community. Yet, BT dose calculation accuracy is highly dependent on scatter conditions and photoelectric effect cross-sections relative to water. In specific situations, differences between the current TG-43 based dose calculation formalism and MBDCAs can lead to differences in calculated doses exceeding a factor of ten.

TG-186 Report

Endorsed by:

AAPM
ESTRO
American Brachytherapy Society
Australasian Brachytherapy Group
TG-186 Guidelines Address Dosimetry Hurdles

- next-generation dose calculation algorithms
- studies evaluating advanced algorithms for:
  - phantom size effect
  - inter-seed attenuation
  - material heterogeneities within the body
  - interface and shielded applicators
- commissioning issues, standard geometries
- patient-related input data (FOV, material assignments)
- CT/CBCT artifact removal for dose calculations
- potential clinical issue, risks, and limitations

provide recommendations to MBDCA early-adopters
TG-186 Guidelines for Prescription Standards

• Perform dose calculations according to the TG-43 formalism and the more accurate heterogeneous calculations.

• File these dose estimates for clinical evaluation in anticipation of sufficient heterogeneity-enabled TPS.

• Radiation oncologist should assess clinical practice of BT using MBDCA, accounting for material heterogeneities, patient scatter conditions, and high-Z attenuation.

• Prescriptions should be based on TG-43 dose calculations until sufficient clinical data and societal recommendations.
TG-186 Guidelines

- maintain inter-institutional consistency like TG-43 approach
- note differences between $D_{M,M}/D_{W,W}$ and $D_{W,M}/D_{W,W}$
  unclear which approach best correlates toxicities/outcomes
- tissue (breast) composition uncertainty is $2^{nd}$ order effect in comparison to advancement from TG-43 algorithm
TG-186 Guidelines

- recommended standardized tissues
  - inter-institutional consistency for uniform evaluation/Tx

- define at each location within the patient:
  - scoring method ($D_{M,M}$, $D_{M,W}$, $D_{W,W}$)
  - material composition, mass density

Dose absorption sensitivity as a function of photon energy

courtesy L. Beaulieu
Dose Scoring Possibilities

- Medium
  - Scoring volume

- Medium
  - Water
  - Scoring volume

- Water
  - Scoring volume
MBDCA TPS Acceptance Testing

• evaluate product performance within specs
• training on proper system function
• test all equipment components and features
  – validate dimensions (TPS applicator library)
• update P&P to ensure system compatibility
• results set baseline for clinical use
• re-perform annually to ensure TPS stability
• independent check calculation
  – hybrid plan of MBDCA positions into TG-43 / water geometry
MBDCA TPS Commissioning Guidelines

- TPS commissioning levels: (1) TG-43, and (2) advanced
- update Quality Management societal standards
- consider AAPM Task Group Reports and Guidance
  - TG-56 Code of Practice for Brachytherapy (1997)
  - TG-59 High Dose Rate Tx Delivery (1998)
- consider AAPM Summer School texts
  - 1994 Chapters 28, 30, 31, 32
  - 2005 Chapters 6, 7, 11, 22, 32, 48
- consider Bruce Thomadsen’s 1999 text
  “Achieving Quality in Brachytherapy”
Need Future Developments

- dual-energy CT permits tissue discernment, but still requires:
  - full patient geometry for radiation scatter calculations
  - corrections for CT-reconstruction artifacts
  - overriding of MRI/US imaging data

- develop retrospective + prospective relationships of
  - dose-to-patient outcomes and dose-to-OAR toxicities

- Registry to house reference data
  - 3D TPS benchmarks
  - standardized tissue info
  - source + applicator libraries
  - blog and repository for users’ group
TG-186 TPS Commissioning Flowchart

1. START
2. Registry: Case Report & Data
3. DICOM Test Case (CTs, ROIs, POIs, plan)
4. Import DICOM Objects
5. Correct Import?
6. NO
7. Re-import correct data series
8. NO
9. Visual inspection (Case TG43 plan)
10. YES
11. Run TG43
12. Correct Loading?
13. NO
14. YES
15. Verify TG43 data
16. NO
17. YES
18. Run MBDDA
19. Plan Eval Pass?
20. NO
21. YES
22. Generate Commission Report
23. Finish
24. NO
25. Check plan input
26. NO
27. YES
28. Copy as New Plan - TG43
29. Copy as New Plan - MBDDA
30. Reference CT Calibration
31. Select dose scoring medium type
32. TPS Manual
33. Check Materials Assigned
34. Match?
35. NO
36. YES
37. Other Commission activity per TG-53
Medical Physics

A generic high-dose-rate $^{192}$Ir brachytherapy source for evaluation of model-based dose calculations beyond the TG-43 formalism
Ballester, Carlsson Tedgren, Granero, Haworth, Mourtada, Paiva Fonseca, Zourari, Papagiannis, Rivard, Siebert, Sloboda, Smith, Thomson, Verhaegen, Vijande, Ma, and Beaulieu

Conclusions: A hypothetical, generic HDR $^{192}$Ir source was designed and implemented in two commercially available TPSs employing different MBDCAs. Reference dose distributions for this source were benchmarked and used for evaluation of MBDCA calculations employing a virtual, cubic water phantom in the form of a CT DICOM image series. Implementation of a generic source of identical design in all TPSs using MBDCAs is an important step toward supporting univocal commissioning procedures and direct comparisons between TPSs.

Table III. Air-kerma strength $s_K$ and dose-rate constant $\Lambda$ for the generic HDR $^{192}$Ir source obtained with several MC methods. Reported uncertainties (absolute uncertainties in columns 2 and 4 and relative ones in columns 3 and 5) are Type A (statistical) with a coverage factor $k = 1$.

<table>
<thead>
<tr>
<th>MC code</th>
<th>$s_K \times 10^{-8}$ U/Bq</th>
<th>$\Lambda$ [cGy/(h U)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALGEBRA</td>
<td>9.798 ± 0.006</td>
<td>1.1113 ± 0.0006</td>
</tr>
<tr>
<td>BrachyDose</td>
<td>9.804 ± 0.001</td>
<td>1.1100 ± 0.0010</td>
</tr>
<tr>
<td>GEANT4</td>
<td>9.791 ± 0.012</td>
<td>1.1104 ± 0.0020</td>
</tr>
<tr>
<td>MCNP5 v.1.60</td>
<td>9.797 ± 0.001</td>
<td>1.1110 ± 0.0004</td>
</tr>
<tr>
<td>MCNP5 v.1.60*</td>
<td>9.812 ± 0.006</td>
<td>1.1107 ± 0.0006</td>
</tr>
<tr>
<td>MCNP6 v.1</td>
<td>9.813 ± 0.006</td>
<td>1.1106 ± 0.0006</td>
</tr>
<tr>
<td>PENEOLOPE2008</td>
<td>9.784 ± 0.006</td>
<td>1.1113 ± 0.0006</td>
</tr>
</tbody>
</table>

Normalized Dose Distributions

Generation of 3D Dosimetric Reference Datasets for Commissioning and Validation of $^{192}$Ir Brachytherapy Model-Based Dose Calculation Software


TH-AB-BRA-2 (Thursday, July 16, 2015) 7:30 AM - 9:30 AM Room: Ballroom A

Infrastructure and Process for Model-Based Dose Calculation Software Commissioning in Brachytherapy

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TH-AB-BRA-5 (Thursday, July 16, 2015) 7:30 AM - 9:30 AM Room: Ballroom A
Summary

• MBDCA TPS allow more accurate dose calcs than TG-43
• MBDCA TPS are available (turnkey) for HDR $^{192}$Ir
• societal recommendations / infrastructure forthcoming
• dosimetric benchmarks required for safe clinical use
• forthcoming Working Group standards and benchmarks
• Rx paradigm shift should be societally-coordinated
• incorporate dose changes cautiously (IRB clinical trial)
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