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?

TG-186 report: Beaulieu *et al*, Med. Phys. **39**, 6208 (2012)

Why move beyond TG-43?

TG-43 approach

Water

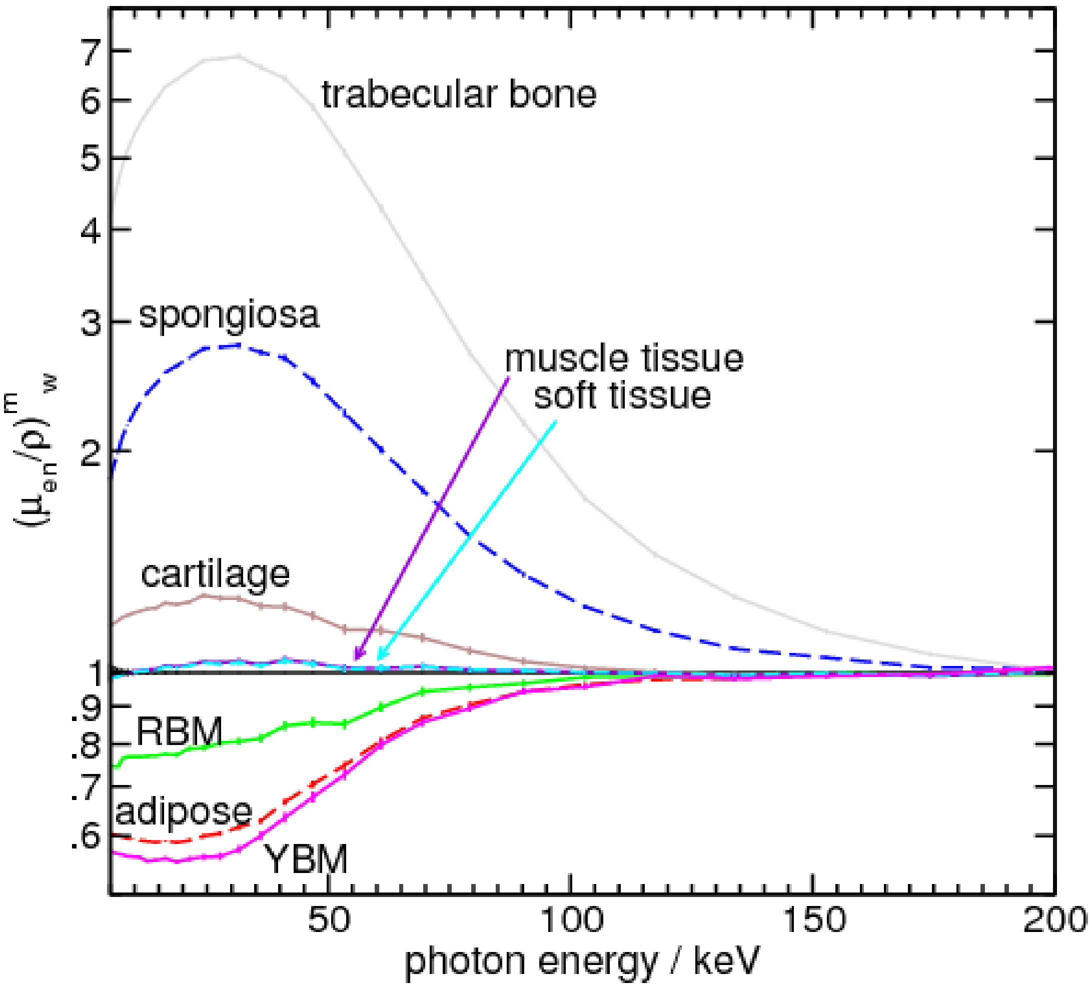
versus

Reality

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

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 report: Beaulieu *et al*, Med. Phys. **39**, 6208 (2012)

TG-186 recommendations

Recommendations focused on three main areas:

1. Dose specification medium selection
2. CT imaging and patient modeling
3. MBDCA commissioning

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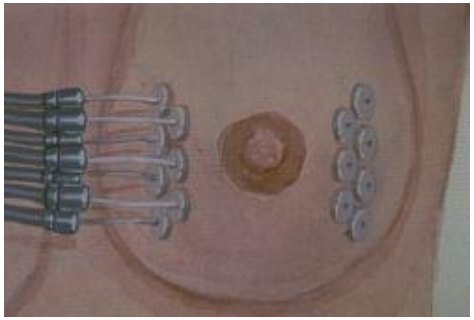
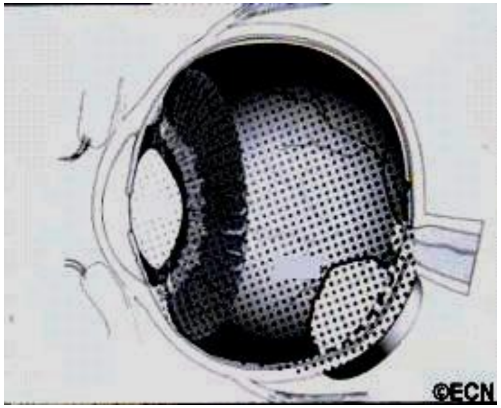
1. Dose specification medium selection

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





→ Adopters of MBDCA must select media for:

- Radiation transport
- Dose specification

Images: www.brachytherapy.com, malecare.org, www.eyecancer.com

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

$D_{x,y}$

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$D_{m,m}$

Scoring volume / dose specification medium

Dose reporting possibilities

$D_{x,y}$

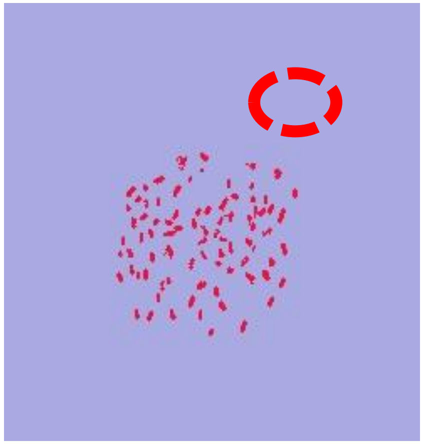
x: dose specification medium

y: radiation transport medium

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

$D_{m,m}$

$D_{w,w}$



Dose reporting possibilities

$D_{x,y}$

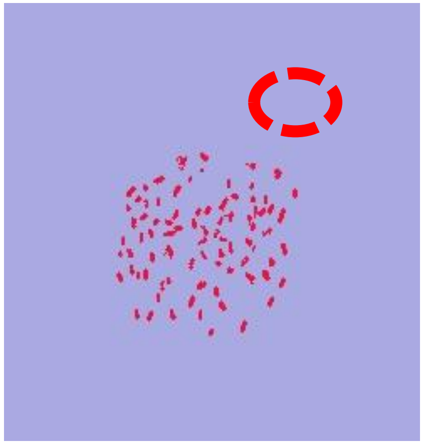
x: dose specification medium

y: radiation transport medium

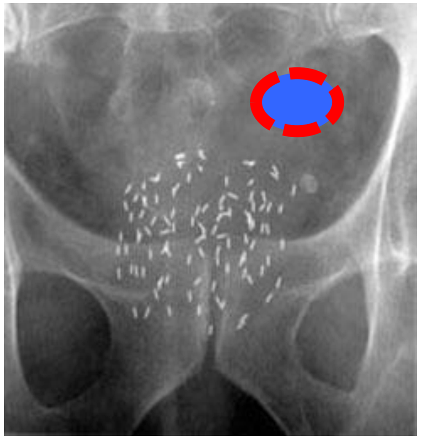
x,*y*: Local medium (m) or water (w)

$D_{m,m}$

$D_{w,w}$



$D_{w,m}$



Which dose to calculate?

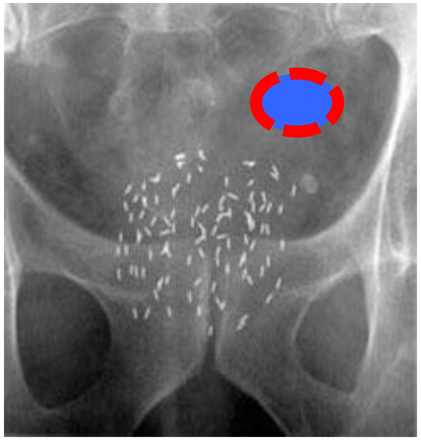
- Adoption of MBDCA is motivated by clinical need for accurate and rigorous estimation of delivered dose distributions

→ Model radiation transport with most accurate tissue compositions available:

$D_{m,m}$

or

$D_{w,m}$



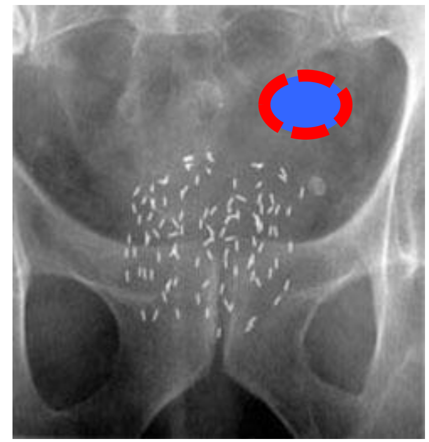
Dose specification medium?

- Debate:

$D_{m,m}$

or

$D_{w,m}$



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Dose specification medium?

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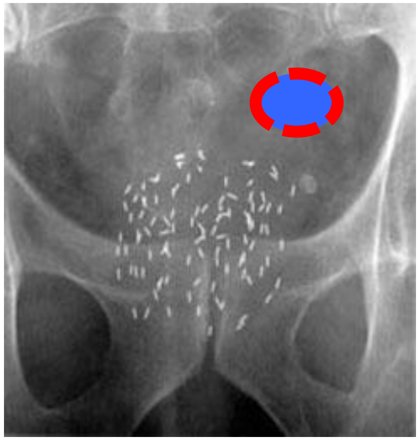

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External Beam:

- 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

Chetty et al, Med. Phys. **34** (2007).

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

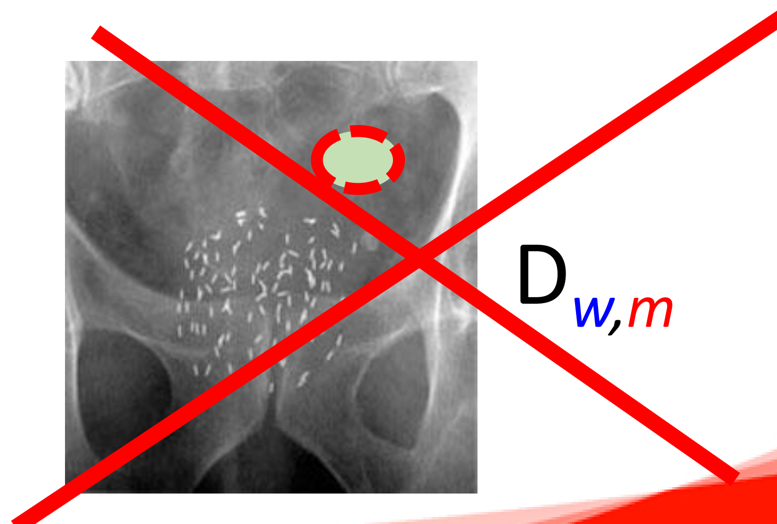
- Differences between $D_{m,m}$, $D_{w,m}$ and $D_{w,w}$(TG-43) significant, especially for low energy brachytherapy
- Cannot generally motivate reporting $D_{w,m}$ to connect with previous clinical experience
- Adoption of MBDCA: potential for significant impact on dose metrics

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

$D_{m,m}$



$D_{w,m}$

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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^-/cm^3)
- 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 III. Material definitions. Water is given for comparison.

	% mass					Mass density
Tissue	H	C	N	O	Z > 8	$g\,cm^{-3}$
Prostate (Ref. 110)	10.5	8.9	2.5	77.4	Na(0.2), P(0.1), S(0.2), K(0.2)	1.04
Mean adipose (Ref. 110)	11.4	59.8	0.7	27.8	Na(0.1), S(0.1), Cl(0.1)	0.95
Mean gland (Ref. 110)	10.6	33.2	3.0	52.7	Na(0.1), P(0.1), S(0.2), Cl(0.1)	1.02
Mean male soft tissue (Ref. 109)	10.5	25.6	2.7	60.2	Na(0.1), P(0.2), S(0.3), Cl(0.2), K(0.2)	1.03
Mean female soft tissue (Ref. 109)	10.6	31.5	2.4	54.7	Na(0.1), P(0.2), S(0.2), Cl(0.1), K(0.2)	1.02
Mean skin (Ref. 109)	10.0	20.4	4.2	64.5	Na(0.2), P(0.1), S(0.2), Cl(0.3), K(0.1)	1.09
Cortical bone (Ref. 109)	3.4	15.5	4.2	43.5	Na (0.1), Mg (0.2), P (10.3), S (0.3), Ca(22.5)	1.92
Eye lens (Ref. 109)	9.6	19.5	5.7	64.6	Na(0.1), P(0.1), S(0.3), Cl(0.1)	1.07
Lung (inflated) (Ref. 109)	10.3	10.5	3.1	74.9	Na(0.2), P(0.2), S(0.3), Cl(0.3), K(0.2)	0.26
Liver (Ref. 109)	10.2	13.9	3.0	71.6	Na(0.2), P(0.3), S(0.3), Cl(0.2), K(0.3)	1.06
Heart (Ref. 109)	10.4	13.9	2.9	71.8	Na(0.1), P(0.2), S(0.2), Cl(0.2), K(0.3)	1.05
Water	11.2			88.8		1.00

i. Consensus material definition

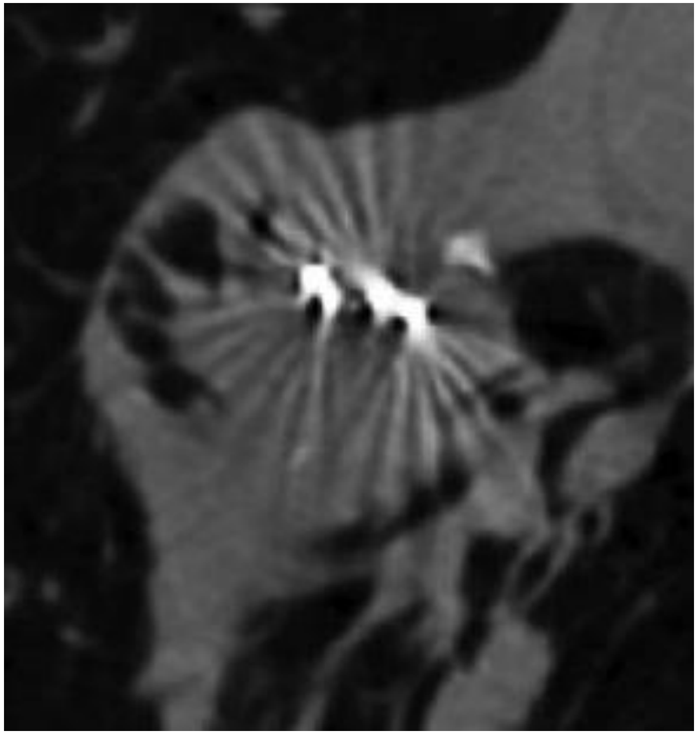
- Clinical physicist: confirm sufficiently accurate and spatially resolved applicator and source models, including correct media assignments
- Applicators, sources should be modeled analytically or with very fine resolution meshes
- Manufacturers should disclose seed and applicator geometry, material 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



Sutherland et al, Med. Phys. **38**, 4365 (2012)

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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

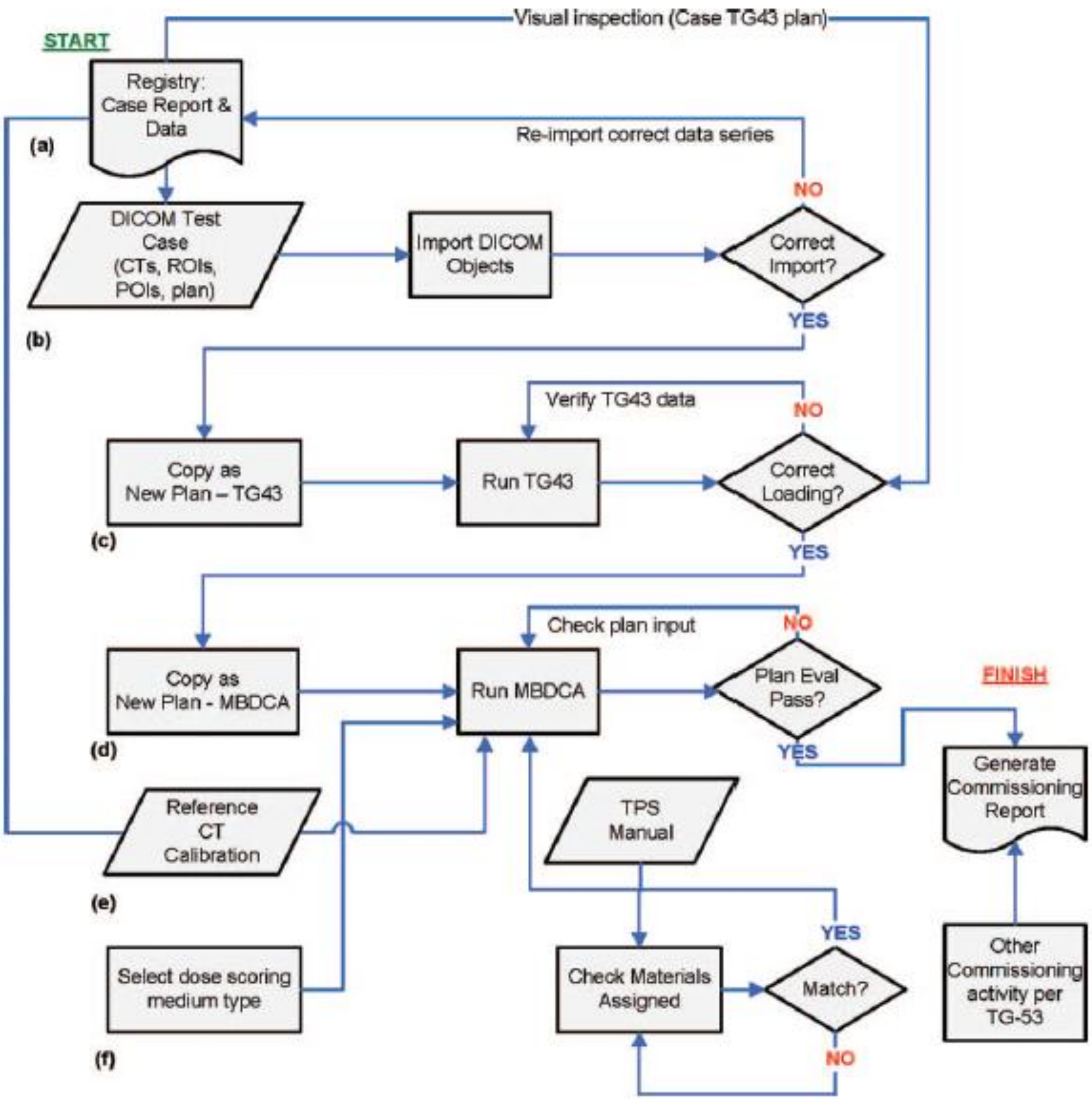
- Comparison of MBDCA TPS 3D dose distributions for specific virtual phantoms mimicking clinical scenarios with benchmark dose distributions for the same phantom geometries

- 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:
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  2. CT imaging and patient modeling
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  → guide field towards greater adoption of accurate MBDCA

- Outstanding research questions…

Thanks

- Members of TG-186: L. Beaulieu, A. Carlsson-Tedgren, J.F. Carrier, S. Davis, F. Mourtada, M.J. Rivard, R. M. Thomson, F. Verhaegen, T.A. Wareing and J.F. Williamson

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