Developments in clinical reference dosimetry

Dose to Water vs. Muscle: Practical Implementation for Different Algorithms

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Disclosure

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Monte Carlo

- Materials are identified from CT# (either explicitly or by general fitting procedure)
- Dose is inherently tallied in the voxels of specified media, for which interaction cross-sections are available ("dose-to-tissue")

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Monte Carlo

- As a rule, commercial MC algorithms organically report dose to tissue and do not require manual corrections
  - Exception: ViewRay explicitly considers patient water (only option) and requires correction
  - If dose-to-water is one of 2 options, some (Monaco) would calculate dose in water of varying density, while most would post-process in Bragg-Gray sense by using S/ρ. VMC++ tallies both
  - Post-processing is conceptually awkward and may introduce non-trivial errors (*Andreo, PMB 2015*)

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Boltzmann Transport Equations Solver

- XRT implementation: Acuros XB
- Determines electron fluence spectrum in volume and calculates dose to voxel by integrating product with L/ρ
- Biological materials identified from CT-to-density: lung, adipose tissue, muscle, cartilage, or bone
- Inherently dose-to-tissue (preferred mode)

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Pencil beam (including AAA)

- Few major TPS have it as only option
- Dose spread is calculated in water
  - Original PB only scales along rayline
  - AAA also scales in orthogonal direction
- Scaling based on electron densities and tissue composition never enters the consideration
- Clearly dose-to-water, hence 0.99 correction is warranted

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Superposition/Convolution

- Most complicated: D_w or D_m depends on implementation
- XiO Multigrid Superposition
  - CT # to e-density conversion
  - No material assignment
  - Dose computed as if patient was water of varying density
  - 0.99 correction to reference dose
- Raysearch
  - Reports dose-to-water by internally converting from dose-to-tissue (original dtt inherent in the basic equation)
  - 0.99 correction

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Typical S/C implementation

- CT to mass density conversion
- Attenuation/absorption coefficients interpolated between tissues of various density; mass coefficients material-dependent

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Basic Equations (*Ahnesjo, PMB 1989*)

$$T(r) = \left(\frac{r}{r_0}\right)^2 \frac{\bar{\mu}(r)}{\rho(r)} \Psi(r_0) exp\left[-\int_{r_0}^{r} \bar{\mu}(l)dl\right],$$

Where $\bar{\mu}(r)$ is the mean linear attenuation coefficient calculated for the medium present at *r*

Then TERMA is convolved with the energy deposition kernel that is defined in water but can be stretched based on local density

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- Primary beam attenuation/absorption is governed by the medium μ/ρ
- Theoretically, should lead to (nearly) dose calculated in tissue
  - *"The collapsed cone and the Monte Carlo, on the other hand, calculate the dose to the medium specified"*

    (*Wieslander & Knoos, PMB 2003*)

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Example of real-life S/C implementations: Pinnacle CCC

- A "black box" evaluation done for this work
- Change the parameters that can be changed and compare to MC
- Use the special "water phantom" feature in Pinnacle

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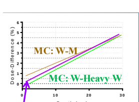

Pinnacle CCC

- Calculated dose at surface to 10+ cm ~halfway between MC water and muscle, gets closer to muscle with depth
- Relationship is depth-dependent
- No single correction factor good for all depths
- Treat as dose-to-muscle for the lack of better alternative and in deference to theoretical formulation of the algorithm

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SAM Question

Collapsed Cone Convolution photon algorithm as described by Ahnesjo and Aspardakis is expected to approximate dose to tissue because:

1. The energy deposition kernel used for C/S is assigned the tissue material and density.
2. The mass attenuation coefficient for TERMA calculation is based on tissue radiological properties.
3. The superposition/convolution equation models the dose distribution in 3 dimensions by taking the local density into account for lateral dose spread calculations.
4. The TERMA decrease with depth is accounted for by using CT# to electron density conversion.

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Answer

#2. In a typical formulation of the C/S algorithm the fluence attenuation/energy absorption is governed by the μ/ρ for tissue as assigned from the CT to physical density table. The energy-deposition kernels are calculated in water, albeit of varying density.

Ahnesjo A, Aspradakis MM. Dose calculations for external photon beams in radiotherapy. Phys Med Biol. 1999;44(11):R99-155.

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Electrons - MC

- MC naturally reports dose to material it transports radiation through
- Some systems can report electron dose-to-water or dose-to-tissue, and tissue is preferred in the context of this report
- Oncentra VMC++ and Eclipse eMC report only dose-to-tissue

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Electrons - PB

- PB has been largely replaced by MC in major TPS
  - All but one have a MC option
- Composition of the medium enters in the scaling factors as mass scattering and stopping power ratios
- However the PDDs in water are used to model depth attenuation
- The result is a hybrid but can be considered dose-in-water (confirmed in Pinnacle by experimentation against MC)

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Recommendations - 1

Linac reference calibration should be reported in water and never converted to muscle *per se*

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Recommendations - 2

- If necessary, a correction of 1% (i.e., multiplication of 0.99 times the dose-to-water) should be applied **in the TPS reference dose specification**
- Application of this correction should be done on an algorithm-by-algorithm basis, bearing in mind that in a general family of algorithms specific implementation may change the approach

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Recommendations - 3

A qualified medical physicist should ascertain if the specific TPS algorithm reports dose-to-water or dose-to-tissue and accordingly set the **TPS reference dose** for that algorithm:

Recommendation – 3 con't

- Dose to medium inherently calculated = no correction:
  - Most Monte Carlo (D_m)
  - GBBS (D_m)
  - Many S/C (Tomotherapy, Monaco, Oncentra, Pinnacle)
- Dose to water inherently calculated = correction of 0.99:
  - Monte Carlo if no D_m option exists
  - Some S/C (Xio, Raysearch)
  - PB (including AAA photons, and electron PB)
  - Non-CT based/Simple measurement-based

Recommendation – 4

- TPS vendors are encouraged to evolve their algorithms to consistently calculate and report dose-to-tissue, so that manual corrections to the reference dose are no longer necessary.
  - The manual correction still leaves ~0.4% uncertainty based on energy and depth. This can be removed and all systems made comparable if all properly report dose to tissue.