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Dose specification for NRG radiation therapy trials

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Ambiguity exists in dose reporting in the medical physics community (1). While heterogeneous dose calculations are standard, algorithms remain that conduct homogeneous calculations. Even amongst algorithms that conduct heterogeneous dose calculations, there are many different implementations that may compute dose to water, or dose to medium. A consistent method for dose reporting for NRG clinical trials is important to ensure that outcomes can ultimately be correlated to doses specified uniformly. Many NRG clinical trials require specification of dose-to-water, Dw. However, it is often unclear if an algorithm is actually computing dose to water or dose to medium. There are also conceptual and practical concerns over some existing methods to convert from Dm to Dw (1,2). This has sparked debate about dose reporting in some NRG protocols. In this communication, we wish to clarify the Dw and Dm concepts for modern dose algorithms, and provide recommendations for dose specification for all NRG clinical trials.

Dose-to-water, Dw, refers to dose computed from particle interactions occurring in water, or water-equivalent material. This is different from dose-to-medium, Dm, in which dose is computed from particle interactions occurring in the specific medium. It is important to note that Dw can be reported to any medium; the details of the methods to convert Dm to Dw, or to compute Dw directly, have been reported by others (2,3,4,5). Modern treatment planning systems (7) use pencil-beam (PB), convolution/superposition (C/S), Monte Carlo (MC) or

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Grid Based Boltzmann Solver (GBBS)-type algorithms to compute dose in heterogeneous patient tissues.

Depending on the type and implementation of the algorithm, for pencil-beam and convolution/superposition algorithms, dose may be computed assuming that particle interactions occur in “water-like” materials (of variable density). The effect of tissue heterogeneity is accounted for by radiologically scaling the primary and/or scatter dose kernels based on the electron density of the material. In these cases, the algorithms ignore the differences in particle interactions resulting from the material composition (atomic number) relative to that of water and are described as calculating “dose to water” Dw. However, many C/S algorithms (and some PB) do partially account for the material composition (atomic composition) by applying material-specific mass attenuation coefficients for photon attenuation. This adjusts the magnitude of the water-based dose kernel. These cases are complicated because they are typically a mixture of dose to medium and dose to water, yielding a blended solution.

The MC or GBBS algorithms naturally compute particle interactions inherently within the media, and therefore compute Dm directly. The Dm can be converted back to Dw in these algorithms, although this is done in different ways by different algorithms. This option is offered in large part as an effort to allow Dm dose distributions to be compared to more “historical” Dw dose distributions (where dose tolerances are well known). However, and importantly, Ma and Li (2) have shown that dose computed to patient tissues by pencil-beam or C/S algorithms is in fact in better agreement with Dm (computed by MC or GBBS algorithms), than Dw converted from the Dm-based dose distributions. That is, converting Dm from a MC or GBBS algorithm back to Dw does not work particularly well to provide a comparison to historical Dw values. While PB or C/S algorithms computed doses similar to MC-calculated Dm values (within 4%), they were substantially different (up to 11%) from MC doses converted to Dw (2,6).

Provided large uncertainties haven’t been introduced by moving from Dm to Dw, then as described above, Dm and Dw show good agreement. The similarity between Dm and Dw is reasonable in tissue because photon dose deposition, in the MV energy range within patient tissues, is dominated by Compton interactions that are dependent mainly on material electron densities, and therefore largely independent of material composition. Dm and Dw are more substantially different in cortical bone, where the difference can be up to 11% (4). For tissues other than bone, the difference between Dm and Dw is on the order of a few percent.

Based on the available literature, we therefore recommend the following for dose specification for all NRG clinical trials:

1. For C/S type algorithms, dose should be reported as computed inherently by the given algorithm.
2. For MC or GBBS algorithms, conversion of Dm to Dw should be avoided. Rather dose-to-medium, Dm, computed inherently by these algorithms should be reported.

3. These principles hold for PB type algorithms and for homogeneous dose calculations when allowed for use in a clinical trial (e.g., conical collimators in stereotactic radiosurgery).

These recommendations make sense for several reasons. For PB or C/S, the user generally has no input on the dose specification, so the reported dose is the only viable option. For MC/GBBS algorithms, use of Dm is numerically largely consistent with historical values. Moreover, application of a conversion back to Dw can introduce numerical and conceptual uncertainty, based on the method use for material specification (1,3,4).

These recommendations demand attention in cases where bone is relevant. If a trial includes a dose constraint on a bony structure, there will be a difference in the reported values between a Dw and a Dm calculation. This difference is less than 4% for soft bone, but is ~11% for cortical bone (4). While this difference is clearly not ideal and will need to be carefully considered for trials where this is relevant, this approach is felt to introduce less overall error into the dose reporting process than conversion of MC/GBBS algorithms back to Dw. Moreover, looking to the future, algorithms are more and more likely to calculate Dm, so this move is a step in the right direction. It should be noted that the above recommendations are consistent with dose reported in the format of IROC-Houston (7) accredited dose calculation algorithms for clinical trials.

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