Why To Use TG-51

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The TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams was published last year[1]. It is recommended for use by the AAPM and the RPC in Houston has started using it as the basis of its clinical dosimetry comparisons. In addition, all clinical members of a COMP committee have voted in favor of a recommendation that TG-51 be adopted for use in Canada.

Despite all this approval and support, the protocol is very much a prescriptive document and the rationale for using it is not as clear as it could be. In this article I would like to present a brief rationale for why TG-51 should be used instead of TG-21.

The arguments for changing to TG-51 from TG-21 are summarized in the text box.

In the following I will concentrate on the issue of the improved accuracy and indirectly address the other issues along the way. I will also discuss why TG-51 has adopted $\%dd(10)_x$ as a beam quality specifier. For a more general introduction to the advantages of using absorbed-dose calibration factors, see ref [2].

Where does the improved accuracy come from for photon beams?

1) TG-51 gets the absorbed dose in a ^{60}Co beam correct since it uses a calibration factor directly. When using air-kerma and absorbed-dose calibration factors traceable to Canadian primary standards, the doses determined with TG-51 are 0.1 to 0.8% higher than those determined using TG-21 (the exact value depends on the chamber used; data are from Shortt et al[3], and Seuntjens et al [4]). If one corrects all the known mistakes in TG-21 and uses the same data sets as in TG-51, these discrepancies range from -0.47% to +0.33%, so at least part of the problem is due to errors in TG-21, but the rest of the problem must be due to other, as yet not understood problems with TG-21 or the data used (any errors in the standards would show up as a constant offset). If one is using calibration factors traceable to NIST, all of the above figures are increased by 1.1% because of the known differences between the NIST and NRC primary standards for air-kerma and absorbed dose to water[3]. Given that the uncertainties on the primary standards for absorbed dose to water and air kerma are roughly equal, then by changing to TG-51 there is a clear increase in accuracy in the dose assigned in a ^{60}Co beam since the uncertainty in TG-21 to convert from air kerma to absorbed dose is removed. Furthermore there is a noticeable change in the assigned dose, which is a 1.1% larger change for calibration factors traceable to NIST.

2) For photon beams, TG-21 used stopping powers from ICRU Report 35 whereas the electron beam portion of the protocol used the more accurate and definitive values from ICRU Report 37[5]. TG-51 consistently uses Report 37 stopping powers which reduces the assigned dose in accelerator photon beams by up to 1.3% compared to TG-21.

3) TG-21 ignores the fact that many ion chambers have aluminum electrodes. Ma and Nahum[6] have done a complete set of calculations showing that such electrodes increase ion chamber response by up to 0.8%. Since this also affects air-kerma calibration factors, it is not a major effect in photon beams, but it does increase the dose assigned in high-energy photon beams by up to 0.3% and TG-51 takes this into account.

Fortunately, for accelerator photon beams these 3 effects tend to cancel and so the dose assigned in accelerator photon beams using TG-51 is about the same as that assigned with TG-21 when using NRC traceable calibration factors or about 1% higher using NIST traceable factors. Ding et al[7] and Huq[8] have experimentally confirmed this.

Where does the improved accuracy come from for electron beams?

1) TG-21 was unclear about how to determine R_{50}, the depth at which the dose fell to 50% of its maximum. TG-51 has clarified and simplified this by requiring a measurement of I_{50}, the depth at which the ionization drops to 50% and then uses a simple equation to get R_{50}.

2) TG-21 used stopping-power ratios calculated for mono-energetic electron beams but Ding et al[10] showed that these could lead to errors of up to 1.8%. TG-51 has overcome this shortcoming by changing to a new reference depth for electron beams at $d_{ref} = 0.6\ R_{50} - 0.1$ cm. This is at dose maximum for low-energy beams but deeper for high-energy beams. By making this change in the reference depth, the TG-51 protocol is able to use the stopping-power ratios calculated for the realistic electron beams and at the same time have a much simplified data set[11]. This reduces the dose assigned by up to 0.6% for low-energy electron beams and increases it by up to 1.2% for high-energy beams.

3) TG-51 takes into account the aluminum central electrode in many Farmer chambers and in electron beams this leads to a 0.7% increase in the assigned dose.

4) By avoiding the conversion from air to water based quantities in ^{60}Co beams, TG-51 makes the same gains in accuracy for electron beams as outlined above for

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Advantages of TG51 Versus TG21

*TG-51 is much simpler conceptually since it avoids the irrelevant quantity air-kerma.

*TG-51 is much less work to use (once converted!)

*TG-51 is easier to teach and has none of the many known errors in TG-21.

*TG-51 has improved accuracy.

*The TG-51 formalism allows direct measurement of the major factors in the protocol (k_Q, k_{ecal}, k'_{R50}).

photon beams.

So the overall gain in accuracy in electron beams using TG-51 is increases of between 0 and 3% compared to TG-21, the larger changes being for measurements with chambers having aluminum electrodes at high energies. Ding et al have confirmed these expectations[7].

TG-51 recommends cross-calibrating plane-parallel chambers in high-energy electron beams but allows the use of ^{60}Co calibrations of plane-parallel chambers. This latter option is to meet US legal requirements and the cross-calibration technique is to be strongly encouraged in Canada since the data required to use the ^{60}Co calibration factors are somewhat suspect[7](despite being my own calculations, and at the risk of reducing our calibration income!).

Why switch to using %dd(10)$_x$ from TPR$_{20,10}$?

Perhaps the most controversial aspect of TG-51 concerns the issue of beam quality specification in photon beams. Why change?

Consider what happens if NRC measures a k_Q factor for an NE2561 ion chamber in a beam with TPR$_{20,10}$=0.791 and then asks the British standards lab (NPL) to do the same thing. The factors measured differ by 1.2% with a measurement uncertainty of about 0.4%. If we now specify the beam qualities in the two labs using %dd(10)$_x$ we get agreement at the 0.1% level. This is because TPR $_{20,10}$ does not specify the quality of the beams as well as %dd(10)$_x$. If we now ask, How well does this NRC measured k_Q agree with the value predicted by TG-51? the answer is, within 0.5% using %dd(10)$_x$ but it would disagree by 1.6% if TG-51's physics were implemented using TPR$_{20,10}$. The data are from Seuntjens et al[4] who also show that what occurs in this specific example (admittedly extreme) is generally true for different ion chambers and different laboratories. So the need for %dd(10)$_x$ is well established experimentally and was predicted by calculations in 1993[12].

Some claim that %dd(10)$_x$ is hard to measure because of electron contamination effects. For beams with energies of 10 MV and above, one needs to insert a 1 mm lead sheet (being given away for free at the World Congress in Chicago) in the beam instead of measuring the depth-dose curve in the open beam. Then one uses a simple formula to deduce the value of %dd(10)$_x$ in the open beam taking into account the electron contamination generated by the lead and the hardening of the beam by the lead. If we assume that these Monte Carlo calculations are wrong by 50% (and we know they are more accurate than that!), then for a beam with %dd(10)$_x$ = 80%, the error in the assigned dose would be 0.17%. If we altogether ignore the electron contamination correction with the lead foil, the error in the assigned dose is 0.35%. So for an uncertainty concerning electron contamination effects of no more than a few tenths of a percent, we remove an uncertainty (when using measured values of k_Q) of up to 1.1% due to beam quality specification issues.

The Measured Values

One distinct advantage of the TG-51 protocol over the TG-21 protocol is that the major factors (k_Q , k_{ecal} and k'_{R50}) can be measured directly using primary standards for absorbed dose to water whereas many factors in TG-21 are impossible to measure directly (eg, N_{gas}, P_{wall}, (L/rho) etc). Seuntjens et al[4] have measured the most important of these, viz k_Q , and report that for measurements with 20 ion chambers of 6 types at 3 energies, the rms deviation between TG-51 values and measured values is 0.4%, which is comparable to the measurement uncertainty. This gives confidence in the use of these factors. One could, of course, also measure the overall accuracy of TG-21 and Seuntjens et al report that the rms deviation vs TG-21 is 1.7%. They also report that an optimal air-kerma based protocol has an rms deviation from their data of 0.7% (this means that the *extra* rms deviation introduced by using and air-kerma based protocol is larger than the *entire* rms deviation using TG-51).

Conclusions

The TG-51 protocol is not only easier to use than TG-21, it is more accurate and has been experimentally verified for photon beams. The hope is that once it is fully implemented in Canada there will be an improvement in radiotherapy, if only because TG-51 will save overworked medical physicists some time, while at the same time improving accuracy in the doses they assign and minimizing the chances of mistakes.

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