Implications of TG-43 for Dose Prescription and Calculations for I-125 Eye Plaques

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The Collaborative Ocular Melanoma Study (COMS) has defined dose prescription, calculation and reporting criteria for ^{125}I eye plaque treatments. The dose calculation constants and formalism specified in the COMS Manual of Procedures, Chapter 12, "Radiation Therapy," paragraph 12.2.13, "Dosimetry Information," were based on the best information available in 1985. Advances since then in the dosimetry ^{125}I seeds have been reviewed periodically. The body of published data and recommendations now make advisable the adoption of new dose prescription and calculation for ^{125}I eye plaques.

The COMS Radiation Therapy and Physics Committee has concluded that the dose calculation constants and prescription for COMS plaque patients should be changed. The prescription dose will be 85 Gy at 5 mm depth or the tumor apex, whichever is greater. This prescription dose, combined with new calculation constants will assure that the energy absorbed at the prescription point is the same as that using the previous protocol specifications. The effective date for such changes to the protocol is targeted as November 1, 1996.

Discussion:

The American Association of Physicists in Medicine (AAPM) has published new recommendations for dosimetry of interstitial brachytherapy sources (1,2). This documentation addresses dosimetry of ^{125}I, model 6711 and 6702 seeds. The recommendations include new constants assigned to the various sources and a new dose calculation formalism. Based primarily on the work of the National Cancer Institute funded Interstitial Collaborative Working Group (3), it has been determined that for ^{125}I seeds, the absorbed dose in a homogenous water phantom is lower than the dose calculated using the old formalism by 15% and 11% for the model 6711 and model 6702 seed types, respectively.

For COMS eye plaque dosimetry there are two other effects which decrease the actual dose delivered at the prescription point. The gold plaque (shell) attenuates some radiation that would otherwise be back-scattered to the prescription point. There is an approximately 5% decrease in dose due to the presence of the gold shell. The second effect is due to the physical properties of the silastic seed carrier insert, which has a higher attenuation for ^{125}I x-rays than water. This effect has only been characterized for the model 6711 seed, and is possibly less for the model 6702 seed. Combined with the effect of the gold shell, the dose reduction from these two attenuation effects is on the order of 10-15% for model 6711 seeds (4).

The net dose reduction is approximately 25%. That is, in treating choroidal melanoma which the COMS ^{125}I eye plaques with model 6711 seeds, a prescription of 100 Gy at the tumor apex actually delivers a dose of approximately 75 Gy. There exists a dose difference of 5% between plaques using model 6702 seeds versus model 6711 seeds.

Until now it has been recommended that for consistency in COMS in the above dosimetric considerations should be ignored for dose prescription, calculation, and reporting.

An important change that will need to be implemented for COMS eye plaque dosimetry is that the National Institute of Standards and Technology (NIST) has developed and prepared a new calibration standard for ^{125}I seeds (5). The previous standard, established in 1985, is now known to be contaminated by non-penetrating low energy photons (4.5 keV titanium x-rays, which penetrate only about 0.1 mm in tissue). The change in calibration will reduce the stated seed strength by approximately 10% for both seed models and as such, the dose rate constant, Λ, will increase by nearly 10%.

Considering the AAPM recommendations and the change in the NIST calibration standard, it is now determined that COMS dosimetry should result in a revised prescription dose and required dose calculation parameters. However, it is recommended that we continue to employ the isotropic point source approximation, and ignore dose anisotropy, the effect of the lip on dose calculated at peripheral structures, and the attenuation effects of the gold shell and the silastic seed carrier. The following are the rationale for the latter recommendations.

1. Point source vs. line source: At a prescription point of 5 mm apical height, the "error" using a point source calculation rather than a line source calculation ranges from only 1.2% to 1.7% for a 20 mm plaque and a 12 mm plaque, respectively, and decreases with increasing depth.

2. Dose anisotropy: The prescription point lies on the perpendicular bisectors of the seed axes. The anisotropy factor is unity for the prescription point. Requiring two-dimensional dosimetry, including the geometry factor and the anisotropy factor would place a significant burden on COMS physicists, may be incompatible with some planning computers, and would require significantly more complex test cases for validation by the RPC.

3. Effect of lip: Quantitative data in the literature exists only for a single seed at the center of a 20 mm plaque (4). Data for a "fully loaded" plaque do not exist.

4. Effects of gold shell and silastic insert: Again, the only published data are from de la Zerda et al for a single seed at the center of a COMS plaque (4). Data for a "fully loaded" plaque do not exist. Based on the data from de la Zerda, the best estimate of the "actual" dose delivered at the prescription point, using the current COMS specifications as well as the proposed specifications, for a COMS plaque with model 6711 seeds, is approximately 71 – 76 Gy.

Using the AAPM guidelines, the prescription for COMS plaque patients will be changed to 85 Gy. The vast majority of COMS cases have been conducted using model 6711 seeds, a prescription of 85 Gy calculated using the new protocol is equivalent to approximately 100.5 Gy using the old constants. For model 6702 seeds, a prescription of 85 Gy calculated using the new protocol is equivalent to approximately 95.2 Gy using the old constants. With the new calculation parameters, the dose

delivered by plaques containing model 6711 and model 6702 seeds will be equivalent (ignoring possible differences in the effects due to the gold shield and silastic insert).

Following the TG-43 recommendations, seed strength is expressed in terms of air-kerma-strength, the “dose rate constant” is used, and the tissue attenuation data of Ling (6711) and Schell (6702) are replaced by revised data.

Depending on the local computer planning system used for eye plaque dosimetry, many institutions may be unable to implement the AAPM TG-43 formalism (e.g., specifying source strength as “air kerma strength,” and using the “dose rate constant”). To effect the change in dose calculation, the exposure rate constant and/or the f-factor and tissue attenuation factors specified for COMS dosimetry must be changed, and will be different for the two seed models.

With the new NIST calibration standard, the specified dose rate constant should be changed.

Introducing new calculation constants for COMS dosimetry required re-certification of physicists with respect to satisfactory completion of test cases using the new dose calculation constants.

For reporting on the COMS Form RP, it was suggested that the only modification would be the specification of seed strength as air kerma strength in units U ($\mu Gy \bullet m^2/hr$), in addition to seed activity in units mCi.

TG-43 Dosimetry for COMS ^{125}I Plaques

The starting point for the AAPM recommendations is specification of source strength in terms of air kerma strength, S_K, with units U ($=\mu Gy \bullet m^2/hr$). For ^{125}I seeds, the conversion factor from apparent activity to air kerma strength is 1.270 U/mCi.

A new quantity is introduced, the **dose rate constant**. $\Lambda\left(cGy \bullet h^{-1} \bullet U^{-1}\right)$, which is defined as the dose rate water at a distance of 1 cm on the transverse axis from the center of a unit air-kerma strength source in a water phantom. The dose rate constant includes the effects of source geometry, the spatial distribution of radioactivity within the source, and scattering in water surrounding the source. Currently, Λ =0.965 $cGy \bullet h^{-1} \bullet U^{-1}$ and 1.036 $cGy \bullet h^{-1} \bullet U^{-1}$ for model 6711 and model 6702 ^{125}I seeds, respectively (2). The numerical value of this quantity depends on the standardization measurements to which the air kerma strength calibration of source is traceable.

The dose rate to water at 1 cm distance, perpendicular to the source axis, is calculated as the product of air kerma strength and dose rate constant, i.e., $S_K \bullet \Lambda$ (cGy/hr). For calculation of dose rate using a point source approximation and ignoring dose anisotropy, the TG-43 formalism reduces to the equation:

$$\dot{D}(r) = \left(S_K \bullet \Lambda \bullet r_0^2 / r^2\right) \bullet g(r) \qquad (1)$$

where r is the distance from the point source in cm, r_o is 1 cm, and g (r) is the **radial dose function**, which accounts for the effects of absorption and scatter in the medium along the transverse axis of the source. This quantity is essentially identical to the "tissue attenuation and scatter" data specified in the COMS protocol, though TG-43 update published in 2004 has provided revision of the data to be used for ^{125}I seeds (2).

Sample calculation: Consider a single seed at the center of a COMS plaque. For a calculation height of 5 mm, the point source is at a distance of 7.4 mm (5 mm height + 1 mm scleral thickness + 1 mm silastic + 0.4 mm seed radius). Assume a model 6711 seed of strength 5.00 U (3.937 mCi).

Using the TG-43 update constants and formalism, with g(0.74 cm) = 1.019, the dose rate at r = 0.74 cm is calculated using equation (1) as:

$$\dot{D} = \left(5.0\,U \bullet 0.965\ cGy/h/U \bullet (1\,cm)^2 / (0.74\,cm)^2\right) \bullet 1.019 = 8.98\ cGy/h \qquad (2)$$

Some planning systems used for eye plaque dosimetry maybe incompatible with the TG-43 formulism. As an example, the Theratronics Theraplan/TP-11 systems (V05B/V09B and earlier) allow the user to specify source strength only in units mCi, Bq, or mg. Dose rate is calculated using the equation:

$$\dot{D}(r) = A \bullet \Gamma \bullet f \frac{g(r)}{r^2} \qquad (3)$$

where with A the activity in mCi, Γ (R cm^2/mCi/h) is the exposure rate constant, f (cGy/R) is the exposure to dose conversion factor, and g(r) is the tissue attenuation factor. Dose calculation can be made compatible with TG-43 by conversion of air kerma strength to apparent activity in mCi (1.27 U/mCi), and suitable re-definition of Γ and/or f, such that:

$$S_K \bullet \Lambda = A \bullet \Gamma \bullet f$$

The exposure rate constant for ^{125}I stated by TG-43 is the same as the COMS specified value, 1.45 R cm^2/mCi/h. It is appropriate therefore, to simply redefine the value of the *f*-factor in order to achieve the same statement of dose (rate) as TG-43. The current and revised values for Γ and f for COMS eye plaque dosimetry are given in the table below. Also given are the revised values which would be adopted following the change in the NIST standard for ^{125}I, assuming a 10% decrease in stated seed strength.

Model 6711	Before NIST Change	After NIST Change
Γ (R cm^2/mCi/h)	1.45	1.45
f (cGy/R)	0.91	0.845

Model 6702	Before NIST Change	After NIST Change
Γ (R cm^2/mCi/h)	1.45	1.45
f (cGy/R)	0.91	0.907

Using equation (3), the calculation for the example above would then be:

$\dot{D}$ = 3.937 mCi 1.45 Rcm$_2$/mCi/h•0.845 cGy/R•1.019/(0.74 cm)^2 = 8.98cGy/h which gives the same result as equation (2).

Though differences from the data of Ling (6711) and Schell (6702) are minor, the TG-43 recommended tissue attenuation factors, g(r), should be implemented. Note that the TG-43 polynomial fit of the radial dose functions for ^{125}I are based on data measured only to 7 cm. If a computer data file is to be used for brachytherapy in addition to eye plaque dosimetry, it is advised that a suitable extrapolation of the radial dose function be made for distances greater than 7 cm.

References:

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