TECHNICAL NOTE
Verification of ophthalmic brachytherapy treatment planning

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Abstract
Ophthalmic brachytherapy dose calculations were performed as an independent verification of commercial dosimetry software (BEBIG Plaque Simulator). Excel spreadsheets were constructed to follow the formalism of the AAPM Task Group No. 43. As a software commissioning tool, TG43 seed-based coordinates were reformatted to be compatible with plaque-based BEBIG dose tables for centrally positioned seeds. Plaque central axis doses were also calculated for rings of seeds. Close agreement with BEBIG doses was obtained in both cases. Tailored spreadsheet versions were subsequently created to verify patient treatment plans. Treatment time and dose to a specified central-axis point are calculated for ROPES plaques fully loaded with I-125 model 6702 seeds.

Keywords: Brachytherapy, Ophthalmic, Dose calculations, Treatment planning, Choroidal melanoma

Introduction
Christchurch Hospital has an ophthalmic brachytherapy service to treat retinal tumours. Radioactive iodine-125 seeds are arranged in a small metal plaque which is surgically attached to the patient's eye for several days. Treatment planning is performed using the "Plaque Simulator" software developed by Astrahan[1] and supplied by a German company, BEBIG. The commissioning process of an updated version (version 3.57) involved verifying that the software models the radiation field surrounding the seeds according to the 1995 TG43 formalism[2] (TG43 stands for Task Group No. 43 of the American Association of Physicists in Medicine Radiation Therapy Committee). An Excel spreadsheet based on TG43 was developed to convert dose information from a seed based to a plaque based geometry, enabling comparison with output from the BEBIG software. Reduced versions of the commissioning spreadsheet are now used for verification of patient treatment plans.

Method
Basis of spreadsheet calculation
Following the TG43 formalism, dose rate in the vicinity of a seed is calculated from the following equation:

$$\dot{D}(r,\theta) = S_k \, \Lambda \, [G(r,\theta)/G(r_o,\theta_o)] \, g(r) \, F(r,\theta)$$

Where $\dot{D}(r,\theta)$ is dose rate, S_k is air kerma strength, Λ is the dose rate constant, $G(r,\theta)$ the geometry factor, $g(r)$ the radial dose function, and $F(r,\theta)$ the anisotropy function.

Air kerma strength S_k is obtained from the average activity during treatment, using the activity to S_k conversion factor (U/mCi) given in TG43. The average activity is calculated from activity at assay, time between assay and implant ($t_{implant}$), treatment duration ($t_{treatment}$), and half-life, according to the equation:

$$A_{avg} = A_{assay} \, (t\_ /\ln 2) \exp[-\ln 2(t_{implant} /t\_)] \, .(1-\exp[-\ln 2(t_{treatment} /t\_)])$$

The dose rate constant Λ (which is the dose rate to water 1 cm from a 1 U source) is related to air kerma strength standard. When NIST implemented a new standard for low energy brachytherapy seeds on 1/1/1999, Λ changed by a reciprocal factor[3].

The geometry factor G(r,θ) is the first approximation to the spatial variation of the radiation field; it is calculated as the field of an ideal line source, as shown in Figure 1.

$$G(r,\theta) = (\text{atan}[r \sin\theta /(r \cos\theta - L/2)] - \text{atan}[r \sin\theta /(r \cos\theta + L/2)]) / (L\, r \sin\theta)$$

where L is the active seed length, and (r,θ) are the seed based coordinates. The reference point (r_o ,θ_o) is chosen according to TG43 as r_o = 1 cm, $\theta_o = 90^o$.

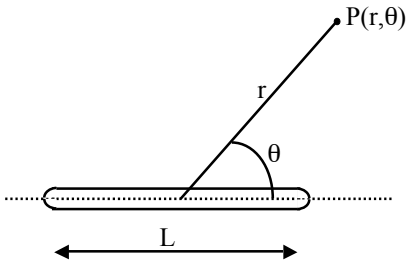

Figure 1: Seed based geometry

The radial dose function g(r) adjusts the fall-off with distance of the ideal line source field to fit empirical measurements perpendicular to the seed. It is calculated from a 5th order polynomial fit (given in TG43) over the 5 – 70 mm range.

Lastly the anisotropy function F(r,θ) compensates for angular variation. It is tabulated in TG43 over a range of 10 to 70 mm radial distance in 10 mm steps, and for θ of 0^o to 90^o in 10^o steps. The commissioning spreadsheet linearly interpolates from a lookup table based on the TG43 table. Because of the erratic pattern of the values, the 10 mm values are used for any shorter distances, rather than extrapolation. BEBIG 3.57 does not use the full TG43 F(r,θ) function but a one-dimensional function F(θ), which is F(10mm,θ) taken from TG43. For comparison, the commissioning spreadsheet also calculates alternative doses based on F(10mm,θ).

Compatibility with BEBIG dose table format

The BEBIG Plaque Simulator produces dose tables formatted to a plaque based coordinate system. The dose tables give dose at regular grid points on the plane with axes "off-axis distance" and "central axis distance" as defined in Figure 2.

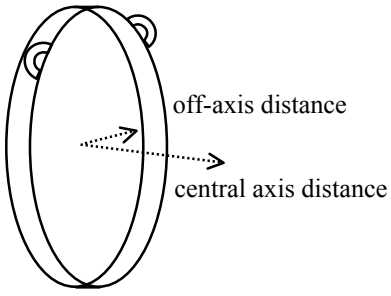

Figure 2: Plaque based coordinate system

The commissioning spreadsheet links the TG43 seed based geometry into the BEBIG plaque dose table format for two scenarios; complete dose tables for a single seed in the middle of the plaque, and dose along the central axis for a ring of seeds aligned end to end.

For the single seed, BEBIG requires the following parameters: seed offset, sphere radius (of the inner plaque surface), and seed tilt (the anti-clockwise rotation of the seed from vertical) as shown in Figure 3.

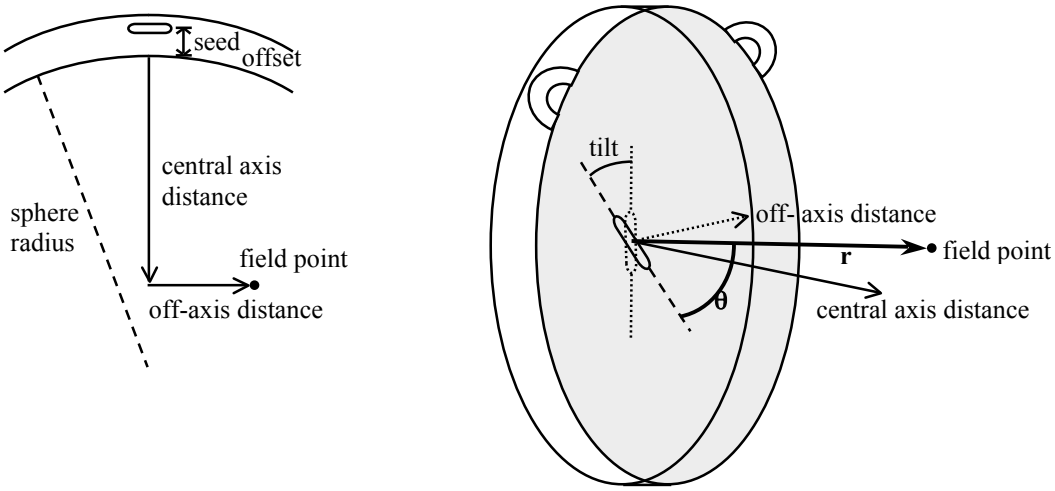

Figure 3: Seed-plaque geometry for a single central seed

Dose at each field point is calculated from the seed based coordinates (r,θ) which are obtained from the plaque parameters via the following equations:

$$r = \sqrt{(\text{CAX distance} + \text{offset})^2 + (\text{OAX distance})^2}$$

$$\theta = \text{acos}(\text{OAX} \,.\, \sin(\text{tilt}) / r)$$

where CAX is central axis distance, and OAX is off-axis distance.

For the ring of seeds, only dose along the plaque central axis is calculated. The number of seeds in the ring is required, and the size of the ring is specified by α, the angular separation of the seeds from the central axis, as shown in Figure 4.

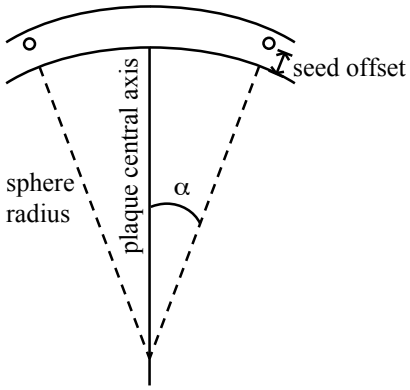

Figure 4: Geometry of a ring of seeds

Dose at each field point on the plaque central axis is calculated from (r,θ) obtained via the following equations:

$$r = \sqrt{(\text{CAX distance} + \cos\alpha \,.(r_{sphere} + \text{offset}) - r_{sphere})^2 + (r_{ring})^2}$$

$$r_{ring} = (r_{sphere} + \text{offset}).\sin\alpha$$

$$\theta = 90^o, \quad \text{(since the seeds are aligned perpendicular to the central axis.)}$$

Results

Commissioning spreadsheet

For the single central seed, doses were tabulated for an array of 1 to 20 mm central axis distance and 0 to 12 mm off-axis distance. The COMS (Collaborative Ocular Melanoma Study) protocol for ophthalmic brachytherapy uses a reference point 5 mm from the inner sclera of the eye as the dose prescription point for small tumours. This is assumed to correspond to 6 mm from the inner plaque surface – 6 mm central axis distance, 0 mm off-axis distance on the dose table. Results of the dose comparison using a model 6702 seed are summarised in Table 1. The apparently large discrepancies for the 90^o tilt case occurred at the most oblique angles; the central region, which is of significance to patient prescription was unaffected.

Seed tilt	Relative difference in dose		
	min (any point)	max (any point)	COMS point
0^o	-2.8 %	-0.7 %	-0.8 %
30^o	-2.8 %	1.6 %	-0.8 %
90^o	-7.3 %	13.5 %	-0.8 %

Table 1. *Relative differences between Commissioning Spreadsheet dose tables and BEBIG 3.57 dose tables for a single central seed*

Central axis doses from spreadsheet rings of seeds were compared with BEBIG predictions for the plaques currently used by the hospital. The spreadsheet version of the15 mm notched plaque is only approximate, as it assumes that all seeds are aligned end to end around the ring, whereas in the plaque the two seeds closest to the notch are slanted inwards (see Figure 5).

Figure 5: Seed arrangement in ROPES 15mm notched plaque

Results for three ROPES plaques filled with model 6702 seeds are summarised in Table 2.

Plaque	Relative difference in dose		
	min (any central axis point)	max (any central axis point)	COMS point
11mm ROPES plaque - one ring of 5 seeds ($\alpha = 17.5^o$)	-1.4 %	-0.8 %	-0.9 %
15mm ROPES plaque - inner ring of 3 seeds ($\alpha = 10^o$) - outer ring of 7 seeds ($\alpha = 27^o$)	-1.2 %	-0.8 %	-0.9 %
15mm notched ROPES plaque - inner pair of seeds ($\alpha = 10^o$) - middle pair of seeds ($\alpha = 22.5^o$) - outer crescent of 5 seeds ($\alpha = 27^o$)	-1.1 %	1.7 %	-0.2 %

Table 2. *Relative differences between Commissioning Spreadsheet and BEBIG 3.57 central axis doses for plaques loaded with seeds of uniform activity*

Tools for treatment plan verification

Before a treatment plan produced on the commercial software is accepted, key results must be verified by an independent method. Two worksheets derived from the commissioning spreadsheet are used for this verification.

Plaques are left in place on the patient's eye for the time required to deliver the prescribed dose to a particular point, normally the apex of the tumour. The worksheets require the height of the tumour apex (measured from the inner sclera), choice of plaque, seed activity and date/time of assay, applicable doserate constant, and date/time of plaque insertion. Because a backscatter factor to account for scatter from the plaque shell is applied in our BEBIG calculations, the same factor can be applied in the worksheets. The factor is dependent on distance from the seeds and is linearly interpolated from data pairs (taken from BEBIG) for each seed ring.

An initial check worksheet (which does not allow for source decay during treatment) gives the time required to reach the specified dose to the tumour apex. The initial check worksheet was compared with the BEBIG software for both set dose and set treatment time. Because the worksheet neglects source decay, the underestimation of treatment duration increases for longer treatments. A four day treatment time was underestimated by 3%, while a seven day treatment was underestimated by 5% for all plaques, with the exception of low apex tumours on the 15 mm notched plaque, where the underestimation is smaller.

A final check worksheet (including source decay during treatment) calculates the average dose rate and total dose accumulated for a given treatment duration.The comparison between the final check worksheet and the BEBIG software is summarised in Table 3.

Plaque	Relative difference in dose		
	min (1-12mm)	max (1-12mm)	COMS point
11mm	0.7 %	1.1 %	0.8 %
15mm	0.8 %	1.1 %	0.9 %
15mm notched	- 0.5 %	1.1 %	0.2 %

Table 3. *Relative differences between final check worksheet and BEBIG 3.57 calculated doses to tumour apex for ROPES plaques, loaded with uniform activity model 6702 seeds, tumour apex from 1-12mm.*

Conclusion

Comparison of doses generated by the BEBIG Plaque Simulator 3.57 software with those calculated using the home-grown commissioning spreadsheet and treatment plan verification worksheets showed very close agreement. As the spreadsheets are based directly on the TG43 formalism, these results confirm that the commercial software conforms to the accepted dosimetry and provide a useful verification tool for individual treatment plans.

Acknowledgments

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