Dosimetry with GAF Chromic: Experimental verification of software accuracy in stereotactic radiosurgery with GammaKnife for treatment of ocular melanoma

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Introduction

In recent years, radiosurgery with GammaKnife has demonstrated considerable success in the treatment of some new types of cerebral pathologies, such as socalled functional pathologies, and choroid melanomas. In both cases, the radiosurgical approach proposes an administration of high doses- often, two or three times higher than conventional treatment. In addition, the ocular melanoma presents an "eccentric" target as the lesion is often positioned at extreme peripheral limits. In such conditions, the question arises, is the Treatment Plan software (TPS) always reliable or are there existing factors that may compromise the computation of the dose distribution? The answer suggests that an accurate and verifiable dosage result would be complex, if not impossible, if done with commonly utilized equipment (ionization chamber, diodes or TLD). A valid alternative is the new, solid state GAF chromic detector which demonstrates the ionized radiation through a chemical-physical process of polymerization that changes the color of the film from transparent to an intense blue in proportion to the quantity of absorbed radiation. GAF chromic film, easily positioned in any area inside a phantom, quantifies the absorbed dose of the simulated target. Such quantitative analysis is done by elaboration of the binary images obtained by the single GAF film readings.

The scope of this work is to evaluate the projected output of the Treatment Plan software for verifiable doses utilizing MD55 GAF chromic film and a specifically designed phantom. The set-up conditions are identical for treatment of choroid melanoma.

Materials and Methods

The equipment used for the study include:

1) Phantoms: The first phantom consists of a tissue-equivalent sphere with a diameter of 16 cm. It is formed from two segments of a sphere of 5 cm in height that contain 16 (5 mm in thickness) sections in which it is possible to position the GAF chromic film. Specifically designed supports connected to the phantom permit, using computerized tomography, a three-dimensional view of the position of the film. When the coordinates are determined, the phantom is exposed. In tomography, the phantom's baricenter absolute coordinates are assigned equivalent to (X_A,Y_A,Z_A=100.,100.,100.). The second phantom consists of a tissue-equivalent sphere with a diameter equal to the first phantom. The inside of the sphere is designed with a tunnel that reaches the center permitting the positioning of the ionization chamber of 0.07 ml in coordinates (X_A,Y_A,Z_A=100.,100.,100.). At such coordinates, it is possible to calculate the dose/rate (Gy/m) of the 201 isocentric sources of Co^{60} according to the dosimetric protocol ICRU#24 and to verify the linearity of the electrometer response connected to the chamber.

2) MD55 GAF Film, CCD Reader, Lens: The CCD chamber is a chamber cooled to -40°C equipped with a 16 bit A/D converter and a lens with a focal length and an interval apertura of 28mm f/4-16. The light source of the microdensitometer utilizes a 60 diodes device (gallium arseniure) emitting light, with wavelengths, for a maximum dose sensitivity, selected in such a manner that the emission peak coincides with the absorbance peak of the 4x4cm^2 GAF film. The spatial resolution is 0.3mm.

3) Tests with GAF: For the calibration curve, a total of 40 measurements were done; 5 measurements every reading interval (15,30,45,50,60,75,90 Gy); and other 5 readings to measure the environmental radiation. For the isocenter measurements, (X_A,Y_A,Z_A=100.,100.,100.), ten exposures were done: four single exposures; and for two exposures, 3 layers of film were used. Also, the same procedure was used for the "eccentric zones" using the X_A,Y_A,Z_A=100.,100.,100. relative coordinates. Every single measurement, in which the physical dimension did not exceed 3 cm of diameter, were read after a few days in order to permit a steady-state of the polymerization process, and then converted in a binary file (TIF) for further elaboration.

3) Software: The most complex aspect of this study consisted in selection of the elaboration algorithms (written using C++) of the binary matrices. In fact, the two-dimensional spatial distribution of the dose in isocentric conditions presents a variable plateau according to the four collimators used (4, 8, 14, 18mm), and an extremely high grade dose in the adjacent millimeters. In such conditions, the single pixel spatial features are extremely important. For every single matrix (472x378 pixels), it was necessary to verify: a) the non-clustered spatial distribution of the noise in order to replace the gray value of a pixel by a neighborhood average only if that pixel appears to be noisy (local noise removal); and b) the radiation isotropy (invariant for rotation XY). Then single array gradient was determined creating comparable isocontouring, together with the clean image, with those provided by the Treatment Plan software.

Results

Dose evaluation tests conducted in conditions for profound lesions (>4cm) (Fig. 1) demonstrated a matching TPS and optimal experimental measurements (maximum 1% Error); whereas, tests conducted in "eccentric zones" (1-2cm under the skull) (Fig. 2) demonstrated a dose difference between calculated doses and measured doses (+/-7% Error). In such conditions, also the isodose distribution was not identical.

In addition, an extremely relevant aspect was the dosimetry of the 4mm collimator of which the company provides only information obtained using the Montecarlo method; until now, it has not been possible to quantify the reliability with experimental apparati.

Figure 1. Dose distribution in isocentric phantom. Isotropic situation and matching between TPS and experimental dosimetry.
Figure 2. Dose distribution in 'eccentric target'. The TPS overestimates the dose distribution., while the GAF reveals an inexpected halo surrounding the dummy's border.

Conclusions

The importance of the dosimetric method with GAF derives the ability to quantify the dose in terms of absolute units as well as visualize it. Thus, even though GAF has been only recently introduced, it has shown to be an indispensable instrument in complex physical dosimetric situations. The physics of radiotherapy often uses the parametric formulae or semi-empirical algorithyms extremely refined yet difficult to verify experimentally in specific conditions- as in the case of a simulated ocular melanoma- for the calculation of dose distribution. In such "extreme" conditions, it may be necessary to apply modified parametrization in order to achieve comparable experimental verification.

References

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Fig. 1

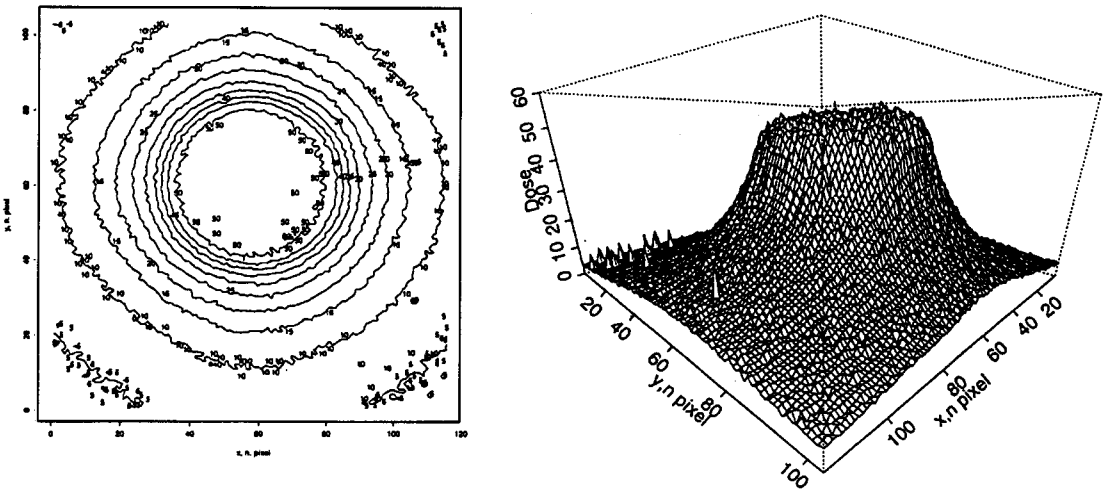

Fig. 2