Evaluation of the uncertainties in the TLD radiosurgery postal dose system

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Abstract: Radiosurgery is a single-fraction radiation therapy procedure for treating intracranial lesions using a stereotactic apparatus and multiple narrow beams delivered through noncoplanar isocentric arcs. The Radiological Science Laboratory (LCR/UERJ) operates a postal audit programme in SRT and SRS. The purpose of the programme is to verify the target localization accuracy and the dosimetric conditions of the TPS. The programme works in such a way those TLDs are sent to the centre where they are to be irradiated to a certain dose. The aim of the present work is estimate the uncertainties in the process of dose determination, using experimental data.

Keywords: Uncertainty, dosimetry, postal system, radiosurgery.

1. INTRODUCTION

Stereotactic radiosurgery (SRS) is a single-fraction radiation therapy procedure for treating intracranial lesions using a stereotactic apparatus and multiple narrow beams delivered through noncoplanar isocentric arcs. The same procedure is called stereotactic radiotherapy (SRT) when used to deliver multiple dose fractions [1]. Both techniques comprise precise delivery of a high dose to a small target volume with the goal of a positive therapeutic gain. SRS and SRT require patient immobilization and repositioning with an invasive frame, a non-invasive frame, or a frameless system to direct precise radiosurgery beam targeting . SRS and SRT require careful error assessment at each step of the treatment process. This includes assessing the integrity of the stereotactic device, the spatial accuracy of the imaging modality, and the accuracy of the radiation beam delivered to the patient. The accurate placement of the intended radiation dose is fundamental to these techniques. Small errors in the placement of the radiation dose from individual beams or beamlets can result in an inaccurate estimate of the accumulated dose as well as an inaccurate estimate of the steepness and location of the high dose gradient region that may be designed to protect adjacent critical structures and organs.

To guarantee a high quality standard, a comprehensive Quality Assurance (QA) programme is extremely important to ensure that the measured dose is consistent with the tolerance considered to improve treatment quality.

A QA programme can be implemented using a head phantom with or without an anthropomorphic form and a dosimeter that can measure the dose delivered during the therapy and its distribution in the volume treated.

The Radiological Science Laboratory (LCR/UERJ) operates a postal audit programme in SRT and SRS. The purpose of the programme is to verify the target localization accuracy in known geometry and the dosimetric conditions of the TPS. The programme works in such a way those thermoluminescence dosimeters (TLDs), consisting of LiF chips, are sent to the centre where they are to be irradiated to a certain dose. The TLD are then returned, where they are evaluated and the absorbed dose is obtained from TLDs readings. The aim of the present work is estimate the uncertainties in the process of dose determination, using experimental data.

2. MATERIAL AND METHOD

2.1. Irradiation procedure

The head phantom was made of PMMA material and constructed with high accuracy. Is consisted of a cylinder with a diameter of 16 cm and a length of 21 cm with several modular components to accommodate spherical imaging markers, radiochromic film and TLDs. Precise instructions for the computed tomography study, dosimetric planning and dose delivery were mailed to the radiotherapy clinic. The institution imaged the phantom, developed a treatment plan and irradiated the phantom according to the plan. The present study used mini-thermoluminescent cylinders and radiochromic films. A mini TLD cylindrical-type TLD 700H (LiF: Mg, Cu, P) with a 3 mm diameter, a 0.38 mm length and a 2.6 g/cm^3 density was also used. The annealing process was performed in a Thermolyne/4700 oven by pre-irradiation annealing at 240°C for 10 min. This pre-annealing was performed to erase all the information due to any previous irradiation from a thermoluminescence material to restore the crystals to their initial conditions before irradiation. The general purpose of this thermal treatment was to restore the trap-recombination centre structure to the former one obtained after the initialization procedure. The post-irradiation procedure at the reader was performed at 165°C for 10 s. This was necessary to erase the low temperature peaks. The readout process was performed with a Harshaw/QS 3500 reader [5].

Measurements were performed to determine the values of the correction factors as a function of the absorbed dose, the beam energy and fading after irradiation.

The TLD readings at the point of interest were corrected by the mean background thermoluminescence response (BG), the individual sensitivity factor (S_i) and the correction for the variation of the dosimeter response as a function of the beam energy (F_{depen}) and for time, and variations of TLDs readings (F_{corr}) according to Equation (1), to obtain the absorbed dose (D).

$$D = \frac{(TL - BG)\cdot 10^2}{S \cdot F_{lin} \cdot F_{depen} \cdot F_{corr}} \qquad (1)$$

The TLD response for a given dose depends on the photon energy, due to the dependence of the TL material's mass absorption coefficient (μ_{en}/ρ) on energy [6]. The energy correction factor (F_{depen}) is defined as the ratio of the response R per unit dose measured at the D=1 Gy in a Co γ ray beam to a response R per unit dose at 1 Gy in the x-ray beam quality $TPR_{20/10}$. The values of the correction factor for different beam qualities are approximated by a linear fit that was made to TL irradiations showed in equation 2.

$$F_{depen} = 0{,}4736(TPR_{20/10})^2 0{,}8433(TPR_{20/10}) + 1{,}3225 \qquad (2)$$

In the dose range of interest (0,5-10 Gy) the dose response exhibits a small supralinearity effect, which requires to be corrected for. This effect arises primarily from competitive mechanisms in the recombination stage [7]. The dose response non-linearity correction factor is the ratio of the TL response per unit dose measured at the dose of 1 Gy to the Tl response per unit dose measured at the dose D. The non-linearity factor (F_{lin}) was determined by making a linear fit to the experimental data showed in equation 3.

$$F_{lin} = -9{,}71924 \times 10^{-10} (D)^3 + 4{,}74633 \times 10^{-07} (D)^2 + 2{,}92386 \times 10^{-04} (D) + 0{,}97078 \quad (3)$$

As far as the variation of the response with time is concerned, the thermal fading was not observed; otherwise an increase of the response with time is measured. The correction for the delayed response alteration with time (F_{corr}) [8].

2.2. Expressions of uncertainties

The methodology used in the present work for estimating the uncertainties is based on the recommendations of ISOGUM (ISO Guide to the Expression of Uncertainty in Measurement) [8].

By calling the TL-BG reading simply as L and taking the partial derivates for each variable (L,S, F_{lin}, F_{depen} and F_{corr}, we have the equations 4, 5, 6, 7 and 8:

$$\frac{\partial D}{\partial L} = \frac{10^2}{S.F_{lin}.F_{depen}.F_{corr}} = \frac{D}{L} \quad (4)$$

$$\frac{\partial D}{\partial S} = -\frac{L.10^2}{S^2.F_{lin}.F_{depen}.F_{corr}} = -\frac{D}{S} \quad (5)$$

$$\frac{\partial D}{\partial F_{lin}} = -\frac{L.10^2}{S.F_{lin}^2.F_{depen}.F_{corr}} = -\frac{D}{F_{lin}} \quad (6)$$

$$\frac{\partial D}{\partial F_{depen}} = -\frac{L.10^2}{S.F_{lin}.F_{depen}^2.F_{corr}} = -\frac{D}{F_{depen}} \quad (7)$$

$$\frac{\partial D}{\partial F_{corr}} = -\frac{L.10^2}{S.F_{lin}.F_{depen}.F_{corr}^2} = -\frac{D}{F_{corr}} \quad (8)$$

Assuming that the factors in equation 1 are uncorrelated, the combined relative uncertainty in the dose determined from the TLD readings is the square root of the sum of the squared relative uncertainties.

The uncertainty in the ratio is determined from error propagation according to equation 7:

$$\left(\frac{u_D}{D}\right)^2 = \left(\frac{u_L}{L}\right)^2 + \left(\frac{u_S}{S}\right)^2 + \left(\frac{u_{F_{lin}}}{F_{lin}}\right)^2 + \left(\frac{u_{F_{dpen}}}{F_{depen}}\right)^2 + \left(\frac{u_{F_{corr}}}{F_{corr}}\right)^2 \quad (7)$$

3. RESULTS

The calculations of the uncertainties in the LCR TLD postal dose programme were performed as described in the previous section. The uncertainties associated with the dose determination are listed below:

$\left(\frac{u_L}{L}\right)$ = 0.0019. The uncertainty in the mean TLD reading of a single TLD was estimate as the arithmetic mean of the distribution of standard deviations of the mean for a large number of TLDs that have been irradiated with the same dose.

$\left(\frac{u_S}{S}\right)$ = 1%. This was the sensitivity coefficient maximum value estimated.

$\left(\frac{u_{F_{lin}}}{F_{lin}}\right)$ = 0.012. This was the percentage deviation of the linear fit of the curve to the experimental data.

$\left(\frac{u_{F_{dpen}}}{F_{depen}}\right)$ = 0.0005. This is the maximum value to round up.

$\left(\frac{u_{F_{corr}}}{F_{corr}}\right)$ = 0.011. This was the maximum correction to time that was used in this work.

The combined relative uncertainty in the dose determined from the TLD readings is presented by equation 9.

$$\frac{u_D}{D} = \sqrt{(0,0019)^2 + (0,01)^2 + (0,012)^2 + (0,0005)^2 + (0,011)^2} \quad (9)$$

The relative uncertainty in the determined dose was calculated with equation 9 giving a value of 1,93%.

4. DISCUSSION

The major components in the uncertainty in the dose determination are the uncertainties in the sensitivity, linearity and time correction.

5. CONCLUSION

An analysis of the uncertainties in the dose evaluation process in LCR TLD postal dose programme has been performed. The analysis comprises uncertainties in the reading of the dosimeters, uncertainties in the calibration coefficient, and uncertainties in correction factors for energy dependence and dose response non-linearity.

The largest contributors to the uncertainty have been found to be the sensitivity, the energy correction factor and the dose response non-linearity correction factor.

Statistical uncertainty can be reduced by performing repeated measurements.

The statistical uncertainty is a reproducibility index not only of the dosimeters but also of relevant instrumentation (TLD reader, annealing oven, and the ionization chamber used for the calibration) and measurement set-up. Therefore, instruments should be checked for reproducibility and consistency over longer periods of time in order to ensure that their impact on the statistical uncertainty of TLD measurements is of minor importance.

7. REFERENCES

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