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Comprehensive quality assurance for intracranial radiosurgery treatments using a postal system

Garantía de calidad para tratamientos de radiocirugía intracranial usando un sistema postal

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ABSTRACT: Radiosurgery is a high-precision technique for delivering, in most cases, a single highly conformal dose to a stereotactically localized target. It can be indicated for small intracranial injury treatment, using either multiple sources of 60Co (γ rays) or high energy photon beams produced by linear accelerators. In order to minimize the impact of inaccurate localization of the target or dose delivery, a rigorous Quality Assurance (QA) program must be enforced, which should include an independent auditing system. This work proposes a simple and reliable postal QA phantom to be used as an independent evaluation. In it two important parameters were verified such as, the dosimetric precision of the planning system, by comparing the absorbed doses measured in the target volume using different dosimeters (ionization chamber, films, thermoluminescent dosimeters and L-alanine dosimeters) all calibrated against a small volume ion chamber. The exact positioning of the target volume was localized using air spaces and small steel spheres to find the appropriate target coordinates. The head phantom and the instruction sheets were extensively tested and sent by mail to selected institutions. The overall results were very encouraging and suggest that the proposed phantom may be used as a postal system as part of an independent QA tool in radiosurgery.

Keywords: Radiosurgery, quality control, postal system.

INTRODUCCIÓN

Radiosurgery refers to the precise delivery of a high and single radiation dose to a small target volume with the goal of positive therapeutic gain. For that, the Quality Assurance is extremely important for ensuring that the dose measured is consistent with the tolerances considered to improve the quality of treatment (Schell et a., 1995) and as a result of the opacity of the cranial vault, target volume definition relies strongly on the anatomic accuracy of the imaging modalities. When Linac-based systems are used for radiosurgery, target coordinates are conventionally obtained using computed tomography (CT) and/or magnetic resonance (MR) imaging with a frame affixed to the head. Recently special hardware and software has been introduced for frameless target localization and patient position tracking. A single beam, defined by an appropriate collimator size, the number of isocenters and the number of treatment arcs, are used to create an ideal treatment plan. The main goal of treatment planning is to maximize tumor coverage with a very sharp dose fall-off to limit damage to surrounding normal tissues. Treatment is typically done as an outpatient procedure in cases in which frameless localization hypofractionated radiosurgery is applicable. The x, y and z target coordinates are centered at a point intersected by the vertical axis, around which the couch rotates. The Linac rotates in a single plane around a horizontal axis that intersects the vertical axis of couch rotation at the target site, as described by Luxton *et al*. (1993) (Luxton *et al*, 1993). The dose calculation, tissue maximum ratios (TMRs) and dose profiles are measured for each collimator size as a function of depth. For a given arc, the mean TMR for all beam directions is calculated and the total dose due to the arc is inferred. As an approximation, an arc is considered to

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be the sum of the dose distributions from a series of fixed beams. For intracranial radiosurgery, heterogeneity corrections due to bone, tissue and air are not applied in the dose calculation. The maximum error in absolute TMR that would result from ignoring heterogeneity corrections is less than 1%.

This premise is very important in the design of phantoms for use in QA programs to measure the dose and to verify the target localization coordinates (Ramasesham & Heydarian, 2003). Considering that a single high dose is delivered, there is no room for radiobiological compensation if a wrong dose is delivered. Therefore, a QA program must be used in order to guarantee the desired level of accuracy for the dose delivered to each patient (De Almeida *et al*., 2005; Derreumaux *et al*., 1995; Luxton *et al*., 1993). Misadministration of a single-fraction delivery is considered to have occurred when the treatment dose differs from the prescribed ones by 10% or more. Redundant QA checks by other team members are recommended, as well as regular refresher courses for all users. It is also strongly advisable to have periodical independent auditing in the QA program to enhance the quality and consistency of the dosimetric data and the target localizing systems. This approach will certainly minimize the possibility of accidental and fatal doses, such as the ones recently reported (Derreumaux, 2008; Institut de Radioprotection et de Sûreté Nucléaire, 2008).

The purpose of this work is to describe an alternative system that uses a plastic head phantom capable of functioning as an independent auditing tool, using several tested dosimeters, all suitable for use as a postal system. The overall target localization in a known geometry and the treatment planning system's dosimetric and non-dosimetric conditions are checked. The use of the phantom described in this work follows a specific protocol that explains step by step how to use the information obtained. The results demonstrate that the dosimeters studied are in agreement with established tolerances (American Association of Physicists in Medicine, 1995).

MATERIALS AND METHODS

Phantom design

The head phantom, as shown in Figure 1, was made of PMMA material and constructed with high precision. It consists of a cylinder with a radius of 16 cm and a length of 20 cm with several modular components to accommodate imaging spherical markers, ionization chamber, film and both termoluminescent and alanine dosimeters. The modularity of the phantom components allows imaging of the marker positions using CT that normally is the equipment used for the target volume localization. The phantom can be mounted in orthogonal planes and can be rotated at different orientations to perform 3D Quality Assurance.

The phantom and the irradiation protocol were extensively tested prior to submitting to the participating institutions.

Fig. 1. Head phantom mounted in a Lecksell-type frame with its various components used for performing the tests.

Dosimetric Systems

The selection of suitable detectors for dose determination in the small fields required in radiosurgery is a very critical issue due to a stringent requirement of high spatial resolution. The use of small field size, together with high energy radiation beams, introduces difficulties in performing dosimetry, such as the absence of lateral electronic equilibrium and the existence of a sharp gradient dose at the field edge (Wolfram, 2006). To overcome these difficulties, the dosimeter size should be small (Duggan & Coffey, 1998). Several types of dosimeters have been previously applied to small field dosimetry, including: radiographic and radiochromic films, miniature ionization chambers, liquid ionization chambers, thermoluminescent dosimeter (TLD), diamond and silicon diodes, and MOSFETs (Calcina, 2007; Duggan & Coffey, 1998; Mc

Kerracher & Thwaites, 2002; Perucha *et al*., 2003). A new formalism for reference dosimetry of small and nonstandard fields, using small ion chambers, has recently been proposed by Alfonso *et al*. (2008) (Alfonso *et al*., 2008). In the present study, a small volume ionization chamber, films, mini-thermoluminescent cylinders and mini-2-Methyl-Alanine dosimeters were used. A cylindrical ionization chamber, PTW-Freiburg model 31010, with a 0.125 cm3 volume and a PTW/UNIDOS electrometer, both calibrated at the PTW secondary standard dosimetry laboratory, were used as references, as recommended by the TRS 398 (INTERNATIONAL ATOMIC ENERGY AGENCY, 2000).

The short-term and long-term stabilities were 0.04% and 0.31%, respectively. A mini TLD cylindrical-type MTS-N (LiF: Mg, Cu, P) with 2 mm diameter, 0.5 mm length (0.0016 cm3) and a density of 2.6 g/cm3 was kindly provided by Institute of Nuclear Physics, Poland (Bilski *et al*., 2002).

Prior to irradiation, the TLD was annealed in a Thermolyne/4700 oven for 10 min at 240°C, and after irradiation, the readout process was performed with a Harshaw/QS 3500 reader, following the procedures described by Bilski *et al*. (2002) Bilski *et al*., 2002). Over the study period, a maximum standard deviation of 1.88%, stability of 0.01% and a negligible fading (0.025 nC day-1) were observed. The radiographic film Kodak/X-Omat V was selected and the optical density measured with a densitometer PTW-Freiburg/DensinXauto/79115 with a 1 mm focal spot. A maximum standard deviation of 1.3% was observed. Minidosimeters of 2-methyalanine (2MA) with millimeter dimensions and a mass of 1 mg were used to assess the doses. The dosimeters were selected from a batch of around 500 pellets made from a homogenous mixture of L-alanine Sigma Chemical Company/A-7627, and pure paraffin in a proportion of 80% L-alanine and 20% paraffin, as described by Chen *et al*. (2007) (Chen *et al*., 2007). Following the requirements for spatial resolution in radiosurgery dosimetry, the intended nominal dimensions for a cylindrical mini pellet were a 1 mm diameter and a 3 mm length.

For the electron paramagnetic resonance (EPR) measurements, a K-Band (24 GHz) spectrometer was used for the irradiated and non-irradiated minidosimeter spectra recordings. By increasing the resonance frequency (24 GHz), the sensitivity of the spectrometer was enhanced (Poole, 1983), allowing measurements in alanine minidosimeters irradiated with doses of tens of grays. All of the spectrometer components and the different parameter settings used for spectra recording were described in a previous work (Chen *et al*., 2007). TLDs, film and 2MA dosimeters were calibrated against the ionization chamber with a 6 MV photon beam produced by a Siemens/Mevatron linear accelerator at a 100 cm source surface distance (SSD) using a 10 × 10 cm2 field size placed at a build-up depth of 1.5 g.cm-2 of PMMA (INTERNATIONAL ATOMIC ENERGY AGENCY, 2000). Doses in the range of 0.5-30 Gy were used for 2MA, 0-10 Gy for TLDs and 0-1.2 Gy for the films. The individual absorbed dose calibration sensitivities of each system were determined and used to calculate the absorbed dose values for each of the experiments described in the following sections.

RESULTS

The most relevant measurements were: the target localization coordinates in the Treatment Planning System (TPS); the mechanical precision verification of the LINAC locating coordinates and the Treatment planning QA.

Table I. Uncertainty values associated with the localization of tumor targets through the TPS of each institution.

Evaluated Points	Uncertainty (%)		
	Institutions		
	A	B	C
1	0.22	0.19	0.15
2	0.15	0.31	0.29
3	0.13	0.23	0.30
4	0.21	0.18	0.23

The Target localization coordinates

The head phantom was fixed in a stereotactic frame and couch and then filled with water. A smaller cylinder of 6.9 cm diameter and 9.9 cm length containing an air cylinder of 2.0 mm diameter and 2.0 cm length to simulate the target volume, was inserted into the empty vault in the phantom as shown in Figure 2a. With anterior and lateral fiducial markers attached to the frames, CT images were taken in 2 mm slices. The images were introduced into the TPS to determine the dot coordinates of

Table II. Maximum deviations observed between the center of the cone and the reference marker (steel spheres).

Evaluated Points	Max Desviation (mm)		
	Institutions		
	A	B	C
1	1.0	0.2	0.2
2	0.3	0.2	0.5
3	0.2	0.1	0.2
4	0.2	0.2	0.2

each target marker, which were compared to the reference values. Table I summarizes the Uncertainty values associated with the localization of tumor targets through the TPS of each institution.

Mechanical precision verification in the LINAC locating coordinates.

For this evaluation, steel spheres with 3.0 mm diameters were placed in four points in the phantom, as shown in figure 2b. X-ray films were taken with the gantry in 0o and 90o positions using a cylindrical treatment cone with a diameter of 2 cm in Institution A and a 2 x 2 cm2 field collimated by a multileaf system in institutions B and C. Table II presents the differences between the center of the cone or field and the center of the spheres.

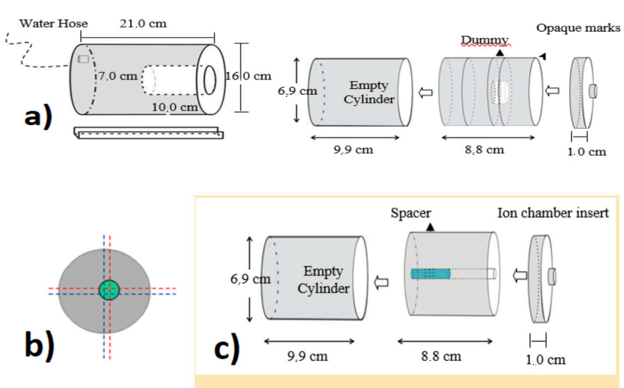

Fig. 2. a. A large cylinder filled with water with a central hollow to fit the inserts and a smaller PMMA cylinder with opaque marks. b. Geometry verification of the Linac alignment, comparing the center of the cone with the steel ball position. c. Irradiation geometry of the ionization chamber.

Treatment-planning QA

Taking the X-ray images as a reference for the mass that will be irradiated, the irradiation time translated for monitor units (MU) was calculated in order to integrate 10 Gy in the target volume (air bubble). The TLD and 2MA detectors were positioned in the phantom simulated target volume at distances of 0.5, 1.0 and 3.0 mm from each other, as shown in figure 2c.

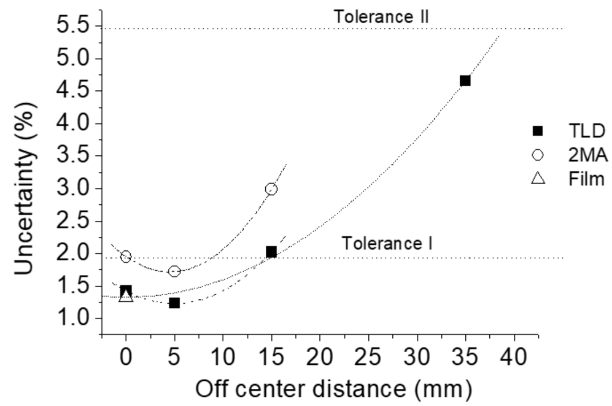

Fig. 3. Maximum uncertainties for the absorbed dose values measured with TLD, 2MA and Film compared with the values calculated by the TPS. The tolerance I is related to distances from o up to 5 mm and tolerance II for distances higher than 5 mm up to 35 mm (American Association of Physicists in Medicine, 1995).

The three institutions were asked to irradiate the target volume with doses of 10 Gy and 25 Gy for the TLD and 2MA dosimeters, respectively (see Figure 3).

For all the measurements evaluated, the absorbed dose results are within the established tolerances according to the American Association of Physicists in Medicine protocol (American Association of Physicists in Medicine, 1995).

DISCUSSION

Radiosurgery is a special technique that requires dosimetry and positioning accuracy at milimetric level. The treatment fields are often fairly small, and therefore the spatial resolution required for the detectors is much more rigorous. In addition, because high single doses are delivered, the impact of an incorrect target localization or dose delivery can be damaging to the patients. The AAPM Task Group 42 (Schell, 1995) and the RadiationTherapy Oncology Group (Shaw, 1993) have published general recommendations and guidelines on the subject and a new formalism for dose calculation, using an ionization chamber has recently been proposed by Alfonso *et al*., in 2008 (Alfonso, 2008).

In relation to target localization coordinates, the results presented in table I, show associated uncertainties of less than 1 mm, which are within the recommended overall tolerance of 2.0 mm (American Association of Physicists in Medicine, 1995).

Table II presents mechanical precision verification in the LINAC locating coordinates and the observed values < 1 mm, are within the recommended tolerance of 2 mm made by the AAPM, in 1995, and IAEA, in 1999 (INTERNATIONAL ATOMIC ENERGY AGENCY, 1995; INTERNATIONAL ATOMIC ENERGY AGENCY, 1999).

The results presented in Figure 3 show that the uncertainties increase with distance from the center. For instance, at 5 mm from the center, the results are below 2%, within the tolerance recommended value (American Association of Physicists in Medicine, 1995), but for 15 mm and 35 mm they are progressively larger. The 2MA dosimeter shows better results for the higher dose, and the TLD for the lower one, and in combination, the two systems provide good consistency.

We suggest that as a result of recent accidents involving radiosurgery treatments (Derreumaux, 2008), it should be mandatory to establish a rigorous QA program that includes an independent auditing verification of the adopted procedures and a postal phantom with dosimeters suitable for the measurements could be used to control several institutions.

CONCLUSION

The main conclusion drawn from this work, based on the results from the three evaluated institutions, is that the proposed and tested postal system is easy to handle, shows roughness and metrological consistency and can be used as a reliable, independent auditing tool as part of a QA program in Radiosurgery.

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RESUMEN: La radiocirugía es una técnica de alta precisión para administrar, en la mayoría de los casos, una sola dosis altamente conformada en un objetivo localizado estereotípicamente. Puede estar indicado para el tratamiento de pequeñas lesiones intracraneales, utilizando múltiples fuentes de 60Co (rayos γ) o haces de fotones de alta energía producidos por aceleradores lineales. Con el fin de minimizar el impacto de la ubicación inexacta de la administración de la meta o de la dosis, se debe aplicar un riguroso programa de control de calidad (QA), que debe incluir un sistema de auditoría independiente. Este documento propone un fantoma postal de control de calidad simple y fiable que se utilizará como evaluación independiente. Se verificó dos parámetros importantes, como la precisión dosimétrica del sistema de planificación, comparando las dosis absorbidas medidas en el volumen objetivo mediante diferentes dosis (cámara de ionización, películas, dosímetros Termoluminiscentes y dosímetros de L-alanina) todos calibrados con una pequeña cámara de iones de volumen. El posicionamiento exacto del volumen objetivo se localizó utilizando espacios aéreos y pequeñas esferas de acero para encontrar las coordenadas de destino adecuadas. El fantoma principal y las hojas de instrucciones fueron ampliamente probados y enviados por correo a instituciones seleccionadas. Los resultados generales fueron muy alentadores y sugieren que el fantoma propuesto puede utilizarse como sistema postal como parte de una herramienta independiente de control de calidad en radiocirugía.

Palabras clave: Radiocirugía, control de calidad, sistema postal

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