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Original Article

DOSIMETRIC CHARACTERIZATION OF CIRCULAR COLLIMATOR RADIOSURGICAL BEAMS

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ABSTRACT

The Purpose: Is to describe the dose measurements for small stereotactic radiosurgery x-ray beams and to evaluate the accuracy of the measured dose in the small fields where lateral electronic equilibrium is not complete.

Materials and Methods: The experiments reported in this paper were carried out at the Radiotherapy Department of the Alexandria Armed Forces Hospitals. A 6-MV linear accelerator (Siemens Primus, Germany) with collimators (Howmedica Leibinger, Germany) is used for radiosurgery at this department. The collimator used in this study was 100 mm high and its outer diameter was 70 mm. Nominal field diameters at the isocenter range from 8.9mm to 41mm. Relative Output Factors (ROFs), Tissue-Maximum Ratio (TMR), beam profiles, penumbra, beam flatness and symmetry and field size factors were measured. Micro-ionization chamber and conventional Kodak Ready pack films were used.

Results: Relative Output Factors (ROFs), Tissue-Maximum Ratio (TMR), beam profiles, penumbra, beam flatness and symmetry and field size factors were measured. The ROF values showed field diameter dependence, decreasing with decreasing diameter. The agreement between the film and the microchamber in perpendicular and in parallel positions were within 6.06% and 4.42% for the fields with diameter ranging from 8.9mm to 41mm respectively. The variation in TMR is limited to 8.4% between the smallest and largest cones at 10cm depth. The maximum dose increased with increasing the cone diameter for the cones 8.9, 12.3 and 15.9mm and seems erratic for the other cones. The penumbra width seems broader when measuring the beam profiles with microchamber.

Conclusion: For narrow X-ray beam dosimetry of fields with diameter ranging from 8.9mm to 41mm, the microchamber seems to be the more suitable detector for ROF and TMR measurements. Using the microchamber in beam profile measurements is not recommended because of the broadening in the penumbra width.

Key Words: Small fields, stereotactic radiosurgery, physical characteristics.

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INTRODUCTION

In its early development, radiosurgery was a technique for treating a sharply delimited lesion in the brain by focusing a high single dose of radiation from external sources into a stereotactically defined target.[1] This “closed surgical procedure” was developed in 1951 by the Swedish neurosurgeon Lars Leksell[2] with the aim of “avoiding the trephination of the skull and the risk of infection or intracranial bleeding” that sometimes complicate the use of other stereotactic tools, such as a radiofrequency probe.

Today radiosurgery is used as a particular irradiation procedure devised for producing a required radiobiological effect (vessel obliteration or tumor control) by focusing radiation from external sources into a stereotactically defined cerebral lesion1.

Since in both definitions a certain dose is delivered to intracranial contents, the main prerequisites of the technique are the pinpoint localization of the target and the steep dose decrease of the absorbed dose at the edges of the target volume. This is achieved by taking advantage of the particular physical characteristics and/ or geometry of incident beams. Therefore, radiation dosimetry plays a vital role in the outcome analysis of stereotactic radiosurgery (SRS). In linear accelerator (linac) radiosurgery, the dosimetric characteristics including relative output factor (ROF), tissue-maximum ratio (TMR), and beam profile must be determined prior to muliplanar dosimetric calculations[3]. Because of the small fields in SRS, there are some special problems. Duggan and Coffey[4] refer to these problems, which are the volume averaging, electronic disequilibrium and its consequences, and field size dependence in details. For these reasons, special equipment and methods have been used to measure the dosimetry for radiosurgery.

The purpose of this work is to describe the dose measurements for these small X-ray beams and in particular to evaluate the accuracy of the measured dose in the small fields where lateral electronic disequilibrium exists.

MATERIALS AND METHODS

2.1 SRS system :

The experiments reported in this paper have been carried out at the Radiotherapy Department of the Alexandria Armed Forces Hospitals. A 6-MV linac (Siemens Primus, Germany) with tungsten collimators (Howmedica Leibinger, Germany) is used for SRS at this department. The collimator used in this study was 10cm high and its outer diameter was 7cm. Nominal field diameters at the isocenter range from 8.9mm to 41mm. The holes in the collimators were made with a straight drill. They produce beam edges which are sharper than those defined by the movable jaws because they are closer to the isocenter.

2.2 Detectors and dosimeters:

The ideal detector for radiosurgery dosimetry should have several properties: high spatial resolution (which usually means small size), and a dose response that is field size, energy, and dose rate independent, linear, reproducible and stable. There is no one detector used for radiosurgery dosimetry which fulfills all these conditions. The ionization chambers fulfill these conditions except its poor spatial resolution. Therefore a special ionization chamber was made for SRS that has a rather high spatial resolution designated as a microchamber. The microchamber used in this study is Pinpoint chamber manufactured by PTW Company (Freiberg, Germany). The active volume of this chamber is 0.015 cm^3 with inner diameter 2mm. Kodak x-ray ready Pack films were used in the ROF measurements. For ROF measurements, UNIDOS electrometer (PTW, Freiberg, Germany) was used for measuring the absolute dose. For beam data acquisition, MP3-S Therapy beam analyzer (PTW, Freiberg, Germany) was used.

2.3 Dose measurements:

2.3.1 Relative output factors:

ROF measurements for different SRS collimators were performed at the isocenter and at depth of maximum dose (dmax) in the water tank with Pinpoint chamber. ROFs were measured twice. Once, while the chamber was perpendicular to the central axis of the beam and another while the chamber was parallel to the central axis of the beam. The chamber was used with its long axis parallel to the central axis of the beam to minimize the area of the chamber[5]. To determine the effective measuring point along this axis, identical measurements of dose against depth were made with the pinpoint chamber in that geometry. ROFs were determined by finding the ratio of the measured data for field sizes to that of the calibration condition (the value for a 10 x 10 cm^2 field at dmax and focus-skin distance (FSD) equal 100cm). ROF measurements were also performed with the film in RW3 solid water slabs, where films were positioned at the isocenter at dmax. RW3 slabs solid water is a water equivalent material with an electron density relative to water of 1.00 and a physical density of 1.012 g /cm^3. The film calibration was performed in the solid water under the reference conditions, that is FSD = 100 cm, dmax = 1.5 cm, 10 x 10 cm^2 field size, and the film characteristic curve was determined by establishing the density-to-dose relationship under the same conditions of processing and scanning as in SRS film dosimetry.

2.3.2 Tissue maximum ratios:

TMRs for SRS collimators were measured in a water tank using the MP3-S PTW beam data acquisition system with microchamber. The microchamber was orientated parallel to the beam central axis. The sensitive point of chamber is positioned at the isocenter of machine (FAD = 100 cm) where the sensitive point at 2.4mm from the top of chamber. The water level above the detector was pumped out from 25 to 0 cm (FSD varied from 75 to 100cm). The TMR accessory (floating level detector) was utilized.

The parameters, which are essential for the description of the curves, analyzed using DIN-protocol. These analyzed parameters are dmax, the dose at the depths of 0-cm (D0), 10-cm (D10), and 20-cm (D20) in percentage of maximum dose, the quality index (QI), nominal accelerating potential (NAP). QI that is a measure for the radiation quality defined as: QI = D20/D10. NAP is determined from the QI according to the AAPM TG21 protocol[6]. Numerical values are obtained from a fit to the curve given by Nizin and Kase.[7]

2.3.3 Beam profiles:

Beam profiles for SRS collimators were measured at the isocenter at 5 cm depth in water with the microchamber using MP3-S. These profiles are normalized to 100% at the center of the beam. The analysis parameters, which are essential for the description of the beam profile curves, are the penumbra regions of the curves, which are defined as the lateral distance between 20% and 80% of the maximum dose. The field size which defined as the width of the beam profile curve at the 50% dose value. The maximum and minimum doses (Dmax and Dmin) within the flattened region, the homogeneity and symmetry of the profile. The homogeneity is defined as:

$$Homogeneity = \frac{(D_{\max} - D_{\min})}{(D_{\max} + D_{\min})} * 100\% \qquad 1$$

The symmetry is defined as:

$$Symmetry = Absolute \frac{(a-b)}{(a+b)} * 200\% \qquad 2$$

Where a and b are the areas to the left and right of the central beam respectively. The areas are limited by the central beam and the 50% field width.

The symmetry is defined as:

$$NAP = 10^{\left[0.173 * \frac{D_{SSD\,10} + D_{SSD\,20}}{D_{SSD\,10} - D_{SSD\,20}} - 1.0\right]} \qquad 3$$

Where DSSD100/DSSD200 is the unnormalized dose at 10cm and 20cm.

RESULTS

3.1. Relative output factor measurements:

Table 1 shows (ROF) values for small circular fields of diameter ranging from 8.9mm to 41mm measured with a 0.015cc ionization microchamber in its two positions and those measured with X-ray films. The ROF values showed field diameter dependence, decreasing with decreasing diameter. The agreement between the film and the microchamber in the perpendicular position was within 6.06% for the fields with diameters ranging from 8.9 mm to 41 mm. The agreement between the film and the microchamber in the parallel position was within 4.42%, while the agreement between the microchamber in parallel and perpendicular positions was within 4.20%.

Table 1: Collimator relative output factor (ROF) measured with X-ray film and a microchamber in parallel and perpendicular positions.

Field Size	Detector		
	XV-2 Film	Microchamber	
		In Parallel	In Perpendicular
10x10 cm	1.00	1.00	1.00
Diameter (mm)			
8.9	0.686	0.687	0.691
12.3	0.762	0.767	0.801
15.9	0.788	0.825	0.838
19.6	0.818	0.847	0.871
23.2	0.844	0.868	0.890
26.9	0.861	0.884	0.903
30.4	0.876	0.895	0.909
36	0.882	0.908	0.917
41	0.886	0.917	0.924

3.2. Tissue maximum ratio measurements:

TMR values of the small circular fields measured with the microchamber are shown in figure 1. TMR data varied with the cone sizes. In general, the larger cones have higher TMR values. In these measurements, the variation in TMR is limited to 4.7% between the 12.3- and 30.4-mm cones at 10cm depth. A maximum increase of 8.4% in TMR is notice between the smallest and largest cones. The characterization parameters for the TMR curves are summarized in table (2). The variation of dmax with cones is in the range from 12.5mm for 8.9mm cone size to 16.5mm for 36mm cone size. The dmax for the smallest three cones 8.9-, 12.3- and 15.9mm increased with increasing the cone size. For cones from 19.6mm to 41mm, the variation with cone size seems erratic. The dmax can be treated at a constant depth of 15mm within the limits of experimental accuracy. From the characteristic parameters in table (1) and by comparing with the reported data, there is an excellent agreement.[8,11]

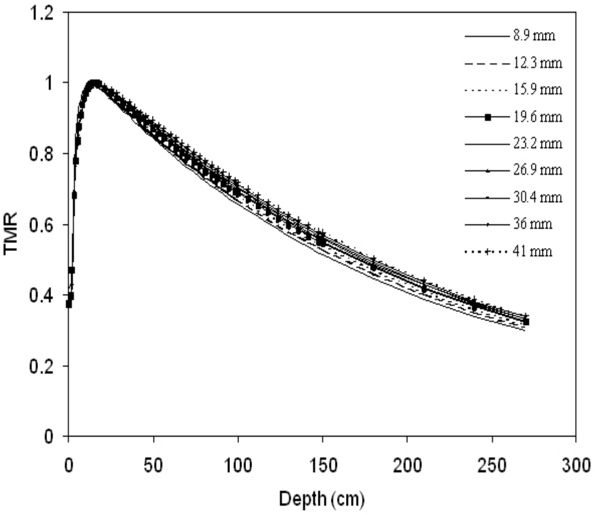

Fig. 1: TMR of the representative cones using microchamber.

Table 2: Characterization parameters, for the description of the TMR curves.

Cone Diam. (mm)	Dmax (mm)	D0 (%)	D10 (%)	D20 (%)	QI	NAP (MV)
8.9	12.5	0.413	0.656	0.408	0.6212	3.69
12.3	13.5	0.385	0.671	0.422	0.6287	3.85
15.9	15	0.374	0.681	0.431	0.6324	3.94
19.6	14.5	0.372	0.688	0.437	0.6348	4.0
23.2	15	0.372	0.694	0.442	0.6366	4.04
26.9	15	0.373	0.699	0.446	0.6382	4.08
30.4	16.5	0.376	0.704	0.450	0.6391	4.10
36.0	15.5	0.381	0.712	0.456	0.641	4.15
41.0	15.5	0.384	0.718	0.462	0.6428	4.20

* NAP: Nominal accelerating potential
* Dmax: depth of maximum dose
*D0: dose at surface
*D10: dose at 10 cm depth
*D20: dose at 20 cm depth.

3.3. Beam profiles:

Representative profiles of the circular beams are shown in figure (2). These profiles are normalized to 100% at the center of the beam. Table (3) summarizes the characteristic parameters for the beam profile curves. In the table, the dosimetrically determined cone sizes and penumbra width (20 - 80%) are shown. The cone sizes measured were within ±0.3mm. These results are in agreement with published data 8,13 for similar cones. This indicates that photon scattered in the auxiliary collimator do not contribute significantly to the dose. The penumbra widths typically ranged from 2.64mm for the collimator 8.9mm to 4.79 mm for collimator 41mm. Heydarian et al.[13] calculated the penumbra widths (20 – 80%) for similar collimator sizes and the same energy using different detectors Diamond, Diode, and Film. Table (4) shows the comparison between the penumbra widths measured by the micro chamber in this study for collimators 15.9mm and 41mm diameters with their results. Although the microchamber is designed especially for SRS measurements, it has a poor spatial resolution compared to the other detectors. This is clear from the comparison in table (3) where the penumbra width is particularly wide in the microchamber measurements compared to other detectors.

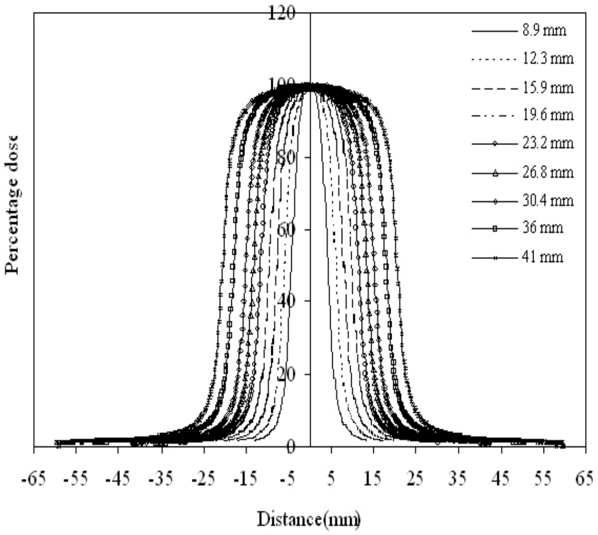

Fig. 2: Dose profiles measured with microchamber for a set of collimators.

Table 3: Characterization parameters, which are essential for the description of the beam profile curves.

Cone size (mm)	Penumbra (mm)	Field size (50 %)	Dmax (%)	Dmin (%)	Homog (%)	Symmetry (%)
8.9	2.64	8.6	*	*	*	*
12.3	2.95	12.1	*	*	*	*
15.9	3.09	15.8	*	*	*	*
19.6	3.27	19.5	*	*	*	*
23.2	3.32	23.1	101.18	100	0.59	101.12
26.8	3.48	26.7	100.18	98.86	0.67	100.6
30.4	3.57	30.3	100.72	99.05	0.84	101.08
36.0	3.71	36	100.46	98.19	1.14	100.77
41.0	4.79	41.3	100.75	97.82	1.48	100.87

The software is not able to perform analysis because the flattening area for the collimator size is too small.

Table 4: The comparison between the Penumbra widths measured for two collimators with different types of detectors.

Collimator Diameter (mm)	Penumbra width (mm)				
	Micro-chamber	M Heydarian et al. measurements14			
		Diamond	Diode	Film	EGS4
15.9	3.09	1.85	2.45	2.65	2.01
41	4.79	2.72	3.50	3.2	2.23

DISCUSSION

The significant problem in the measurement of the dosimetric characteristics of linac SRS is in the selection of the appropriate detector. This detector should be considerably smaller than the beam radius[12]. Conventional detectors, such as the Farmer type ionization chamber, are too large to measure the side electron equilibrium which is not established for narrower beams[3]. The comparison between the different types of detectors which were

EGS4:

Electron-Gamma Shower which is a general purpose Monte Carlo simulation of the coupled transport of electrons and photons in an arbitrary geometry for particles with energies above a few keV up to several TeV.

Used in the measurement of the dosimetric characteristics for linac SRS sufficiently studied[13-17]. In arrangement of these detectors for its spatial resolution, the X-ray film is the first but the microchamber is the last.

This study is to answer this question, if there is only the microchamber as a SRS detector, is it enough to perform the measurement of the dosimetric characteristics for linac radiosurgery or not?

4.1. Relative output factor measurements:

ROF is one of the simplest measurements required for radiosurgery but also the most demanding of dosimeters[4]. Requires a detector with adequate spatial resolution. American association of physicist's in medicine (AAPM) Task Group 4216 recommends that the detector size perpendicular to the beam be less than 3-mm for a 6 MV beam with a full width at half maximum (FWHM) at isocenter of 12.5mm. Bjarngard et al.[11] reported that a 2-mm diameter detector was small enough for a 8.5-mm beam. They recommend a detector size of 1-mm or less for a 5-mm beam, and using at least two different dosimeters to measure ROFs. According to this recommendation, ROF measured by two detectors, microchamber in two positions and X-ray film. Although the sensitive volume of the microchamber is smaller than that of the conventional detectors, the microchamber is inferior to X-ray film in regard to spatial resolution.

The use of X-ray film seems to be appropriate for the relative dose measurement of small fields because of its excellent spatial resolution. However, film dosimetry is time-consuming and requires relatively complex and controlled development procedures[12]. In table (1), the microchamber was suitable for the ROF. The ROF values showed considerable field size dependence, increasing with increasing field size. Sixel et al. also reported a field size dependence of the ROF for the nominal field diameter ranging from 10mm to 30mm.[14]

4.2. Tissue maximum ratio measurements:

There are two methods for acquisition of the TMR, either calculated from depth dose curves or measured directly from a linac. For SRS fields it is best to measure it directly by changing the depth in the phantom without moving the detector. There are several reasons for this. Duggan and Coffey[4] mentioned these reasons in 1998. In this study TMR was measured directly from linac to avoid these problems. For the analyzed parameters, there is no significant difference between the TMR measured by microchamber and the corresponding TMR measured by other detectors[3]. The microchamber is adequate for measurement the TMR in SRS techniques.

4.3. Beam profile measurements:

Beam profile measurements are affected by different factors, namely the finite size of the detector, the change in electron transport in the detector, variation in the detector directional response[18], detector energy dependence, and dose rate dependence. The penumbra broadening due to the finite size of the sensitive volume of the detector[19,20] is the most important factor. Thus conventional ionization chambers were not used for beam profile measurements because of their very large sensitive volumes[13]. The microchamber was designed specially for SRS, and many centers performed the SRS measurements using it.

CONCLUSION

The micro chamber detector available for radiosurgery is adequate for measuring ROF and TMR. The ROF decreased with decreasing field diameter. The depth of maximum calibrated TMR increased with increasing field diameter for the three collimators 8.9mm, 12.3mm, and 15.9mm but the variation seems erratic for other cones.

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