THE PHOTON BEAM CHARACTERISTICS OF LINEAR ACCELERATOR EQUIPPED WITH ADDITIONAL NARROW BEAM COLLIMATOR

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Abstract

In this contribution laboratory set-up with electron linac installed in SINS, and attached narrow-beam collimator for photon beam are presented. Characteristics of circular photon beams of diameters ranging from 10.0 to 30.0 mm at isocentre are reported. Specific quantities measured include: relative output factors, beam profiles (off-axis factors), and central axis attenuation of beams. Measurements of these parameters were performed in a water phantom using small cylindrical ionisation chambers.

1 INTRODUCTION

Stereotactic radiosurgery (SRS) using external beams of radiation has become an important method of treatment of small intracranial lesions such as: arteriovenous malformations, benign or malignant primary tumours and isolated metastases. In this non-invasive technique a high dose of radiation is delivered to the stereotactically localized lesion, while minimaly irradiating adjacent normal brain tissue.

The concept of stereotaxis is to localize accurately in space any desired region of the brain. The stereotactic frame " locks" the patient's head into a fixed position with respect to a coordinate system related to the imaging and treatment machines. Computerized tomography (CT), magnetic resonance imaging (MRI) and digital subtraction angiography (DSA) are used as imaging techniques. Once the target volume is defined a dose planning is performed [1].

For many years radiosurgery was performed either with gamma beams from multi-mini cobalt sources so-called gamma knife unit or with heavy charged particle beams from cyclotrons.

However recent developments have led to use the photon beams from isocentre linear electron accelerators as radiation sources for radiosurgery [2],[3]. These accelerators are a noteworthy alternative to expensive and complex gamma knives and heavy particle accelerators.

Linear electron accelerators are now generally available in the most radiotherapy centres. The modifications which are needed to adapt modern linacs to radiosurgery, are relatively simple and consist typically of a set of additional tertiary collimators to define the beams with diameters from 10 to 30 mm, a remotely controlled motorized couch, brackets or a floor stand for a mounting the stereotactic frame.

Once a central point of the tumor is located at the isocentre of the accelerator a whole treatment is performed by combining rotation of an accelerator with a sequential number of patient couch positions.

We have designed in our laboratory a set of tertiary collimators and the collimator mount fittable to the head of the linac. The aim of this report is to present the dosimetric features of these collimators in terms of beam characteristics.

2 MATERIALS AND METHODS

2.1. Accelerator and Collimators

The standard collimators of the linac consist of a conical primary collimator and two pairs of adjustable secondary collimator jaws. The primary collimator defines the maximum dispersion angle of the radiation beam. The secondary collimator jaws restrict the beam in x and y direction and define a rectangular radiation field. The source-to-axis distance (SAD), i.e. the distance between the beam focus and the isocentre, is 1000 mm.

The collimator mount is directly fixed to the collimator of linac and is fitted with an adjustment device, which permits the centering of the collimator at the isocentre. The tertiary collimators are made from lead and are lined with 2 mm aluminium. They have divergent edges inside for reduce transmission penumbra. The three additional collimators are 110 mm thick with 10, 20 and 30 mm field size diameters, respectively, at the isocentre.

The outer diameter of the collimators is 68 mm. The rectangular collimator of the linac is set to a field $5x5cm^2$ when additional collimator is used.

2.2. Detectors

Accurate dosimetry of small-field photon beams used in stereotactic radiosurgery (SRS) and radiotherapy (SRT) is difficult because of the presence of lateral electronic disequilibrium and steep dose gradients. The detectors used for measurements of absorbed dose distribution must be small in respect to the size of radiation field and must have a sufficient spatial resolution. Therefore small volume ion chamber, diode, diamond detector and film are proposed for that purpose [4].

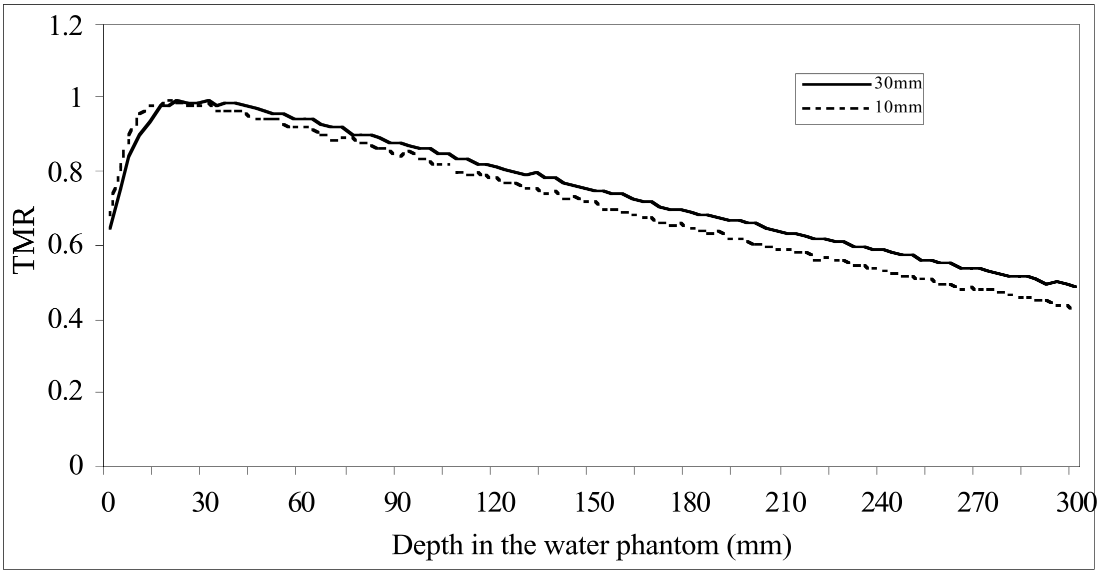

Figure 1. Tissue maximum ratio (TMR) of 15 MV photon beam, measured for 10 and 30 mm collimator diameters with 0.12 cm^3 ion chamber.

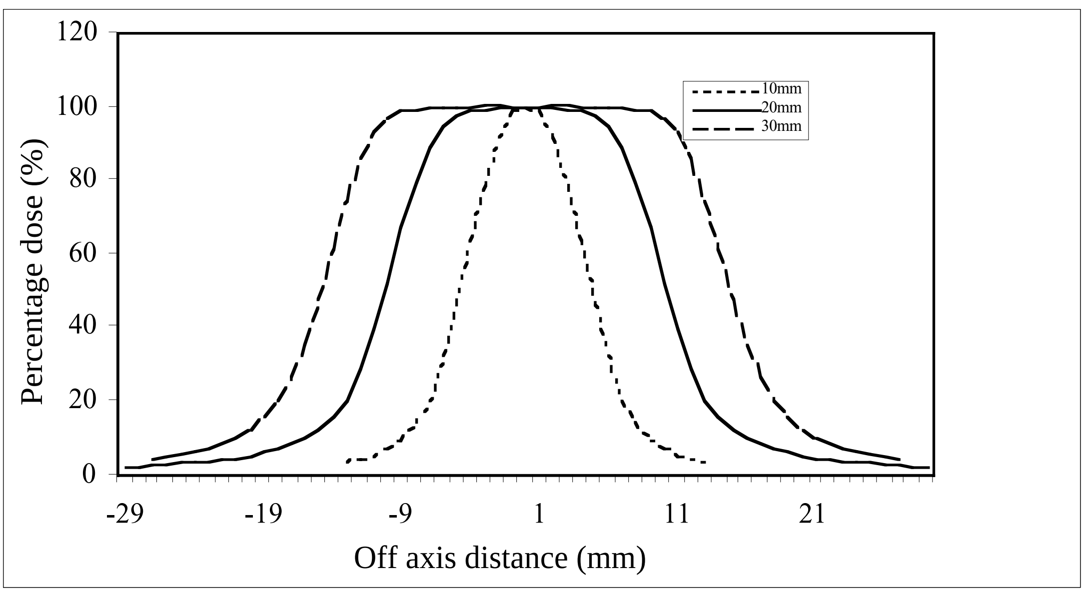

Figure 2. Beam profiles (OAR) of 15 MV photon beam formed with collimators of 10, 20 and 30 mm in diameter, measured with 0.12cm^3 ion chamber.

In this study measurements were done with small-volume Scanditronix ion chamber type RK and Wellhöfer pinpoint chamber type IC04.

Active volumes of the RK thimble chamber and IC04 pinpoint chamber are 0.12 cm^3 and 0.03 cm^3, respectively. We used the parallel and perpendicular orientation of the ion chamber axis to the beam axis. Scanditronix RFA 300 water-scanning system and dosimeter Ionex type 2500/3 from Nuclear Enterprices Ltd. were used with the RK ion chamber and pinpoint IC04 chamber, respectively.

3 RESULTS

Depth dose curves, beam profiles and output factors for the three additional collimators were measured and the following characteristics of the small fields of 10, 20, 30 mm in diameter at the isocentre were determined:

- tissue maximum ratio (TMR),
- off axis ratios (OAR) and
- total scatter factors (S_t).

All measurements were performed at Source Surface Distance SSD equal 970, 975, 980 mm for 30, 20 and 10 mm diameter collimator respectively.

3.1. TMR

Tissue Maximum Ratio (TMR) is defined as:

$$TMR(c,d) = D(c,0,d)/D(c,0,d_{max})$$

where d is depth in the phantom, d_{max} is reference depth, c is collimator diameter. The d_{max} depth of maximum calibrated TMR was found between 19 mm and 30 mm and increased with increasing field diameter.
Figure 1 shows TMR as a function of depth for collimator diameter equal 10 mm and 30 mm.

3.2. OAR

Off Axis Ratio (OAR) defined as:

$$OAR(c, r, d) = D(c, r, d) / D(c, 0, d)$$

is the ratio of the dose measured at a radial distance r relative to the dose at the central axis for a collimator diameter c.

The parallel orientation of the ion chamber axis to the beam axis provided better resolution in beam profile compared to the perpendicular orientation. Measurements results for beam profiles performed with parallel orientation of the ion chamber are presented in Figure 2. The values of the penumbras for measured beams are in the range of 4.0 to 5.4 mm. From our previous experiments [5], [6] we know that penumbras for the same collimator are less from 2 up to 3 mm when we use diamond detector for measurements.
Unfortunately we have not possibility to use diamond in our laboratory set-up.

3.3. S_t

Total Scatter Factor is defined by:

$$S_t(c) = D(c, 0, d_{max})/D(10x10\ cm^2, 0, d_{max})$$

and is the ratio of the dose at a depth d_{max} on the central axis for a collimator diameter c relative to the dose measured at the same point in a standard 10x10cm^2 calibration field.
Output factor measurements were made along the central axis of the beam at the isocentre, using ion chamber. From performed investigation we could see that S_t for the circular collimator is the function of primary jaws field size setting.

The Total Scatter Factors for the beam formed with collimators 10, 20 and 30 mm in diameter and with fixed primary jaws field size setting: 5x5 cm^2 were 0.69; 0.83 and 0.90 respectively.

4 CONCLUSIONS

Radiosurgery with photon beams from linear accelerator is an attractive radiosurgical technique, since it is relatively simple and can be implemented on most isocentric linear accelerators. The necessary modification is attaching to the accelerator head the additional narrow beam collimator. Three additional collimators with isocentre diameters of 10, 20 and 30mm were constructed in our department, attached to laboratory set-up with 15 MV electron linac and the dosimetric characteristics of circular photon beams have been measured.

The diamond detector was found to be more appropriate choice for beam profile measurements than the ion chamber and yields more accurate results.

Tissue Maximum Ratio (TMR) and Total Scatter Factor (S_t) for 20 and 30mm collimator diameter can be measured with ionisation chamber with sensitive volume 0.03 but for 10 mm collimator diameter the 0.015cm^3 ion chamber would be better choice.

The dosimetric characterisics of investigated collimators were found to be suitable for stereotactics radiosurgery and radiotherapy.

REFERENCES

[1] A.Wysocka " Physical aspects of treatment planning in linac-based radiosurgery of intracranial lesions" Reports of Practical Oncology and Radiotherapy, Vol.3, No.3, 59-66, 1998.

[2] E.B.Podgorsak, B.Pike, A.Olivier, M.Pla and L.Souhami "Radiosurgery with high energy photon beams: a comparison among techniques", Int.J.Rad. Oncol.Biol.Phys. 16, 857-865,1989.

[3] A.Wysocka, "Physical aspect of stereotactic radio-surgery with application of the linear accelerator arc method", Nukleonika ,Vol.41, No.2, 11-20, 1996.

[4] C.F. Serago, P.V. Houdek, G.H. Hartmann, D.S. Saini, M.E.Serago and A.Kaydee, "Tissue maximum ratios (and other parameters) of small circular 4,6,10,15 and 24 MV x- ray beams for radiosurgery", Phys.Med.Biol., Vol.37, No 10, 1943-1956, 1992.

[5] G.Hartmann,A.Wysocka,"Test reports of the PLATO stereotactic radiosurgery software",ACTIVITY-Int. Nucletron-Oldelf.Rad.J.Special Report, No. 6,.56-62,

[6] A. Wysocka, J. Rostkowska, M. Kania, W. Bulski, J. Fijuth, "Dosimetric characteristics of circular 6MV X-Ray beams for stereotactic radiotherapy with a linear accelerator", Acta Physica Polonica B, Vol. 31, No 1, p.81-87, 2000.