NUKLEONIKA 2001;46(3):1–93

ORIGINAL PAPER

The photon beam characteristics of linear accelerator equipped with additional narrow beam collimator

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Abstract In this paper a laboratory set-up with an electron linac installed in this Institute, and an attached narrow-beam collimator for photon beam are presented. Characteristics of the circular photon beams of diameters ranging from 10 to 30 mm at the isocentre are reported. The specific quantities measured include: relative output factors, beam profiles (off axis factors), and a central axis attenuation of beams. Measurements of these parameters were performed in a water phantom using small cylindrical ionisation chambers.

Key words collimator • linear accelerator • narrow beam • photon beam

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Received: 5 January 2001, Accepted: 30 May 2001

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 technique, a high dose of radiation is delivered to the stereotactically localized lesion, the adjacent normal brain tissue being minimaly irradiated.

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 [1]. 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 [6].

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 [3, 4]. These accelerators are a noteworthy alternative to expensive and complex gamma knives and heavy particle accelerators.

Linear electron accelerators are now generally available in 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 mounting of the stereotactic frame. Once a central point of the tumor is located at the isocentre of the accelerator, the whole treatment is performed by combining rotation of an accelerator with a sequential number of patient couch positions.

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

Materials and methods

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 directions 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.

An additional collimator holder is directly fixed to the collimator of the linac and is fitted with an adjustment device, which permits centering of the collimator at the isocentre. Schematic diagram of the whole collimator system is presented in Fig. 1. The tertiary collimators are made of lead and are lined with a 2 mm aluminium layer. They have divergent edges inside to 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 of 5×5 cm^2 when an additional collimator is used.

Detector

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 the 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 [5].

In this study, measurements were done with a small-volume Scanditronix ion chamber, type RK, and a Wellhöfer pinpoint chamber type, IC04. Active volumes of the RK thimble chamber and the IC04 pinpoint chamber are 0.12 cm^3 and 0.03 cm^3, respectively. The chambers have an inner cavity (air cavity) diameter of 4 mm, their length of cavities being 10.0 and 3.6 mm, respectively. We used parallel and perpendicular orientations of the ion chamber axis to the beam axis. The Scanditronix RFA 300 water-scanning system and a dosimeter Ionex, type 2500/3, from Nuclear Enterprices Ltd. were used with the RK ion chamber and the pinpoint IC04 chamber, respectively.

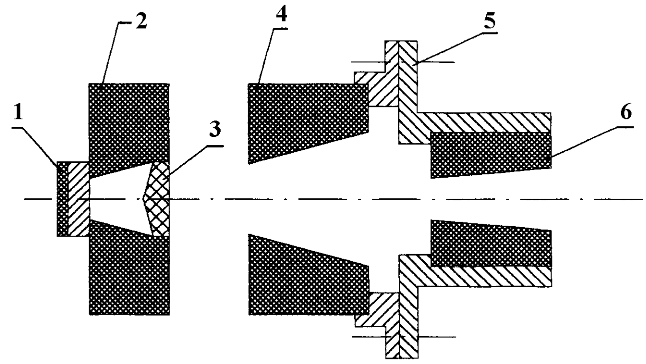

Fig. 1. Schematic diagram of whole the collimator system. 1 – target, 2 – primary collimator, 3 – flattering filter, 4 – secondary collimator, 5 – narrow beam collimator holder, 6 – narrow beam collimator.

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

Tissue Maximum Ratio (TMR)

TMR is defined as

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

where d is the depth in the phantom, d_{max} is the reference depth, c is the collimator diameter.

The d_{max} depth of maximum calibrated TMR was found to be between 19 and 30 mm and increased with increasing field diameter. Fig. 2 shows TMR as a function of the depth for the collimator diameter equal to 10 mm and 30 mm.

Off Axis Ratio (OAR)

OAR defined as

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

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

The parallel orientation of the ion chamber axis to the beam axis provided a better resolution in the beam profile compared to the perpendicular orientation. The results of measurements for beam profiles performed with parallel orientation of the ion chamber are presented in Fig. 3. The values of the penumbras for measured beams are in the range of 4.0 to 5.4 mm. From our previous experiments [2, 7] we know that penumbras for the same collimator are less

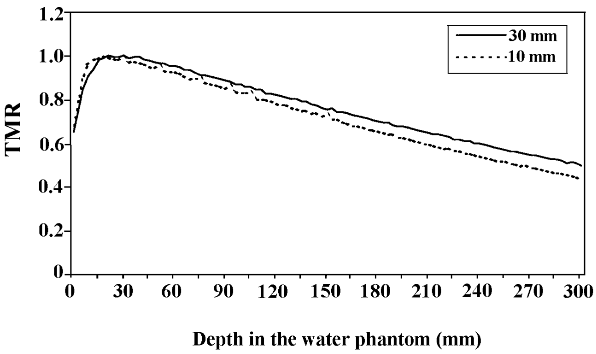

Fig. 2. Tissue maximum ratio (TMR) of 15 MV photon beam, measured for 10 and 30 mm collimator diameters with the 0.12 cm^3 ion chamber.

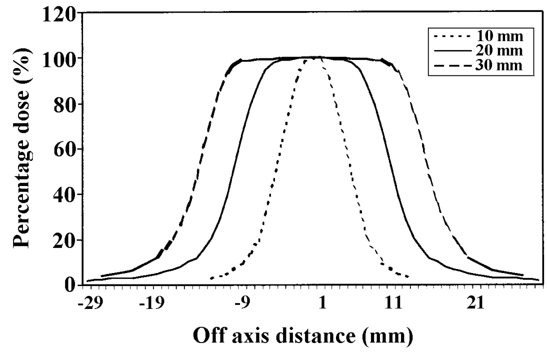

Fig. 3. Beam profiles (OAR) of 15 MV photon beam formed with collimators of 10, 20 and 30 mm in diameter, measured with the 0.12 cm^3 ion chamber.

than 2–3 mm when we used a diamond detector for measurements. Unfortunately, we have not at disposal such a diamond detector in our laboratory set-up.

Total Scatter Factor (S_t)

S_t is defined by

(3) $S_t(c) = D(c, 0, d_{max})/D(10\times10\ cm^2, 0, d_{max})$

and is the ratio of the dose at the depth d_{max} on the central axis for the collimator diameter c relative to the dose measured at the same point in the standard 10×10 cm^2 calibration field.

Radiation Output Factor (ROF) measurements were made along the central axis of the beam at the isocentre, using the ion chamber. From the performed investigation we could see that ROF for the circular collimator is a function of the field size setting of primary jaws.

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

Conclusions

Radiosurgery with photon beams from linear accelerators is an attractive radiosurgical technique, since it is relatively simple and can be implemented on most isocentric linear accelerators. The necessary modification is the attaching an additional narrow beam collimator to the accelerator head. Three additional collimators with the isocentre diameters of 10, 20 and 30 mm were constructed in our Department, attached to the laboratory set-up with the 15 MV electron linac and the dosimetric characteristics of circular photon beams have been measured. The diamond detector was found to be a 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 the 20 and 30 mm collimator diameter can be measured with the ionisation chamber of sensitive volume 0.03 but for the 10 mm collimator diameter the 0.015 cm^3 ion chamber would be a better choice. The dosimetric characteristics of the investigated collimators were found to be suitable for stereotactic radiosurgery and radiotherapy.

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