Comparison of measured and Monte Carlo calculated dose distributions from circular collimators for radiosurgical beams

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Background: Stereotactic radiosurgery is an important clinical tool for the treatment of small lesions in the brain, including benign conditions, malignant and localized metastatic tumors. A dosimetry study was performed for Elekta 'Synergy S' as a dedicated Stereotactic radiosurgery unit, capable of generating circular radiation fields with diameters of 1-5 cm at isocentre using the BEAM/EGS4 Monte Carlo code. ***Materials and Methods:*** The linear accelerator Elekta "Synergy S" equipped with a set of 5 circular collimators from 10 mm to 50 mm in diameter at isocentre distance was used. The cones were inserted in a base plate mounted on the collimator linac head. A PinPoint chamber and Wellhofer water tank chamber were selected for clinical dosimetry of 6 MV photon beams. The results of simulations using the Monte Carlo system BEAM/EGS4 to model the beam geometry were compared with dose measurements. ***Results:*** An excellent agreement was found between Monte Carlo calculated and measured percentage depth dose and lateral dose profiles which were performed in water phantom for circular cones with 1, 2, 3, 4 and 5 cm in diameter. The comparison between calculation and measurements showed up to 0.5 % or 1mm difference for all field sizes. The penumbra (80-20%) results at 5 cm depth in water phantom and SSD=95 ranged from 1.5 to 2.1 mm for circular collimators with diameter 1 to 5 cm. ***Conclusion:*** This study showed that BEAMnrc code has been accurate in modeling Synergy S linear accelerator equipped with circular collimators. **Iran. J. Radiat. Res., 2007; 5 (1): 31-36**

Keywords: *Monte Carlo, dosimetry, radiosurgery, circular cones.*

INTRODUCTION

Stereotactic radiosurgery (SRS) is characterized by the delivery of high radiation dose to a small volume in a short time with high accuracy and high conformality. This involves maximising the radiation dose to damage or destroy a lesion while minimising the dose to the surrounding uninvolved, normal tissue. Linear accelerator-based radiosurgical techniques have been developed since 1980 (1, 2). Stereotactic radiosurgery using linear accelerators is conventionally carried out with single or multiple isocentre, non-coplanar, arcing techniques for radiation delivery (3). It can be performed with small collimated circular beams. Circular collimators (cones) can be attached to linac head as an accessory in traditional stereotactic radiosurgery. Using circular cones, X-rays from the linear accelerators (linacs) are collimated into fine beams and precisely focused to the target volume. They can yield small fields with sharp penumbra.

Accurate dose measurements are made more difficult when the measured field sizes are either comparable to the detector size, or less than the distance required for lateral electronic equilibrium. Several detector characteristics should be considered when choosing a measurement system. The detector size in the radial direction will determine the extent of the beam profile integrated in the reading. Standard detectors are often too large for the small fields considered, which are characterized by high dose gradients and lack of charged particle equilibrium, resulting in a detector read-out that may deviate from the absorbed dose. Various detectors and methods have been reported for dosimetry of small fields. One of these is the PinPoint chamber that is a valuable dosimeter in characterizing small field parameters (4).

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Monte Carlo simulation can be an interesting alternative. Sophisticated Monte Carlo codes are becoming available parallel to the emerging use of small field radiotherapy techniques. The Monte Carlo system BEAM/EGS4 offers the opportunity to model a linear accelerator head very accurately. Most analytical dose calculation methods do not account for electron transport and therefore fail to predict accurately the output of the linear accelerator for small fields. Therefore, Monte Carlo based treatment planning is expected to become the preferred method to calculate the patient dose during treatment with small fields in order to account for the loss of electronic equilibrium, especially in regions of low-density tissues, and near air cavities (5).

This work has aimed to model the linear accelerator Elekta "Synergy S" equipped with circular collimators, and to simulate 6 MV photon beam using the Monte Carlo BEAMnrc simulations and measurements.

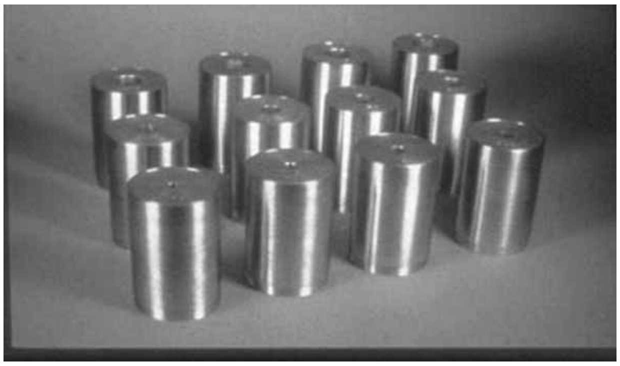

Figure 1. A set of 19 circular collimators from 5 mm to 50 mm in diameter at isocentre distance with 2.5 mm steps.

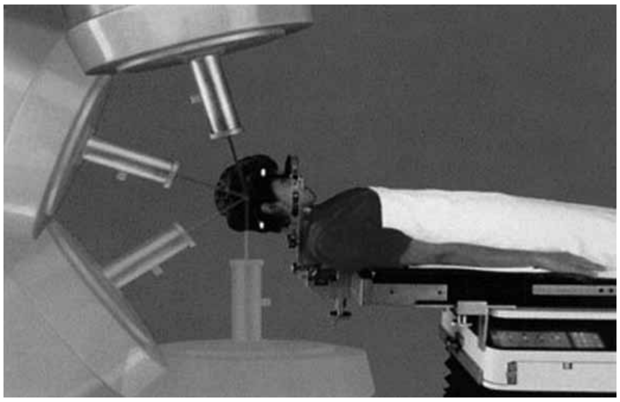

Figure 2. Installed circular cones on the linac head. The radiotherapist is measuring depths using the Radionics Depth Helmet. It provides a quantitative check that the head is not moved relative to the head ring between CT scanning and LINAC treatment.

MATERIALS AND METHODS

Elekta "Synergy S" linear accelerator is a new generation of linacs intended to be used as a dedicated stereotactic radiosurgery/ radiotherapy machine (Elekta, England). Since 1986, circular collimators (Radionics Burlington, MA) have been installed in stereotactic radiotherapy centres. The stereotactic hardware includes a collimator housing, which is fixed to the base plate of the head of the linac, nineteen divergent collimators, a couch mount and different stereotactic frames. A set of 19 circular collimators from 5 mm to 50 mm in diameter at isocentre distance with 2.5 mm steps comes standard (figure 1). In the current work five circular cones with diameter 10-50 mm with 10 mm steps were used. The cones were inserted in a base plate mounted on the collimator head and were used for arc treatments. The collimator housing could easily be mounted to and removed from any linac with precise, reproducible alignment (figure 2). They are all conically molded for sharp penumbra and steel-jacketed for precise alignment.

The dosimetry equipments used in the present work was PinPoint chamber and a dose leader electrometer to obtain integrated readings. The PinPoint thimble chamber (PTW-Freiburg, Germany, type 31006) is a waterproof 0.015 cm cylindrical air chamber with a central electrode made of steel. The sensitive volume is 2mm in diameter and 5mm in length. When calibrated against a PTW Farmer chamber, the PinPoint chambers can be used for depth dose and absolute dose measurements. They have been especially designed for relative beam profile measurements for characterization of LINAC radiation fields where superior spatial resolution is desired e.g. in IORT, IMRT and stereotactic beams.

The Monte Carlo system BEAM/EGS4 (6, 7) was used to model the circular collimators as an accessory attached to "Synergy S" linear accelerator head and to simulate 6 MV photon beam. The component modules (CM) which were used in BEAM/EGS4 to model different sections of the linac head were SLABS for the target and back scatter plate, CONS3R for the primary collimator, FLATFILT for the flattening filter, CHAMBER for the monitor chamber, MIRROR for the mirror, PYRAMIDS for the Millstone collimator, MLCE for the beam modulator, JAWS for the fixed outer diaphragm, APPLICAT for clamp and CONS3R for the steel ring and FLATFILT for circular cones. Beam modulator is the multileaf collimator inside the head of "Synergy S" linac consisting of 80 independent leaves. It has a maximum opening of 16×21 cm^2 and 4 mm leaf width at the isocentre that should be positioned to define a 7.2×7.2 cm^2 field size to limit the leakage. So the only field-dependent part of the linac is the circular collimators.

An incident electron beam on the target with a peak energy of 6.5 MeV, and a Gaussian intensity distribution with a FWHM (full width half maximum) of 0.11 cm in displacement and 0.5 MeV in energy was chosen based on optimization procedure to determine a consistent set of simulation parameters [8]. EGS4 transport parameters ECUT and PCUT were set to 700 keV and 10 keV, respectively. To increase the speed of the simulation, directional bremsstrahlung splitting (DBS) and range rejection (ESAVE = 2 MeV) were enabled.

For phantom dose calculations the user code DOSXYZ was applied [9]. Phase space at source-surface distance SSD=95 cm was used to obtain off axis dose profiles in water phantom at isocentre level, that is at 5 cm depth and source-axis distance (SAD) of 100 cm. Also CHAMBER CM in BEAMnrc with phase space at SSD=98.5 cm was used to calculate PDDs. These parameters were also calculated for different circular cones. The voxel dimensions were adapted according to the expected dose gradients such as 0.5cm in the flat region of the profiles and 0.1 cm in the penumbra region. To obtain acceptable statistical variances all particles had to be re-used more than 100 times to gather 1E+08 particles in the phase space of circular collimator with 5 cm diameter. For smaller field size, fewer particles in phase space were needed to obtain the same statistical variances (better than 0.5%).

Percentage depth doses, off-axis dose profiles and dose penumbras (80-20%) results for circular cones with 1, 2, 3, 4 and 5 cm diameter at 5 cm depth in water and SSD of 95 in water were measured in a Wellhofer water tank (Scanditronix Wellhofer, Germany). Dawson method was applied for correction of chamber measured penumbra for Pin Point chamber [10]. All measured results were compared with the corresponding MC simulation results. The uncertainty in measurements was better than 0.5%.

RESULTS AND DISCUSSION

Energy fluency of the nominal 6 MV photon beam, as well as, the contaminant electrons and positrons were calculated using the BEAMDP code [11]. The energy spectra of photons, electrons and positrons per MeV per incident particle for a 5cm circular collimator field at SSD=95 cm on the phantom surface in air are illustrated in figure 3. Annular areas with diameter of 2 cm were selected from the phase space. Electrons and

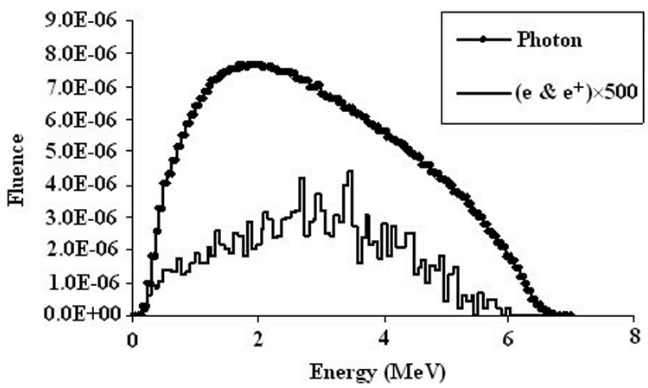

Figure 3. The photon, electron and positron energy spectra /MeV/ incident particle for a circular cone with 5 cm in diameter. Electrons and positrons spectra are multiplied by 500 to be shown on the same graph as for the photon spectra.

positrons spectra were multiplied by 500 to be shown on the same graph as for the photon spectra. The spectrum of contaminant electrons had a similar shape to that of primary photons. This is similar to what has been reported earlier for nine photon beams from different commercial medical linear accelerators of three major manufacturers (12). As seen in figure 3, the energy spectra of incident photons as well as positron and electron peak is at about 2 MeV. The counts per incident electron on the target for photons were about 1000 times more than those of contaminant electrons and positrons. It is well known that the various components of the accelerator's treatment head act as sources of electron contamination. The interaction of the bremsstrahlung beam with the mechanical parts of the linac and the air below the linac head produces a continuous electron spectrum. Their contribution depends on the photon energy and the material of the component (13). The cones are mostly made of Cerroband. Not having high atomic number, the contribution of electron contamination produced by circular collimators, is a small portion of spectrum. Verhaegen *et al.* (1998) (1) performed a full simulation of a dedicated Clinac-600SR Radio-surgery accelerator. Exchangeable field defining cones were inserted in the jaw replacing collimator to define fields from 12.5 to 50 mm. The EGS4/BEAM code was used to simulate this accelerator set-up. Average energies at dmax were found to vary between 2.05 MeV for the 5 mm cone to 1.65 MeV for the 5 cm cone (1).

Measured and MC calculated percentage depth doses for circular cones with diameter 2 cm and 5 cm are compared in figure 4. From this figure, it is clear that there is very good agreement between calculated and measured depth doses (within 0.5%). Heydarian *et al.* (1996) (14) performed EGS4 Monte Carlo dose calculations for Stereotactic radiosurgery (SRS) fields of Siemens Mevatron KD-2 linac at 6 MV. The linear accelerator equipped with stereotactic collimator. For 3×3 cm^2 field, where lateral electronic equilibrium still

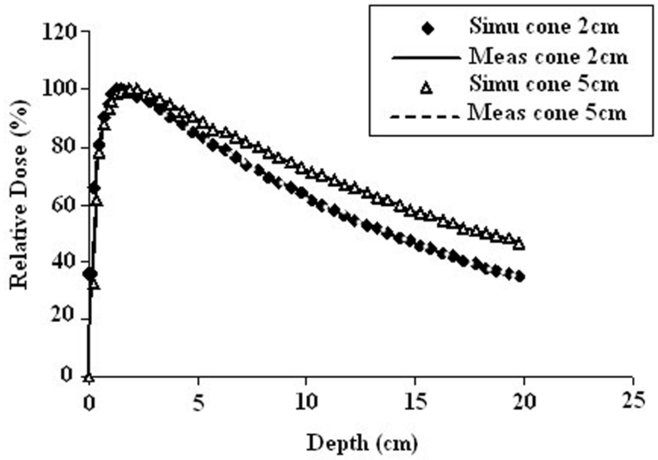

Figure 4. Comparison of calculated and measured percentage depth dose in water for 6MV photon beams of circular collimators with diameter 2 and 5 cm. The graphs are normalized to max dose depth (1.5 cm).

exists at the central axis, and thus the ionization chamber still gives a reliable result, they obtained very good agreement between calculation and ionization chamber measurement for percentage depth dose but comparison of depth doses for a 0.5×0.5 cm^2 field showed the ionization chamber cannot be used for measuring small-field depth doses because the sensitive volume of the ionization chamber (0.125 cm^3) was larger than the beam so it showed larger readings. In the current work, PinPoint chamber with very small sensitive volume (0.015 cm^3) was used for measurement in small fields. So we could get good agreements between calculation and measurement even in small fields that lateral electronic equilibrium doesn't exists at the central axis.

A comparison of the measured and calculated profiles for circular cones with 1, 2, 3, 4 and 5 cm diameter at 5 cm depth in water and SSD=95 are shown in figure 5. Very good agreement within 0.5% or 1mm for all of the cones between calculated and measured profiles with the Pin Point chamber detector was achieved. For circular cones with diameter 3 cm (where lateral electronic equilibrium still exists at the central axis) and also larger diameters, the Pin Point chamber gives more reliable results, so that the measured and calculated profiles agree in penumbra region better than 1 mm. The voxel resolution in the penumbra region was 1 mm for MC calculations and less than 0.5 mm for measurements.

The measured penumbra (80-20%) results for cones with 1-5 cm diameters at 5 cm depth in water phantom and SSD=95 cm are shown in figure 6 comparatively. The penumbra ranged from 1.5 to 2.1 mm for circular collimators with diameter 1 to 5 cm.

Heydarian *et al.* (1996) [14] obtained the penumbra width (20-80%) at the isocentre (SAD=100 cm, 6 cm deep) for 7 mm collimator 1.85, 2.45, 2.65 and 2.01 using diamond, diode, film and EGS4 (Monte Carlo code), respectively. Corresponding results for 23 mm collimator was 2.72, 3.50, 3.20 and 2.23 mm (at Siemens linac) [14]. We obtained penumbra (20-80%) width 1.5 and 1.8 mm for

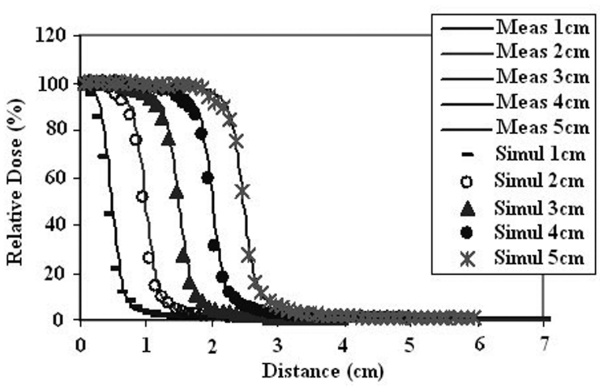

Figure 5. Comparison of calculated and measured lateral off-axis dose profiles for 6MV photon beams of circular collimators with 1,2,3,4 and 5 cm diameter at 5 cm depth in water and SSD=95 (SAD=100 cm). The graphs are normalized to central axis.

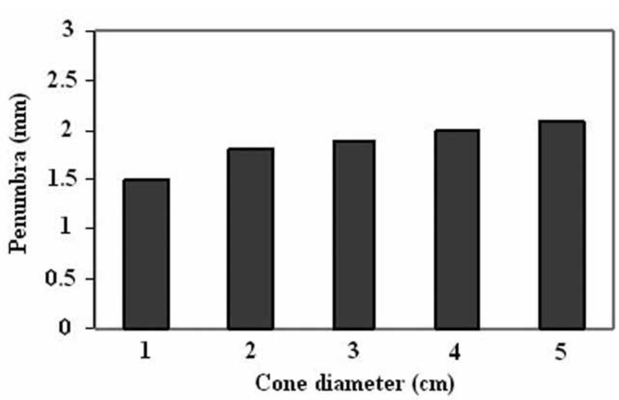

Figure 6. The Pin Point Chamber measured penumbra (20-80%) results for cones with 1, 2, 3, 4 and 5 cm diameters at 5 cm depth in water phantom and SSD=95 cm (SAD=100 cm), obtained from off-axis dose profiles of figure 5.

10 and 20 mm collimator respectively at SAD=100 cm, 5 cm depth using pinpoint chamber (at Elekta Synergy S linac)

The ion chamber 'broadens' the measured penumbra. This is related to volume averaging and the non-water equivalence of an air ion chamber. The combination of both is called 'volume effect'. Obviously, the measured penumbra broadening increases with decreasing penumbra width. For the smallest field sizes, the volume effect of the pinpoint chamber becomes more important.

The penumbra width that is measured with ionization chamber should be corrected considering inside diameter of the chamber. The pinpoint chamber measured broadening of the 20%-80% penumbra is less than 1 mm.

Comparisons of ionization chamber and PinPoint chamber measurements showed that the size of the air cavity to be the most important aspect for detectors with an air cavity. The larger the size of the air cavity, the more the lateral electronic disequilibrium would be, and a lower dose would be obtained for the air within the cavity compared to the case with tissue (water) at the same position. Larger air cavities may further reduce the relative dose reading of detectors. Moreover, the relative dose reading of the detector was also reduced because the detector averages the dose across its sensitive volume [15]. So, pin point chamber is much more suitable for measurement in small fields of circular cones than ionization chamber.

Due to the central steel electrode, the PinPoint chamber over-responds to low-energy Compton scatter analogously to radiographic film. These lead to an increasing sensitivity with field size and depth and the effect is more dominant for lower photon energies. Therefore, the output at 5 cm depth in a 5×5 cm^2 field has been recommended as reference for output factor measurements in a 6 MV photon beam [3].

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