Rep Pract Oncol Radiother, 2006; 11(6): 287-292

Original Paper

Received: 2006.04.24
Accepted: 2006.11.20
Published: 2006.12.22

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Monte Carlo study of electron dose distributions produced by the elekta precise linear accelerator

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Summary

Background Monte Carlo simulation of radiation transport is considered to be one of the most accurate methods of radiation therapy dose calculation and has ability to reduce the uncertainty in the calculated dose to a few percent.

Aims (1) To study the efficacy of the MCNP4C Monte Carlo code to simulate the dose distribution in a homogeneous medium produced by electron beams from the Elekta Precise linear accelerator. (2) To quantify the effect of introduction of various components to the simulated geometry for the above machine.

Materials/Methods Full Monte Carlo simulation of the detailed geometry of the Precise treatment head for 8 and 15MeV energies and 10×10 applicator was performed. Experimental depth dose and lateral profiles at 2cm depth were measured using a P-type diode detector with a 2.5mm diameter. To quantify the effects of different parts of the treatment head, seven cases were simulated for a 15MeV beam to reflect increasing levels of complexity, by step-wise introduction of beam divergence, primary and secondary scattering foils, secondary collimators, applicator, Mirror and Mylar screen.

Results The discrepancy between measured and calculated data is within 2%/2mm at both 8 and 15MeV. In terms of the mean and most probable energies at the surface, the difference was <0.2MeV for the majority of cases and the maximum deviation was no more than 0.3MeV.

Conclusions The results obtained with MCNP4C agree well with measured electron dose distributions. Inclusion of all the main components of the treatment head in the simulated geometry is necessary to avoid discrepancies of about 5% compared to measurements.

Key words **absorbed dose • electron dose distribution • Monte Carlo • dosimetry**

Full-text PDF: http:/www.rpor.pl/pdf.php?MAN=9886

Word count: 1850
Tables: 3
Figures: 6
References: 22

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Background

Monte Carlo simulation of radiation transport is one of the most accurate methods for calculating absorbed dose distribution in radiotherapy and has the ability to reduce the uncertainty in the calculated dose to a few percent [1,2]. MCNP is a general-purpose Monte Carlo code for simulation of neutron, photon and electron or coupled neutron/photon/electron transport. This code is based on ETRAN/ITS codes [3,4]. There are several differences in electron transport between MCNP and EGS based codes. These differences are secondary electron creation, the multiple scattering theory and the cross sections used. The first difference is how they treat the creation of secondary electrons. MCNP uses a class I algorithm (for collisional energy loss), where the energy losses and angular deflections associated with all individual events are grouped together and the energy and direction of the primary electron are not affected by the creation of individual secondary particles. Another important difference between MCNP and EGS4 is the scattering theory used to calculate elastic scattering angular deflections of an electron. MCNP (ETRAN/ITS) uses the Goudsmit-Saunderson theory, which is valid for arbitrary angular deflections [5].

Today, through the development of computer technology, Monte Carlo methods can be used in dosimetry and treatment planning systems [6,7]. The dosimetric parameters of linear accelerator (Linac) electron beams can be used to describe the central axis percentage depth dose (PDD) and beam profiles at specific planes. The parameters of electron beams produced by linacs show differences between manufacturers [8]. Differences mainly involve different designs of the linac head. These variations can be seen even in linacs produced by the same manufacturer. Therefore, for each machine these parameters must be defined separately. The Precise machine is a product of Elekta Oncology Systems.

There have been many studies on the application of Monte Carlo techniques in simulation and defining the electron beam characteristics. Andro et al. [9] studied the influence of energy and angular spread on the depth dependence of the stopping power ratio for clinical electron beams. Udale [10] simulated a 10MeV electron beam from a Philips SL75-20 accelerator and studied the influence of head components on electron beams. In another work [11], the same author compared the electron beam parameters for three Philips linear accelerators (SL75-20, SL75-14N and SL15). The main improvement of the latter two machines over the SL75/20 was using dual scattering foils instead of a single scattering foil. Kassaee et al. [12] investigated the electron beam characteristics for different applicator cone designs by using the ITS Monte Carlo code. They investigated the effects of scattering foils, primary photon collimator and cone applicator on the energy spectrum of a clinical linear accelerator. Rogers et al. [13] carried out a detailed study on the Clinac 2100C linear accelerator using the BEAM code and also compared dose distributions and energy spectra in a water phantom for five linear accelerators. Ebert and Hoban [14] used EGS4 code for studying the effects of electron beam cones and cerroband cutouts on clinical electron beams. Kapur et al. [15] using the BEAM code calculated and analysed the output factors for radiotherapy electron beams. Sempau et al. [16] simulated the Siemens Mevatron KDS linac for three energies (6, 12, 18MeV) using the PENELOPE Monte Carlo code. Central axis depth dose and beam profiles in water were investigated in this study. Antolak et al. [17] used the BEAM code for commissioning of electron beams for a medical linear accelerator.

Aim

The purpose of this work was to study the properties of electron beams in the Elekta Precise machine and evaluate MCNP4C Monte Carlo code

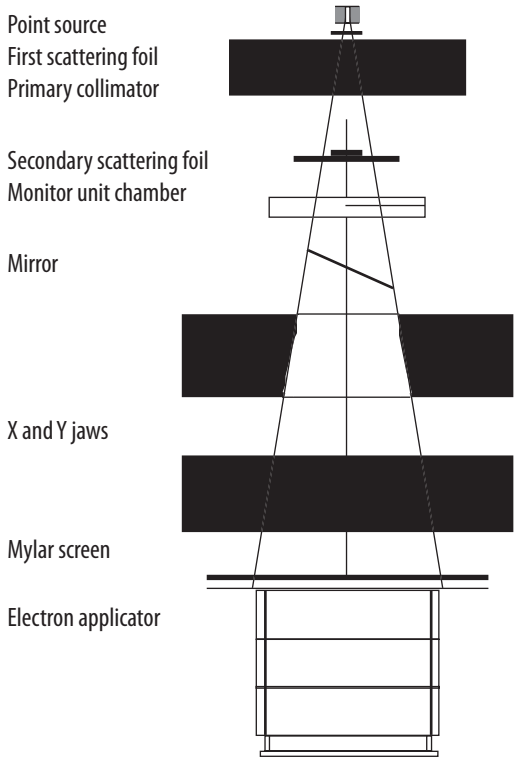

Figure 1. Schematic diagram of the Elekta Precise treatment head.

efficacy as an alternative approach for electron beam specification.

Materials and Methods

The head of the Elekta Precise machine for electron mode has an exit window, primary scattering foil, primary collimator, secondary scattering foil, monitor unit chamber, mirror, X and Y jaws and electron applicator. The applicator includes four scrapers. Figure 1 shows a schematic of the head and an applicator.

MCNP4C Monte Carlo code was used to model the head. The detailed geometry of the treatment head according to the manufacturer's data was used to perform a full Monte Carlo simulation. Two energies (8, 15MeV) and one applicator (10×10) were simulated in this work because of the relevance of these energies in electron beam therapy and the fact that two different scattering foils are used by the linac at the two energies. For scoring the central axis absorbed dose, a cylinder of 2cm diameter in the middle of a water tank of dimensions $20\times20\times10cm^3$ was also modelled. This geometry uses the geometry-equivalence or reciprocity theorem [18] to offer better variance reduction and therefore speed improvements. The smaller cylinder was divided into 50 slabs of 0.2cm thickness to show detail in the build-up region. The electron energy cut-off was 50keV, while photons were transported down to energy of 10keV [Cut: P]. For each energy, in addition to the central axis absorbed dose, the beam profile at a depth of 2cm was also calculated. Simulations were performed using the ITS indexing algorithm mode due to its improved performance compared to the default indexing [19]. A statistical uncertainty of <2% was considered acceptable. Simulations ran on Windows XP OS on a personal computer with a 2.8 GHz CPU and 256 MB RAM.

Depth doses and profiles were measured at a 100cm source-to-surface distance (SSD) in a $50\times50\times50cm^3$ PTW water phantom using a P-type diode detector of 2.5mm diameter. Both depth dose and profile measurements were made at 1mm intervals.

In order to see the effects of different parts of the treatment head on the beam, seven cases (denoted by cases A to G) were simulated for a 15MeV electron beam to reflect increasing levels of complexity. An additional part of the beam defining system was introduced into the simulation in each successive case. In case A, a monoenergetic pencil beam was incident directly on the phantom. In case B, a mononergetic beam with a 1° downward distribution at 100cm from the phantom was used and the effect of intervening air was simulated. In case C, the degree of divergence was increased to 27° corresponding to the real angle between primary collimators. Further parts were added in turn for the remaining cases. 'Full component' includes the mylar screen and mirror in addition to the other components in case G.

Results

The calculated data were compared to measurements. The results are summarized below. Figures 2 and 3 show measured and calculated percentage depth dose curves for 8 and 15MeV electron beams. Cross beam profiles at 2cm deep are shown in Figures 4 and 5 for those energies. The PDDs are normalized to the maximum dose point and beam profiles are normalized at 2cm deep on the central axis. Computer run times were 65 and 75 hours for PDDs and profiles respectively.

Tables 1 and 2 show the difference between measured and calculated dose in PDDs and profiles

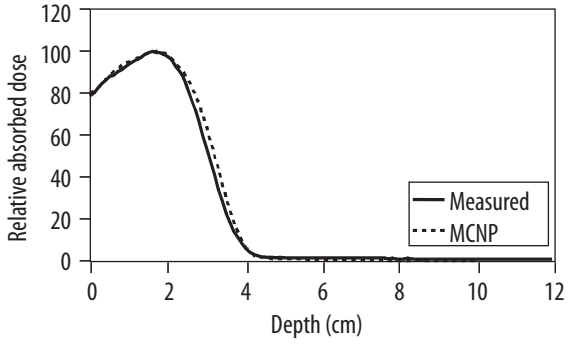

Figure 2. PDD for an 8MeV electron beam.

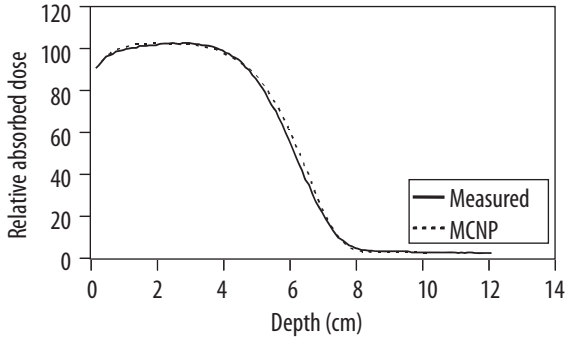

Figure 3. PDD for a 15MeV electron beam.

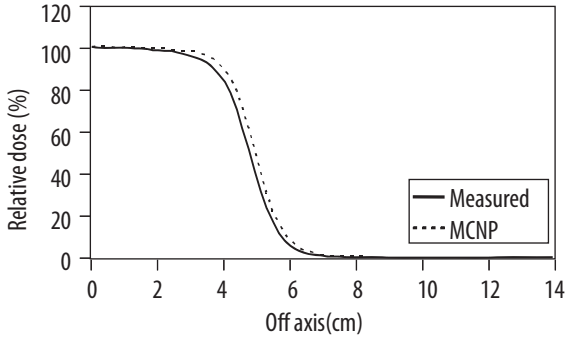

Figure 4. Beam profiles for an 8MeV electron beam (one half displayed).

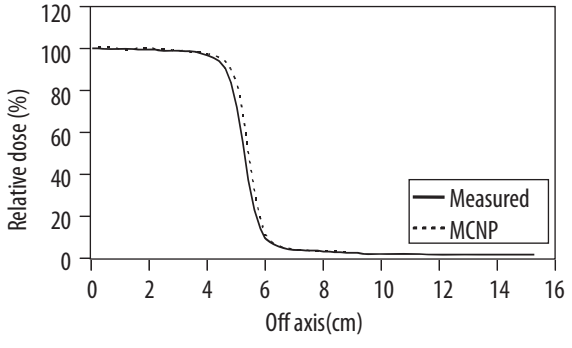

Figure 5. Beam profiles for a 15 MeV electron beam (one half displayed).

Table 1. Differences for measured and calculated PDD.

Energy (MeV)	Differences up to D_{max} %	Differences at D_{max} (mm)	Differences at 50% depth (mm)	Differences at Bremesstralung tail %
8	within 1.2	0.0	1.7	0.4
15	within 1.0	1.0	1.8	0.6

Table 2. Differences for measured and calculated beam profile.

Energy (MeV)	Differences at flat area %	Differences at 50% depth (mm)	Differences at Bremesstralung tail %
8	within 1.0	1.8	0.2
15	within 0.7	1.2	0.1

Table 3. Electron beam energy parameters calculated using the AAPM Task Group 25 method.

Nominal beam energy (MeV)	E_0 (MeV) TG 25		$E_{p,0}$ (MeV) TG 25	
	Calculated	Measured	Calculated	Measured
8	7.2	7.4	8.2	8.1
15	14.2	13.8	15.4	15.3

for both energies. The discrepancies between measured and calculated data are within 2% of D_{max} and within 2mm in high-gradient regions for both 8 and 15MeV energies.

Table 3 shows mean energy at surface, E_0, and the most probable energy at surface, Ep_0, calculated using the AAPM Task Group 25 (TG 25) method [20] for both measured and calculated results:

$$E_0=2.33\ R_{50}$$

$$E_{p,0}=0.22 + 1.98Rp + 0.0025Rp^2$$

where Rp is the practical range. The difference is <0.2MeV for the majority of cases and the maximum deviation is no more than 0.3MeV.

Figure 6 shows the PDD graphs for different cases in the study of the effect of different components on PDD. It can be seen that exclusion of different physical components (such as jaws, collimators, etc) from the simulated geometry in general produces a substantial increase in PDD which would constitute a large error in the results.

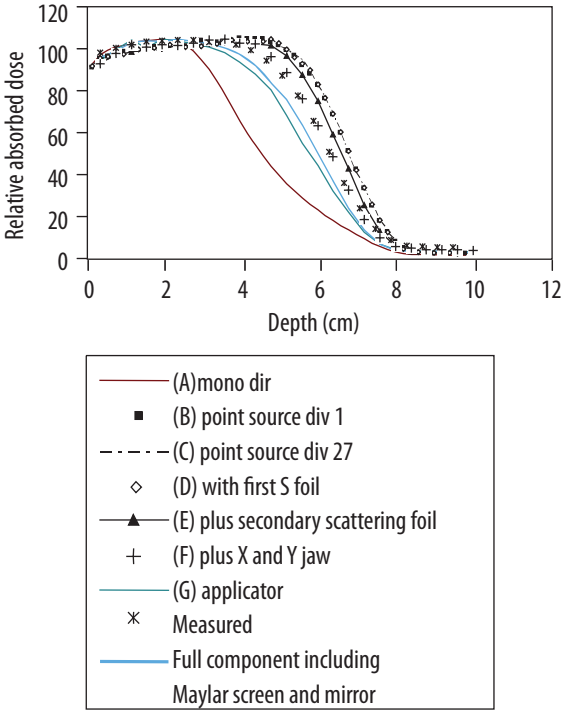

Figure 6. The effects of different simulation components on a 15MeV electron beam PDD.

Discussion and Conclusions

In comparison of MCNP results with experimental measurements, good agreements were found in a homogeneous phantom. A 2%/2mm criterion (including both systematic and statistical uncertainty) has been used in the commissioning of Monte Carlo based dose calculations [21,22]. In our study, discrepancies in both energies were within 2% and within 2mm in a homogeneous phantom. The results obtained with MCNP4C agree well with measured electron radiation dose distributions. This combined with its user friendliness and ability to handle complex geometries makes MCNP4C an attractive code for electron transport calculations.

In terms of the effects of different components, transport of electrons is dominated by the long-range Coulomb force, resulting in large numbers of small interactions. This great increase in computational complexity makes the dose distribution of electron beams more sensitive to collimation than photon beams, because of scatter of the primary electron off the scattering foils, jaws and collimating system as well as the creation of contamination electrons there. Besides scattered primary electrons and high-energy secondary electrons coming from the treatment head, there is another external source of dose to the patient other than the idealized primary beam. Bremsstralung from the treatment components especially from the scattering foils can affect the dose. As can be seen from the results, there is no significant difference between 1° and 27° beam divergence on depth dose but the monodirectional beam shows a very large difference to them. The primary scattering foil showed no significant effect on bremsstralung tail. The reason may be the very small thickness of the scattering foil (0.1–1mm) and the large distance from the phantom surface. In contrast to the primary scattering foil, the secondary scattering foil, X and Y jaws and electron applicator affect the dose by as much as 5% of the maximum dose.

There are still two limitations in the application of MCNP to routine dose distribution calculation in the clinic. The first is the length of the run time. Required time for obtaining acceptable results in this study ranged from 65 to 75 hours in a homogeneous phantom. The second problem is the required hard drive space for storing the RUNTPE file and, in the case of the phase space file, the W file. For application of MCNP in clinics, one should consider the number of calculations and required statistical uncertainties, and

also the geometry. If a high degree of accuracy is required in using MCNP, one needs to take the following into account:

a. The ITS energy indexing algorithm has to be used, since the default indexing method is not consistent with the definition of the energy groups, energy bins and their boundaries, which leads to significant errors.
b. If the *f8 tally is used, tally segmentation is not available and a high spatial resolution cannot be achieved without compromising the accuracy of the calculation.

Because of the low electron and photon energy cut off, the calculated times were long, but by using optimal variance reduction (Weighting, Russian Roulette, …) and phase space file the length of the run time can be reduced.

Our results provide further evidence that, in the application of Monte Carlo codes in electron radiotherapy, the MCNP code can be used as a good and reliable predictor of the dose distribution in homogeneous media. Work is in progress to further evaluate the efficacy of MCNP4C in heterogeneous phantoms.

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