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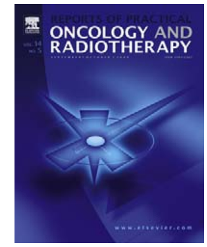

Original article

Verification in the water phantom of the irradiation time calculation done by the algorithm used in intraoperative radiotherapy

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ABSTRACT

Aim: The investigation of the irradiation time calculation accuracy of the GGPB algorithm used for IORT.
Background: Conventionally, breast conserving therapy consists of breast conserving surgery followed by postoperative whole breast irradiation and boost. The use of intraoperative radiotherapy (IORT) enables the boost to be delivered already during the surgery. In this case, the treatment dose for IORT can be calculated by use of General Gaussian Pencil Beam (GGPB) algorithm, which is implemented in TPS Eclipse.
Materials and methods: PDDs and OFs for electron beams from Mobetron and all available applicators were measured in order to configure the GGPB algorithm. Afterwards, the irradiation times for the prescribed dose of 3 Gy were calculated by means of it. The results of calculations were verified in the water phantom using the Marcus ionization chamber.
Results: The results differed between energies. For 6 MeV the irradiation times calculated by the GGPB algorithm were correct, for the energy of 9 MeV they were too small and for the energy of 4 MeV they were too large for applicators with smaller diameters, while acceptable for the remaining ones.
Conclusion: The GGPB algorithm can be used in intraoperative radiotherapy for energy and applicator sets for which no significant difference between the measured and the prescribed dose was obtained. For the rest of energy-applicator sets the configuration should be verified and possibly repeated.

1. Background

Currently, 60–75% of all breast cancer cases are treated with breast conserving therapy (BCT).[1] The rationale for this therapy is that regardless of the tumor the majority (up to 90%[2]) of the microscopic foci are located only in the vicinity of the initial lesions in the thoracic gland.[2–7] In practice, it is a combination of breast conserving surgery and whole breast irradiation (WBI). The prescribed dose is 50–55 Gy, given in fractions during 5–6 weeks. WBI is often followed by a boost to the tumor bed, which reduces recurrence risk by 40%.[8] In the paper by Sas-Korczynska et al., different techniques of postoperative irradiation within breast conserving therapy

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were described and compared.[9] When intraoperative radiotherapy (IORT) is used, the external boost is replaced by intraoperative boost. That kind of treatment minimizes the geographical error and reduces dose in adjacent tissues, such as the myocardium and the lung.

The modern IORT was initiated in 1965 by M. Abe at Kyoto University, Japan.[10,11] The breakthrough in this method was the development of dedicated mobile linear accelerators such as Mobetron. Mobetrons have been produced since 1990s by IntraOp Medical, Inc.[17] Due to the development of that kind of medical machines, it is possible to apply the whole dose of radiation during the surgery and in the operating room.

The irradiation time in IORT is usually determined manually on the basis of tabulated data which describe dose distribution according to the energy, field size and depth. It is a duty of a medical physicist to find such beam parameters that the dose distribution fits best with the dose prescribed by a radiation oncologist. It is crucial to avoid any failure. Additionally, there is usually more than one possibility of choosing the beam parameters to provide an acceptable solution. Likewise, time needed for this procedure is a relevant factor. Therefore, the automation of irradiation time calculation is essential. Results calculated automatically are more reliable as well as easier and faster to obtain.

One of the possibilities is to use the Generalized Gaussian Pencil Beam (GGPB) algorithm implemented in Treatment Planning System Eclipse by Varian Medical Systems Inc. It calculates the three-dimensional dose distribution of electrons in the irradiated medium and the exposure time in which the medium will receive the prescribed dose.

2. Aim

The aim of this paper was to verify in the water phantom the accuracy of the irradiation time calculation done by the Generalized Gaussian Pencil Beam algorithm used in intraoperative radiotherapy for electrons with energies of 4 MeV, 6 MeV and 9 MeV generated by a dedicated Mobetron, and field sizes with diameters from 3 cm to 10 cm.

3. Materials and methods

3.1. *Generalized Gaussian Pencil Beam algorithm*

The Generalized Gaussian Pencil Beam algorithm, implemented in Treatment Planning System Eclipse by Varian Medical Systems Inc. calculates the three-dimensional dose distribution of electrons in the irradiated medium and the exposure time in which the medium will receive the prescribed dose.[13]

Treatment planning systems calculate the irradiation time for given parameters of the beam and the radiation field to achieve the desired dose in tissue. The TPS Eclipse provides a package of several algorithms which calculate the dose distribution and irradiation time. One of them is the GGPB algorithm which was designed for electron beams. Its three-dimensional dose distribution calculation is based on the Fermi-Eyges electron multiple scattering theory and is the sum of three Gaussian functions. The algorithm calculates the dose for irregular fields with arbitrary orientations and collimator rotation angles. It takes into account inhomogeneity of the medium, the radiation scattered in the air and the contribution from bremsstrahlung. The accuracy of the calculations in a heterogeneous medium is ±5% or ±5 mm.[13]

The GGPB algorithm configuration for IORT requires measuring and introducing to the system the following data for each set of used energy and applicator:

- applicator-specific depth dose curves (PDD),
- output factors (OFs) which are doses measured at the depth of the maximum dose depth normalized to the result for the 10 cm applicator,
- electron mean energy derived from PDD,
- normalization factors which ensure that for the calculated dose distribution the dose at the depth of maximum dose is 100%.[13]

3.2. *Dedicated Mobetron*

Electrons were generated by a Mobetron dedicated to intraoperative radiotherapy, made by IntraOp Medical, Inc. This device accelerates electrons to nominal energies of 4 MeV, 6 MeV, 9 MeV and 12 MeV and emits them with low or high dose rate, 250 MU/min or 1000 MU/min, respectively. Electrons are collimated in an applicator which is placed between the accelerator's treatment head and a patient, 4 cm below the treatment head. There are 15 applicators available with diameters ranging from 3 cm to 10 cm and with the increment of 0.5.[14] Applicators have a triple function. They collimate the radiation, determine the radiation field and keep healthy tissues and skin out of the radiation field.[15]

A Mobetron consists of three parts: treatment module, modulator and operators control console. The control console is used for remote control of the beam during IORT. Programming the console means choosing all parameters of the electron beam: nominal energy, irradiation time and dose rate. In addition, before accepting all parameters and confirming the beam on setup, it is possible to watch the patient on the screen at the console, as the beam eye view color video from the integrated camera is placed in the treatment head. The accelerator can be also operated from the modulator. This option, however, applies only to dosimetry, calibration and measurements made to verify and repair the equipment. It should be pointed out that while operating the radiation from the modulator some parts of the beam automatic corrections are disabled.

3.3. *Verification of the GGPB*

According to the International Atomic Energy Agency TRS 398 report, the dose in water for high energy electron beam with quality Q is obtained by applying the formula (1)

$$D_{w,Q} = M_Q N_{D,W,Q_0} k_{Q,Q_0} \quad (1)$$

where M_Q is the reading of a dosimeter corrected for the influence quantities such as temperature and pressure, electrometer calibration, polarity effect and ion recombination. N_{D,w,Q_0} is a calibration factor in terms of absorbed dose to