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A Monte Carlo study on dose distribution validation of GZP6 ^{60}Co stepping source

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ABSTRACT

Aim: Stepping source in brachytherapy systems is used to treat a target lesion longer than the effective treatment length of the source. Cancerous lesions in the cervix, esophagus and rectum are examples of such a target lesion.
Background: In this study, the stepping source of a GZP6 afterloading intracavitary brachytherapy unit was simulated using Monte Carlo (MC) simulation and the results were used for the validation of the GZP6 treatment planning system (TPS).
Materials and methods: The stepping source was simulated using MCNPX Monte Carlo code. Dose distributions in the longitudinal plane were obtained by using a matrix shift method for esophageal tumor lengths of 8 and 10 cm. A mesh tally has been employed for the absorbed dose calculation in a cylindrical water phantom. A total of 5×10^8 photon histories were scored and the MC statistical error obtained was at the range of 0.008–3.5%, an average of 0.2%.
Results: The acquired MC and TPS isodose curves were compared and it was shown that the dose distributions in the longitudinal plane were relatively coincidental. In the transverse direction, a maximum dose difference of 7% and 5% was observed for tumor lengths of 8 and 10 cm, respectively.
Conclusion: Considering that the certified source activity is given with ±10% uncertainty, the obtained difference is reasonable. It can be concluded that the accuracy of the dose distributions produced by GZP6 TPS for the stepping source is acceptable for its clinical applications.

1. Background

Brachytherapy is a method of treatment in which sealed radioactive sources are used to deliver radiation to tumor at a short distance through interstitial, intracavitary or surface applications.[1] Although not as widespread as ^{192}Ir sources, ^{60}Co is also available on afterloading equipment dedicated to high dose rate (HDR) brachytherapy.[2] In modern brachytherapy, treatment planning is performed to define a planning

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target volume (PTV) and to spare adjacent critical structures. Optimization procedure in the determination of the treatment parameters is usually to minimize the variations of the dose values on the surface of the PTV. This aim is achieved by defining a number of points on the PTV surface and determining dwell times (dwell weights) for the source dwell positions within the applicators. For this purpose, stepping sources are used as an option and are loaded in the applicator.[3] Several Monte Carlo methods have been employed to assess the absorbed dose near brachytherapy stepping sources.[4–7] Also there are other Monte Carlo based studies in which dose distributions were calculated around non stepping brachytherapy sources.[8,9] Since the treatment planning process is very important in assuring an optimum treatment in brachytherapy the determination of dose distribution becomes an important task. Therefore, it is necessary to know the extent of dosimetric errors including over- or under-dosage of the target volume.[7] The quality control of treatment planning has been the subject of several studies, and was reviewed in the report by task group (TG) number 59 of the American Association of Physicists in Medicine (AAPM).[10] There are different studies which have already been performed on the GZP6 unit. Bahreyni et al. evaluated air kerma strength for the GZP6 source no. 3 certified by GZP6 unit through in-air measurements and Monte Carlo simulations of this source.[11] Mesbahi performed a Monte Carlo study on calculation of radial dose function for the GZP6 sources nos. 1, 2 and 5.[12] Naseri and Mesbahi in another study simulated the three mentioned GZP6 sources and verified dose distributions for the three sources based on comparisons of the dose distributions obtained from Monte Carlo method by those from GZP6 treatment planning system.[13] As another study, they measured air kerma strength for the three mentioned GZP6 sources.[14] In a previous work by Bahreyni et al. a matrix shift method was developed toward simulation of stepping movement of the GZP6 source no. 6.[15]

2. Aim

As far as we are aware, at the current time there is no published report on the verification of dose distributions using the GZP6 treatment planning system for the stepping source (source no. 6). In this study, the dose distributions calculated by the GZP6 treatment planning system for the stepping source were evaluated using Monte Carlo simulation and the application of a matrix shift method.

3. Materials and methods

3.1. GZP6 stepping source

GZP6 afterloading unit (manufactured by the Nuclear Power Institute of China) has six ^{60}Co source braids including one stepping and five non-stepping source braids. It is used for intracavitary treatments such as brachytherapy of cervix, rectum, esophagus and nasopharynx malignancies. The GZP6 stepping source consists of a ^{60}Co active cylinder with diameters of 2 mm and 1 mm. The source has a very thin nickel plating which is covered by a titanium capsule. The overall length of the titanium capsule is 3.5 mm and its outer

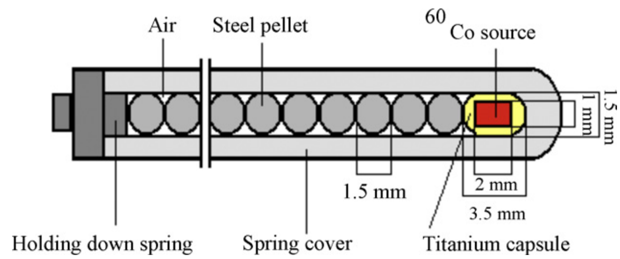

Fig. 1 – A schematic diagram illustrating the stepping source of the GZP6 brachytherapy unit.

diameter is 1.5 mm. There are a number of inactive steel pellets in the source braid with a diameter of 1.5 mm. The active and non-active pellets are covered by a steel spring. A schematic representation of the GZP6 stepping source is illustrated in Fig. 1.

3.2. Treatment planning

GZP6 unit is composed of an afterloading system as well as a treatment planning system. The name of the TPS is GZP6 treatment planning system. This planning system displays dose distribution in the form of isodose curves for the GZP6 sources. The treatment planning system uses Sievert integral for its dose calculations. In the Sievert integral method, a linear source is divided into several segments. Each segment is small enough to be assumed as a point source. Using point source approximation, the integration of the exposure rate contributions from each segment to a given point is then calculated. The following equation represents a classical Sievert integral:

$$I(x, y) = \frac{\mathrm{Meq} \cdot \Gamma_{\mathrm{Ra}}}{Ly} e^{\mu t'} \int_{\theta_1}^{\theta_2} e^{-\mu t \sec\theta'} d\theta' \quad (1)$$

In which, Meq is total source strength (mg Ra Eq); Γ_{Ra} is exposure rate constant of ^{226}Ra source, with 0.5 mm of platinum filter. L is the active length of the source; μ' is effective attenuation coefficient of the source capsule; and t is thickness of the source capsule.

When the source strength is specified in terms of air kerma strength (S_K), Eq. (1) will be changed to the following one[16]:

$$I(x, y) = \frac{S_K}{Ly(W/e)} e^{\mu t'} \int_{\theta_1}^{\theta_2} e^{-\mu t \sec\theta'} d\theta' \quad (2)$$

Esophagus and cervical cancer treatments are being performed in our center using the GZP6 stepping source. The main difference between the dose distributions used in the treatment of esophagus and cervical cancer is related to the difference in the material used in their applicators. The applicator used for treating esophageal cancer is made of plastic while the one used for cervical cancer is of stainless steel. In the present study, the dose distributions were only obtained in the longitudinal plane for the treatment of esophageal cancer by GZP6 treatment planning system. The obtained dose distributions from the GZP6 treatment planning system are based on a dose value of 5 Gy prescribed to the point 0, 0, 1 cm