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Breastdosimetry of ^{99m}Tc-balloon in complementary radiotherapy

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HIGHLIGHTS

- Breast dosimetry of ^{99m}tc-balloon modality.
- Complementary radiotherapy for breast cancer.
- Boost dose application in breast cancer.

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ABSTRACT

Dose reinforcement in primary tumor cavity can complement conventional radiotherapy in patients with early breast cancer. In this study, a dosimetric analysis was conducted by pertechnetate-^{99m}Tc-filled balloon brachytherapy (TBB).

Methods: Dosimetry based on radiochromic films and on a computational voxel thorax model was performed. Calibration protocol achieved a mathematical relationship between dose and optical density in films placed on the surface at a distance of 0–9 cm, 1 cm between them, in which dose values were provided by MCNP® code. Moreover, experimental spatial dose distribution was prepared. A female thorax voxel model was developed in the SISCODES®/MCNP® codes. Additionally, experimental and computational doses at 8–10 mm from balloon surface were compared.

Results: Dose from ^{99m}Tc-balloon, with 16 mm diameter, 32.22 GBq activity, and 24 h exposure time, achieved 8.08 ± 0.42 (Ue) and 8.82 ± 1.76 (Ue) Gy, at a distance of 10 mm from the balloon surface for the experimental data and computational modeling, respectively, thus showing nonsignificant difference. The spatial dose distribution in the chest wall, glandular tissue, breast skin, and lung was presented. The dosimetric findings supported the TBB modality presenting a suitable spatial dose distribution in the tumor bed and preserving the adjacent health tissues.

Conclusion: TBB is a viable adjuvant brachytherapy modality for breast cancer in patients who have an appropriate indication.

1. Introduction

In this study, dosimetry of a reinforcement radiotherapy is addressed in a breast neoplastic site by using a temporary implant of a balloon filled with sodium pertechnetate ^{99m}Tc ($NaTcO_4^-$), a gamma emitter, placed at the tumor bed in patients with an appropriate indication. The aim of this study is to show that sodium pertechnetate ^{99m}Tc($NaTcO_4^-$) balloon brachytherapy (TBB), which can be easily implemented in nuclear medical centers, can provide similar dose prescription at a region of interest equivalent to current standards of practice on breast reinforcement dose protocol, provided by Ir^{192} HDR balloon brachytherapy (BBB) and electronic brachytherapy (EBT). The originality of TBB for breast cancer is recognizable. The significance of the dosimetric study is to improve the quality of a future treatment and to verify patient safety.

1.1. Breast radiotherapy

Radiation therapy (RT) has already established its own clinical value in the treatment of breast cancer both in the early stages and in advanced disease. RT reduces loco-regional recurrence and

Abbreviations: HDR, High Dose Rate; BBB, HDR Ir-192 balloon brachytherapy; EBT, Electronic brachytherapy; TBB, Tc-99 m balloon brachytherapy; RT, Radiation therapy; SISCODES, Sistema Computacional de Cálculo de Dose por método Estocástico; MCNP, Monte Carlo N-Particle; MDR, Maximum dose rate; AAPM, American Association of Physicists in Medicine; ORIGEN, Computer program for interactive graphics and data analysis by OriginLab; RGB, Red, Green, Blue; CS, Computational simulation

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increases overall survival rate. The RT protocol is often applied in daily dose fractions of 1.8–2.0 Gy up to a total dose of 45–50 Gy over a period of 5 weeks. An additional local dose is often performed as reinforcement (boost) in primary tumor area, taken as 1.0–1.5 weeks (Scoenfeld and Harris, 2011). Moreover, reinforcement RT has become the standard care for early stages (I and II) of breast cancer.

1.2. Current standards of practice in complementary brachytherapy

EBT, an X-ray source in a plastic spherical applicator, and HDR Ir-192 BBB provide the current standard of practice on boost dose for breast cancer RT (Melhus et al., 2013). EBT allows performing accelerated partial breast irradiation with minimal shielding (Beitsch et al., 2010). EBT applies X-ray, often operated at a peak voltage < 50 kVp. Moreover, the EBT modality provides polyenergetic Bremsstrahlung X-ray spectra in contrary to a discreet photon spectra emitted by radioisotope sources such as Tc-99m or Ir-192. Intrabeam is an EBT system suitable for partial breast irradiation. The electronic probe is placed onto the interstitial breast tissue on the tumor bed. In the intracavitary treatment, low-energy photon attenuation, as a solid polyetherimide plastic sphere with diameter of 1.5–5.0 cm, covers the electron target sphere (Eaton and Duck, 2010). As dosimetric parameters, Beatty et al. (1996) described a water dose rate of 2.5×10^{-2} Gy s^{-1} at a depth of 1 cm from a 3-mm-diameter treatment probe operating at 40 kVp and 40 mA (Beatty et al., 1996). In the breast lumpectomy, Vaidya et al. (2006) reported a dose of 5–7 Gy at a depth of 1 cm for intraoperative radiotherapy with intrabeam (Vaidya et al., 2006). They also achieved surface doses of 18 and 20 Gy with spherical applicators of diameter 3.5 and 5.0 cm exposed to 25–38 min (Vaidya et al., 2006). Beitsch et al. (2010) reported a clinical trial with EBT (Beitsch et al., 2010). A prescribed radiation dose of 34 Gy was delivered in a postsurgical treatment of early-stage breast cancer in 10 fractions over 5 days with a fractional radiation dose of 3.4 Gy (Beitsch et al., 2010). Tuschy et al. (2013) pointed out two clinical conditions, which may disturb the dosimetric EBT plan applied to early-stage breast cancer, such as an insufficient tumor–skin distance and an oversized wound cavity. Further clinical reasons were unsuitable anatomical surgical conditions and ineligible histologic findings (Tuschy et al., 2013). Indeed, the American Association of Physicists in Medicine (AAPM) guidelines for EBT dosimetry prerequisites are under development (Melhus et al., 2013). In addition, BBB is applied to partial breast radiotherapy, performed by the *mammosite* device. It is a single catheter coupled with an inflated soft balloon of diameter 4–6 cm at its tip, in which a radioactive Ir-192 HDR source is inserted into and located at its center. It is a catheter with a balloon, in which the tip is placed in the lumpectomy cavity (Dickler et al., 2005). BBB takes several minutes to deliver the prescribed dose, about 20 min applied twice daily for 5 days, providing 34 Gy in 10 fractions. BBB is contraindicated in clinical situations in which the tumor bed is in an area of insufficient tissue covering (Ravi et al., 2011). In general, EBT and BBB follow the same prescription dose (Melhus et al., 2013). Despite the usefulness of ^{192}Ir HDR brachytherapy such as BBB, the installation of the high-activity ^{192}Ir-sealed source enclosed into automated after-loading equipment has become quite difficult because of the needs of importation of highly active radioactive source and a large number of radiation protection requirements. On the contrary, Tc-99m generator has been distributed weekly with easy access worldwide. Therefore, Tc-99m may be considered in the RT field; however, a question arises whether RT with Tc-99m may produce similar dosimetry to BBB or EBT protocols.

1.3. Experimental dose measurements and dosimetric simulations

Radiochromic films have currently been used to measure absorbed dose in RT protocols at phantoms for experimental dosimetry (Thompson et al., 2013). In addition, the RT dosimetry can be simulated on SISCODES®/MCNP® code. The SISCODES® code is a dosimetric computational tool to be used in RT planning (Trindade and Campos, 2011). It operates as a three-dimensional interface for the MCNP® code. This system enables simulating RT protocols by considering the heterogeneity of the anatomical and morphological structures (Trindade and Campos, 2011). SISCODES® assists in the preparation of human voxel models and their conversion into the format used in the MCNPv5® code, as well as in the 3D representation of the dosimetry (Trindade and Campos, 2011).

2. Methods

2.1. Experimental setup and dosimeters

The radiation source was assembled with a commercial urological 3cc, size 2 FR, Silicone two-way Foley balloon catheter, pediatric, metal stylet, X-ray opaque line, and catheter spigot, filled with $Na^{99m}TcO_4^-$ in saline solution. $Na^{99m}TcO_4^-$ emits photons of 140 keV energy and a half-life of 6 h. The dosimeters were Gafchromic EBT2 films manufactured by International Specialty Products (ISP).

2.2. Calibration

A total of 10 films with dimension 1.5×0.8 cm were sealed and placed in a plastic support immersed in water, 1 cm away from each other, from the balloon surface up to a distance of 9 cm. A 5-mm^2 area was taken on each film to be analyzed. The guidance and direction of the films were the same during irradiation and digitalization. The set was numbered from the closest as 1–10. The radiochromic film response depends on ambient light exposition, temperature, and humidity. In the experiment, the film was manipulated in dark and at 25 °C ambient temperature. The films were immersed in water during the experiment, covered by a plastic pellicle, which was removed previous to digitalization. The activity of the 3.0-mL saline solution inserted in the silicon balloon was 23.384 GBq. Exposure time was 24 h, equivalent to four half-lives of the radioisotope.

2.3. Digitalization and digital image manipulation

The thin plastic covering the films was removed. They're digitalized on a HP Scanjet G4050 scanner in the transmitting mode. The digitalization was performed in 300 dpi and 48-bit RGB (red, green, and blue), without any color correction and adjustment. The digital images were analyzed using the reading of the intensity of the RGB components. ImageJ software was used to decompose each RGB image. The RGB value of each component was established in a band ranging from 0 to 255. The amount of absorbed dose was correlated to the intensity of the R-component on images.

2.4. Optical density

The mean levels of the R-component were used to calculate the optical densities (ODs) at the selected positions as follows:

$$d = log_{10}\frac{I_0}{I}, \quad (1)$$