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The effects of non-centred catheter and guidewire on the dose distribution around source in catheter-based intravascular brachytherapy with $^{90}Sr/^{90}Y$ beta source

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Abstract

Recently, animal experiments and clinical studies indicate that rates of restenosis can be significantly reduced by short-range ionizing radiation in the dose range of 15–30 Gy applied locally. In the irradiation system with seed form, a manual afterloading device brings the sources to the end of a closed-end catheter by hydraulic pressure in the treatment. The 5 French (5F) catheters contain three lumens for guidewire, radioactive seeds and provides a mean of hydraulic fluid return. Because the lumen for radioactive seeds is not in the centre of the delivery catheter, the dose distribution around the source train may be disturbed. Attenuation of beta rays in the medium is very rapid and the absorption of the beta rays is tightly dependent on the atomic number of the medium. Therefore, the presence of a metallic guidewire inside the target region may disturb the dose distribution behind the guidewire. The aim of this work is to investigate the dose distribution around $^{90}Sr/^{90}Y$ source train with and without the guidewire at a radial distance 2 mm from the catheter centre using the radiochromic film dosimetry. We measured dose variations up to 25% caused by non-centred catheter and 35% dose reduction by the guidewire. The results of this study show that an acceptable homogeneous dose distribution around the $^{90}Sr/^{90}Y$ beta source cannot be achieved, in case of a non-centred catheter and a significant underdose region behind the guidewire may have occurred in the presence of guidewire inside the target region.

Keywords: Intravascular brachytherapy; Non-centred catheter; Guidewire; Radiochromic film dosimetry

1. Introduction

Restenosis after stent implantation in patients with coronary artery disease is caused primarily by an intimal hyperplastic response (Liu et al., 1989). Previous studies have shown that radiation may inhibit cellular hyperplasia by either killing progenitor cells or limiting their replicative capacity, thus reducing the number of clonal populations (Condado et al., 2002; Waksman et al., 1995). In general, the isotopes that are preferred for intravascular brachytherapy (IVBT) are beta emitters because of their suitable features for this therapy (Amols et al., 1996). One of the IVBT irradiation system using beta emitter radioisotope is catheter-based Novoste Beta-Cath. This irradiation system is formed with seeds, and a manual afterloading device brings the sources to the end of a closed-end delivery catheter by hydraulic pressure in the treatment. The cardiologist propels the radioactive seeds down the delivery catheter using a

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sterile water-filled syringe. Thus, an effectively continuous and flexible line source is provided inside the injured vessel region. The delivery catheter used in this irradiation system contains three lumens for guidewire, radioactive seeds and provides a mean of hydraulic fluid return. Because of the delivery catheter's design, the lumen for radioactive seeds is not in the centre of the catheter and a distance of 0.39 mm separates the source lumen centre from the catheter's centre. Due to a short range of beta rays in the tissue, this distance between the centres may have caused an in-homogenous dose distribution.

A metallic guidewire is used in an angioplasty application to place the balloon and other intracoronary catheters. High torquability and steerability properties of these metallic guidewires are very useful for the cardiologist to navigate the balloon and other intracoronary catheters inside the vessel. Besides, the same guidewire is used in an IVBT procedure when the delivery catheter is put into the exact place to irradiate the injured vessel part with the sufficient radiation doses. These guidewires are produced using heavy metal like stainless steel and they have rather higher atomic number than the tissue. On the other hand, attenuation of beta rays in the medium is very rapid and the absorption of the beta rays is tightly dependent on the atomic number of the medium. Therefore, the presence of a metallic guidewire inside the target region, may disturb the dose distribution behind the guidewire.

There are several physical reasons, which may have caused an unwanted in-homogenous dose distribution around the source in catheter-based IVBT using beta emitter radioisotope with short therapeutic range, and to provide a homogeneous dose distribution around the source is difficult. Previous studies have shown that major deviations on the dose distribution may be caused because of (i) source centering and residual plaque (Sehgal et al., 2001), (ii) lateral and longitudinal displacement in case of cardiac motions or calcified plaques (Chibani and Li, 2002), (iii) the off-centring of the source train lumen within the catheter (Roa et al., 2002), (iv) high absorption of the beta rays by metallic guidewire (Li and Shih, 2001; Shih et al., 2002), and (v) metallic stent (Nath et al., 1999b). In the present study, we ignored all the movements of the catheter inside the vessel, instead we investigated the effect of a non-centred catheter and a guidewire on the circumferential dose distribution around the source in the catheter-based IVBT with ^{90}Sr/ ^{90}Y beta emitter using radiochromic film dosimetry in a homogeneous stable phantom, which was made of polymethyl methacrylate (PMMA) in our department.

2. Materials and methods

2.1. The ^{90}Sr/^{90}Y source train

The ^{90}Sr/ ^{90}Y source (Beta-Cath System, Novoste Corporation) used for IVBT to prevent restenosis is a pure beta emitter radionuclide with emissions at average energies of 196 and 934 keV average energy (maximum energies are 546 and 2226 keV, respectively) with a half-life of 28.5 years. The source train consists of 16 radioactive seeds in the form of steel cylinders containing strontium titanate ceramic and two non-active radiopaque marker seeds at each end. The seeds are 2.5 mm × 0.64 mm of size (length × diameter) and the total active source length is 40 mm. When not in use, the source train is stored inside a shielding container, in which they are shielded by acrylic plastic. With the system, dose calculations are made according to the reference vessel diameter and the mean treatment times are 3–4 min.

2.2. The delivery catheter and the guidewire

In this irradiation system, a manual afterloading device brings the sources to the end of a closed-end catheter by hydraulic pressure in the treatment. The cardiologist propels the radioactive seeds down the delivery catheter using a sterile water-filled syringe. There are two radiopaque markers near the distal tip of the delivery catheter that define the treatment length as shown in Fig. 1a. The 5 French (5F) (1 French = 0.318 mm) delivery catheters have an outer diameter of 1.6 mm and it contains three lumens for guidewire, radioactive seeds and provides a mean of hydraulic fluid return as shown in Fig. 1b. The shortest distance between the source axis and the catheter's surface is 0.41 mm, and the farthest distance between the source axis and the catheter's surface is 1.19 mm, while the distance between the source axis and the centre of the catheter is 0.39 mm. The guidewire used in this study is 180 cm long, 0.014 in. (0.0356 cm) in diameter and was made of stainless steel.

2.3. Radiochromic film measurements

Recently, several studies have shown that the radiochromic film dosimetry is ideally in the dosimetry of the brachytherapy sources (McLaughlin et al., 1991; Chiu-Tsao et al., 1994) because it is nearly tissue equivalent and has a near-linear response of optical density vs. dose. The radiochromic film is a thin, almost colourless polyester sheet embedding a chromophore that changes dark blue under the influence of radiation. Typically, the radiochromic film is calibrated in a known radiation field and the relationship between the dose and the film response is determined. The radiochromic film used in the study is known as HD-810 (Nuclear Associates) and has a single layer of radiosensitive material of thickness 7 μm on a 100-μm polyester base. HD-810 films are mainly used for dose mapping in the range of 50–2500 Gy. To obtain more information about radiochromic films, readers are referred to the AAPM task group report no. 55 (Niroomand-Rad et al., 1998).

The treatment depth of a coronary artery in IVBT is 2 mm and the dose rate for beta emitter IVBT sources with catheter-based system is measured at a reference point located at a radial distance of 2 mm from the source axis as