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Factors affecting dose distributions in brachytherapy of coronary arteries with P-32 linear source

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- A Study Design
- B Data Collection
- C Statistical Analysis
- D Data Interpretation
- E Manuscript Preparation
- F Literature Search
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Summary

Background Long-term results of brachytherapy of coronary arteries may be influenced by inhomogeneity of the dose distribution. The dose distribution perturbations due to the presence of stent struts, guide wires and calcium deposits were therefore investigated.

Aim The aim of the study was to investigate dose distribution perturbations due to the presence of stent struts, guide wire and calcium deposits during the irradiation. Both experimental and calculational techniques were applied to elucidate these influences.

Materials/Methods The measurements were carried out with radiochromic foil in a phantom in the presence and absence of the stent and the guide wire. Due to the measurements being limited by the thickness of the detecting foil, the radial dose distribution with or without the metallic stent components were also performed using the MCNP Monte Carlo code. The same code was used to measure the influence of cholesterol plaques on dose distribution in the vessel walls.

Results A large dose reduction in the area shielded by the guide wire was observed. The presence of the stent caused a 15% dose reduction behind the struts. The dose reduction caused by calcium deposits ranged from 11% to 32%.

Conclusions These facts may increase the probability of late restenosis after irradiation due to underdosage. The inhomogeneity occurring behind the guide wire, stent struts and calcium deposits should be taken into account in the analysis of dose distributions for clinical applications.

Key words **brachytherapy • restenosis • beta emitters**

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BACKGROUND

Long-term results of brachytherapy of coronary arteries may be influenced by the absolute dose and by the possible inhomogeneity of the dose distribution. Intracoronary irradiation with beta sources is an effective method in reducing neointimal proliferation after successful angioplasty and stent implantation. However, the restenosis rate seems to be dose-dependent. Long-term results may be influenced by the absolute dose and by the homogeneity in dose distribution. As compared with gamma radiation, beta radiation generally has a steeper fall-off of the dose because of the short range of electrons, so it is important to eliminate the factors that can result in attenuation of therapeutic dose administration to injured artery segments. Such factors seem to be the guide wire present in coronary artery during beta-brachytherapy session, the implanted stent, and the calcium deposits in the vessel wall [1].

AIM

The aim of the study was to investigate dose distribution perturbations due to the presence of stent struts, guide wire and calcium deposits during the irradiation. Both experimental and calculational techniques were applied to elucidate these influences.

MATERIALS AND METHODS

Measurements

Phantom simulations were used to estimate dose distribution perturbations during irradiation performed with and without conventional coronary guide wire in position and with and without a stent. The influence on dose distribution at cylindrical surfaces has been assessed using GAF Chromic dosimetric foil MD55 (Nuclear Associates®). The measuring set up is illustrated in Figure 1 (expanded view). The 5mm wide strips of 55 MD GAF Chromic foil were positioned within a phantom made of PMMA at radial distance of 2.5mm from the center of the catheter. A Galileo III®, 3.0mm centering catheter and 0.014” (0.36mm) Hi-Torque guide wire (both Guidant Corporation, Santa Clara, USA) were used [2]. A Bolton stent made of L 236 stainless steel, 30mm long with 0.2mm diameter struts were used in the experiments and calculations. The P-32 radioactive source (Galileo®, Guidant radiotherapy system) was positioned within the PMMA phantom symmetrically to the GAF foil. The irradiation time was adjusted to get an optical density in the range 1–2. The optical density (in the guide wire experiment) was measured by a modified model 37-443 Densitometer (Nuclear Associates®) with an aperture of 0.5mm, while for the measurements of the effects of stent attenuation a scanner (Microtek Artixscan 1100) was used.

Monte Carlo calculations

The Monte Carlo dose calculations were performed for the vessel reference diameter of 3mm. The MCNP4C code was used. The calculations were done for calcium deposit plaques of the thickness in the range of 0mm to 1mm [3]. The calcium deposit density was assumed as $1.45 g/cm^3$.

RESULTS AND DISCUSSION

Influence of the guide wire on dose distributions

The optical densities (normalized), presented as polar plots, for two runs, with a guide wire present during irradiation (full dots) and without guide wire (open triangles) are shown in Figure 2. The maximum attenuation of beta radiation corresponds to the geometry where the guide wire is parallel to the radioactive source [4]. The dose is reduced to 54% of its maximal predicted value in the most “shady” area. The dose reduction below 80% occupies a polar sector of almost 60 degrees and influences also the reduction of the mean dose delivered to the surface layer to 93% of the predicted one.

Influence of stent struts on dose distributions

The dose distributions behind the stent struts, measured with the GAF foil detector are presented in Figure 3. As can be seen from the measurements, the presence of the stent causes a dose reduction behind the struts of the order of 15%. These measurements have shown the necessity of much deeper studies of a stent attenuation, i.e. when the geometry of measurements such as source – stent – detector position are taken into account. These details have been elucidated by Monte Carlo (MC) calculations [5,6]. The model for stent attenuation by MC calculation is shown in Figure 4, and the results are shown in Figure 5. It can be seen that the maximum attenuation of 34% appears at the tissue adjacent to a stent strut while at a distance of 0.5mm it is less than 5%. The radial dose distributions for different distances R – 1.55mm to 2.2mm are shown on Figure 6.

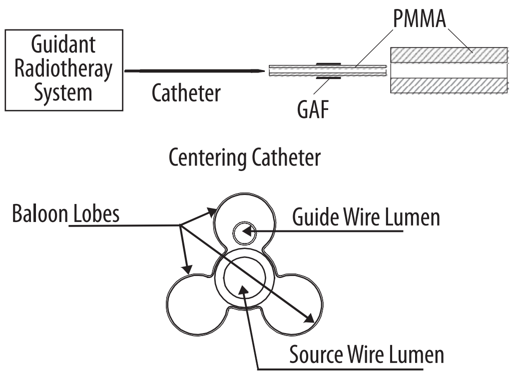

Figure 1. Expanded view of measuring set up for studying the shielding effect of the guide wire and the stent struts.

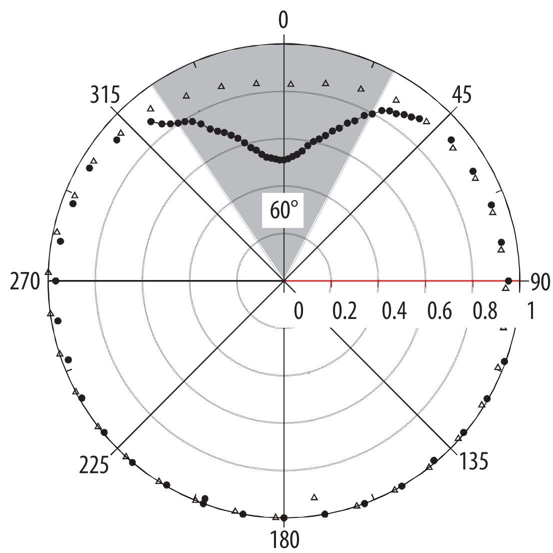

Figure 2. Polar plots of dose attenuation effects of the guide wire. Full dots – dose distribution with guide wire present; open triangles – dose distribution without guide wire.

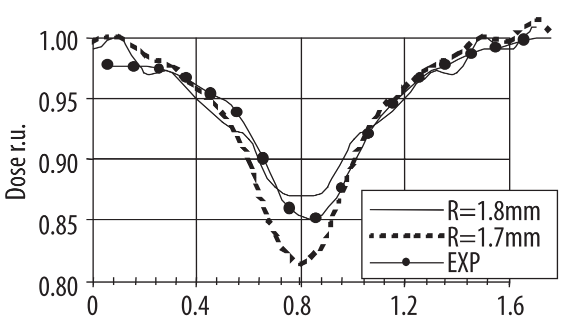

Figure 3. Dose distribution (relative units) along a linear source, behind the stent, as measured by the GAF chromic foil – full dots. The calculated distributions for R=1.7mm and 1.8mm were added to show the consistency of measurements with the calculations.

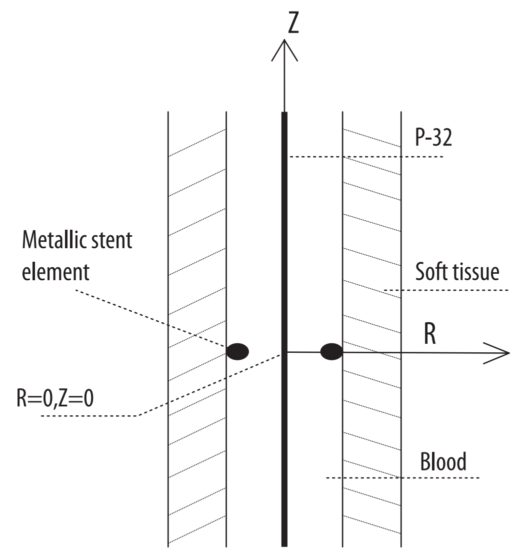

Figure 4. The model for stent attenuation by MC calculation.

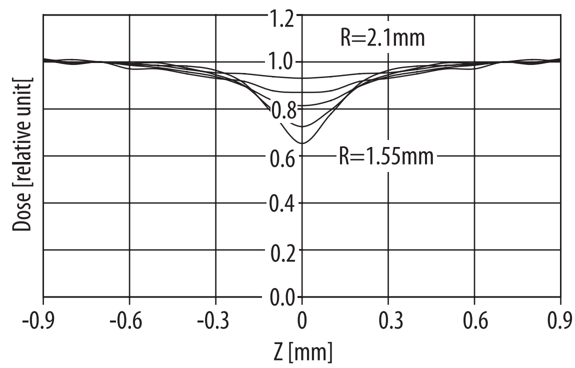

Figure 5. Comparison of longitudinal dose distribution at the different distances, R(mm), 1.55, 1.6, 1.7, 1.8 and 2.1 from the axis of the source.

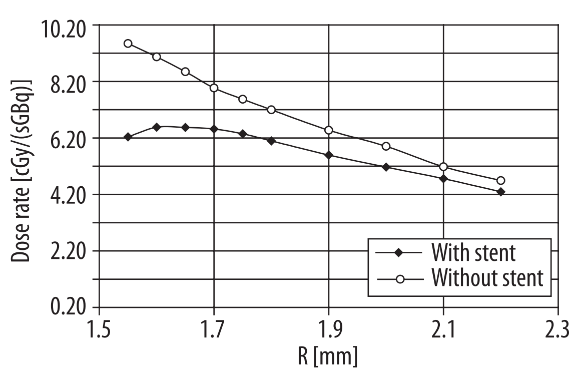

Figure 6. Radial dose distributions, with and without a stent, in the range of R from 1.55mm to 2.2mm.

Table 1. Dose reduction behind the calcium deposits. The vessel diameter is 3mm. The doses were calculated at three different distances from the source axis.

Distance from	No	Deposit thickness [mm]			
The source axis	Deposit	0.25	0.5	0.75	1.0
1.6mm	100%	93%	87%	82%	75%
2.5mm	100%	90%	84%	78%	70%
3.0mm	100%	89%	82%	74%	68%

Influence of calcium deposits on dose distributions

The results of the Monte Carlo dose calculations are presented in Table 1. MC simulations indicate that the dose reduction caused by calcium deposits range from 11% (0.25mm plaque thickness) to 32% (1mm plaque thickness) at 3mm distance from the source. These phenomena may increase the probability of the late restenosis after irradiation due to underdosage.

Conclusions

The inhomogeneities occurring behind the guide wire, stent struts and calcium deposits should be taken into account in the analysis of dose distributions for the actual clinical applications and in calculating the dose-volume histograms (DVH) in the target volume. The results suggest that technical improvements in the centering catheter construction should be made to eliminate the shielding effect of the guide wire.

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