

A comparison study on various low energy sources in interstitial prostate brachytherapy

Mahdi Bakhshabadi, MSc¹, Mahdi Ghorbani, PhD², Mohsen Khosroabadi, MSc¹, Courtney Knaup, PhD³, Ali S. Meigooni, PhD³

¹Faculty of Medicine, North Khorasan University of Medical Sciences, Bojnurd, Iran ²Medical Physics Research Center, Mashhad University of Medical Sciences, Mashhad, Iran, ³Comprehensive Cancer Centers of Nevada, Las Vegas, Nevada, USA

Abstract

Purpose: Low energy sources are routinely used in prostate brachytherapy. ¹²⁵I is one of the most commonly used sources. Low energy ¹³¹Cs source was introduced recently as a brachytherapy source. The aim of this study is to compare dose distributions of ¹²⁵I, ¹⁰³Pd, and ¹³¹Cs sources in interstitial brachytherapy of prostate.

Material and methods: ProstaSeed ¹²⁵I brachytherapy source was simulated using MCNPX Monte Carlo code. Additionally, two hypothetical sources of ¹⁰³Pd and ¹³¹Cs were simulated with the same geometry as the ProstaSeed ¹²⁵I source, while having their specific emitted gamma spectra. These brachytherapy sources were simulated with distribution of forty-eight seeds in a phantom including prostate. The prostate was considered as a sphere with radius of 1.5 cm. Absolute and relative dose rates were obtained in various distances from the source along the transverse and longitudinal axes inside and outside the tumor. Furthermore, isodose curves were plotted around the sources.

Results: Analyzing the initial dose profiles for various sources indicated that with the same time duration and air kerma strength, ¹³¹Cs delivers higher dose to tumor. However, relative dose rate inside the tumor is higher and outside the tumor is lower for the ¹⁰³Pd source.

Conclusions: The higher initial absolute dose in cGy/(h.U) of ¹³¹Cs brachytherapy source is an advantage of this source over the others. The higher relative dose inside the tumor and lower relative dose outside the tumor for the ¹⁰³Pd source are advantages of this later brachytherapy source. Based on the total dose the ¹²⁵I source has advantage over the others due to its longer half-life.

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Key words: ¹²⁵I, ¹⁰³Pd, ¹³¹Cs, Monte Carlo simulation, prostate brachytherapy, prostate cancer.

Purpose

Prostate cancer is the most common cancer in men. In the USA, one in six men is diagnosed with prostate cancer. It's known that 230,000 cases of prostate cancers are reported annually in America, with 27,000 of them are leading to death. In 1960, radiotherapy was introduced as a treatment for prostate cancer [1,2]. Brachytherapy is one of the common radiotherapy modalities applied for treatment of cancer. In this method, a radioactive source is inserted adjacent to or inside the tumor [2]. Normally, a photon emitting source is used for the purpose of brachytherapy. One of the aims of radiotherapy is to irradiate the tumor with a lethal dose, while minimizing the radiation dose received by the surrounding normal tissues. The success in radiotherapy treatment mainly depends on this objective [3].

One option for treatment of prostate cancer is the use of low energy brachytherapy sources such as ¹²⁵I and ¹⁰³Pd [4]. Recently, ¹³¹Cs radionuclide has been introduced

as a brachytherapy source [5,6]. Having a uniform dose distribution inside the tumor to minimize the quantity of hot/cold spots is an advantage in prostate brachytherapy using interstitial implants. The doses to other healthy tissues outside the tumor should be decreased to the minimum amounts. The dose to the sensitive organs should not exceed their tolerance levels [7]. In various studies, ¹²⁵I, ¹⁰³Pd, ¹⁶⁹Yb, and ¹⁹²Ir brachytherapy sources were evaluated in prostate brachytherapy [2,4,8,9]. It should be noted that in addition to ¹²⁵I and ¹⁰³Pd brachytherapy sources, there are also high-dose-rate (HDR) radionuclides (¹⁹²Ir) that are routinely used in prostate brachytherapy. These types of radionuclides are not used as permanent implants.

¹²⁵I, ¹⁰³Pd, and ¹³¹Cs radionuclides are used in permanent brachytherapy of prostate. Each radionuclide has its own advantages but also some disadvantages. ¹²⁵I and ¹³¹Cs have the same energy spectrum, and their average energies are 28.37 and 30.45 keV, respectively. ¹⁰³Pd has

Address for correspondence: Mohsen Khosroabadi, MSc, Faculty of Medicine, North Khorasan University of Medical Sciences, Bojnurd, Iran, phone: +98 58 32211008, fax: +98 58 32247124, e-mail: mohsen.khosroabadi83@gmail.com

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an average photon energy of 20.74 keV. This results to lower dose to the organs at risk such as rectum and urethra, on the other hand, increases the risk of underdosage in the prostate. In contrary, ^{125}I and ^{131}Cs have extension of dose distributions to larger distances, and this results to deliver more dose to the organs at risk for a given prostate dose. However, with these sources, there is a lower probability of cold spots in the prostate. Cases of urethral and rectal complications have been reported for ^{125}I or ^{131}Cs sources [10]. Generally, studies have reported that ^{125}I , ^{103}Pd , and ^{131}Cs radionuclides are used, in addition to prostate, for treatment of tumors in lung, brain, breast, and eye [3,4,5,6,7].

In order to simplify and speed up the calculations, approximations are used in brachytherapy treatment planning systems [2]. On the other hand, dose distributions can be calculated more accurately by Monte Carlo codes such as MCNP, EGS4, and Geant4. Zhang *et al.* [11] simulated a prostate model as a sphere with radius of 1.5 cm, while forty eight ^{125}I sources were defined within the prostate. Then isodose curves were obtained for prescribed doses of 108, 144, 145, and 160 Gy on the target volume. Their results demonstrated that the VariSeed™ treatment planning system (Varian Medical Systems, Inc., Palo Alto, CA, USA) has 29% and 136% larger dose coverage than the Monte Carlo simulation with 150% and 200% isodose lines, respectively. This was due to the simplification of the seed characteristics using a point source approximation and neglecting inter-seed attenuation in this treatment planning system. The calculations had more accuracy using the MCNP code.

Task group No. 64 of American Association of Physicists in Medicine (AAPM) [7] suggests that technical innovations, image-based planning, computerized dosimetry analysis, and improved quality assurance have important roles in modern prostate brachytherapy. These factors lead to increased tumor control and decreased toxicity in normal organs. The Radiation Therapy Committee of the AAPM formed task group No. 64 to review the current techniques in prostate seed implant brachytherapy. This task group has been also committed to summarize the knowledge in various aspects in prostate brachytherapy including treatment planning, dose specification, and reporting. It recommends practical guidelines for the clinical medical physicist community and identifies issues for future investigation in this field [7]. The details on physical aspects and the related issues in prostate brachytherapy can be found in this report.

Heintz *et al.* [9] evaluated physical and dosimetric characteristics for various ^{125}I sources in prostate brachytherapy. Their assessment was performed on the differences in designs, construction, and dosimetric characteristics of each source and the results were compared with those of an Amersham 6711 source model (Amersham, Little Chalfont, UK). This led to present a simple equation that can be used clinically to convert the standard strength of 6711 source to an equivalent strength of a new brachytherapy source.

In a study by Meigooni *et al.* [12], the effect of the dosimetric differences of ^{125}I and ^{103}Pd sources were evaluated within the scope of their clinical applications. The

quantitative and qualitative evaluations were performed via comparisons of dose distributions and dose volume histograms in prostate implants with various designs of the ^{125}I and ^{103}Pd sources. The comparisons were with identical implant scheme including the same number of seeds for each source. The results were compared with the Amersham 6711 ^{125}I and the Theragenics 200 ^{103}Pd seeds (Theragenics Corporation, Buford, Georgia, USA).

There was no significant difference between the dose distributions of the new designs of ^{125}I and ^{103}Pd sources in a typical prostate implant compared to the ^{125}I and ^{103}Pd reference sources. However, this plan needs to be evaluated for any new design of brachytherapy source.

While various studies have been performed on dose distribution evaluation in prostate brachytherapy, to the best of our knowledge, there are not any study on dosimetric assessment and comparison of ^{125}I , ^{103}Pd , and ^{131}Cs sources with the same geometries in interstitial prostate brachytherapy. The aim of the current study is to compare dose distributions of ^{125}I , ^{103}Pd , and ^{131}Cs sources in interstitial prostate brachytherapy. Additionally, the use of ^{131}Cs radionuclide as a hypothetical source in interstitial prostate brachytherapy is evaluated.

Material and methods

In this study, a Mills Biopharmaceuticals ProstaSeed ^{125}I source (model 125SL) (Oklahoma City, USA) has been simulated. The validation of this source simulation was performed in a previous study on this source model [2]. In the present study, the validated source simulations were used in all further source simulations. All the simulations were performed using a Monte Carlo N-particle transport code (MCNPX, version 2.6.0) [13]. MCNPX code was developed by Los Alamos laboratory, and is used worldwide for transport of various types of particles in nuclear physics and medical physics applications. ^{125}I radionuclide is a common source for prostate brachytherapy in medical centers worldwide [14]. The ProstaSeed ^{125}I source (Core Oncology, Santa Barbara, US) is composed of five silver spheres, on which radioactive ^{125}I radionuclide was coated superficially. These spheres are placed in a titanium capsule having side walls with thickness of about 0.05 mm. The external length of the capsule is 4.5 mm and its external diameter is 0.8 mm. The titanium capsule has thickness of 0.3 mm on both end welds of the source. The geometry of the source model, including dimensions as well as the compositions of materials is shown in Figure 1 [2,15]. The hypothetical ^{103}Pd and ^{131}Cs sources were simulated and used for prostate brachytherapy simulations in this study with geometries based on the commercially available ProstaSeed ^{125}I source (model 125SL). However, in the hypothetical ^{103}Pd and ^{131}Cs sources, the active cores were replaced by pure ^{103}Pd and ^{131}Cs radionuclides, respectively. The photon spectra used in the simulations of these sources are based on previous studies on the sources: Rivard *et al.* [15] for ^{125}I , Rivard [16] for ^{103}Pd , and Rivard [17] for ^{131}Cs , which are presented in Table 1. Using these spectra the photon yields for the ^{125}I , ^{103}Pd , and ^{131}Cs are: 1.4757, 0.7714, and 0.8138 photons/dis, respectively. Probable electron emissions (Auger, con-

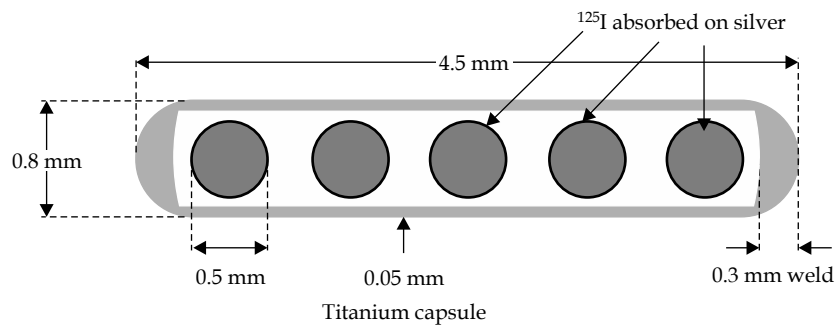


Fig. 1. A schematic figure of the IAI ^{125}I brachytherapy source indicating dimensions and materials

Table 1. Photon energy spectrum for ^{125}I , ^{103}Pd , and ^{131}Cs brachytherapy sources

^{125}I source [15]		^{103}Pd source [16]		^{131}Cs source [17]	
Photon energy (keV)	Photons per disintegration	Photon energy (keV)	Photons per disintegration (%)	Photon energy (keV)	Photons per disintegration (%)
27.202	0.406	20.074	22.4	4.11	8.6
27.472	0.757	10.216	42.3	29.461	21.1
30.98	0.202	22.717	10.4	29.782	38.9
31.71	0.0439	23.312	1.94	33.562	3.63
35.492	0.0668	39.755	0.0683	33.624	7.02
		62.51	0.00104	34.419	2.13
		294.95	0.0028		
		357.46	0.0221		
		497.054	0.00401		

version, etc.) by these radionuclides were not considered, since they are absorbed in the source's capsule due to their low energy and have not considerable effect on the dose in the phantom.

With the same procedure as the study by Ghorbani *et al.* [2], Monte Carlo simulations of the prostate tumor and brachytherapy source implants were performed. The prostate was considered as a sphere with radius of 1.5 cm and forty-eight sources were distributed within the prostate. A schematic geometry indicating the distribution of the sources, prostate and the surrounding phantom is illustrated in Figure 2. The prostate was composed of four-element soft tissue, which was presented by International Commission on Radiation Units and Measurement (ICRU) report No. 44 [18]. Based on this report, soft tissue has four elements with weight fractions as follows: 76.2% oxygen, 11.1% carbon, 10.1% hydrogen, and 2.6% nitrogen. The normal tissue was defined as the surrounding medium (phantom) and was composed of four-component soft tissue in the form of a sphere with radius of 25.0 cm. A sphere composed of air with radius of 150.0 cm around the soft tissue phantom was also defined. The forty-eight sources were distributed in the volume of the tumor in such an arrangement that included eight arrays of sources, each array included six sources. The sources' arrays were placed symmetrically on a circle with 1.2 cm radius in the prostate (Figure 2). It should be noted

that by alignment of six sources having distances between each other, especially on the peripheral regions, some of them are located outside the prostate. This arrangement is optimum to have a suitable dose distribution in the prostate and it is routine in clinical practice of prostate brachytherapy. The arrangement of the sources and tumor was similar to those used in the previous studies on prostate brachytherapy [2,11]. The distributions of the ^{125}I brachytherapy sources and hypothetical ^{103}Pd and ^{131}Cs sources were similar to each other.

Type 1 mesh tally (using "pedep" option) was used to score the photon doses in this step. The use of this tally type and this option in MCNP equals to application of F6 tally, which scores kerma. Kerma can be used as an approximation for absorbed dose calculation in the positions where there is electronic equilibrium. It can be mentioned that electronic equilibrium exist at distances, which are not in the close vicinity of the source. This mesh included $2\text{ mm} \times 2\text{ mm} \times 2\text{ mm}$ voxels, in which the value of tally was scored. Energy cut off for photon and electron was 10 keV in the Monte Carlo input programs. Except for the energy cut-off, no other variance reduction technique was used in the above mentioned simulations. In the Monte Carlo programs, a photon source was defined, while both photons and electrons were transported and the photon tally was scored for the purpose of calculation of photon dose. This leads to transport of various

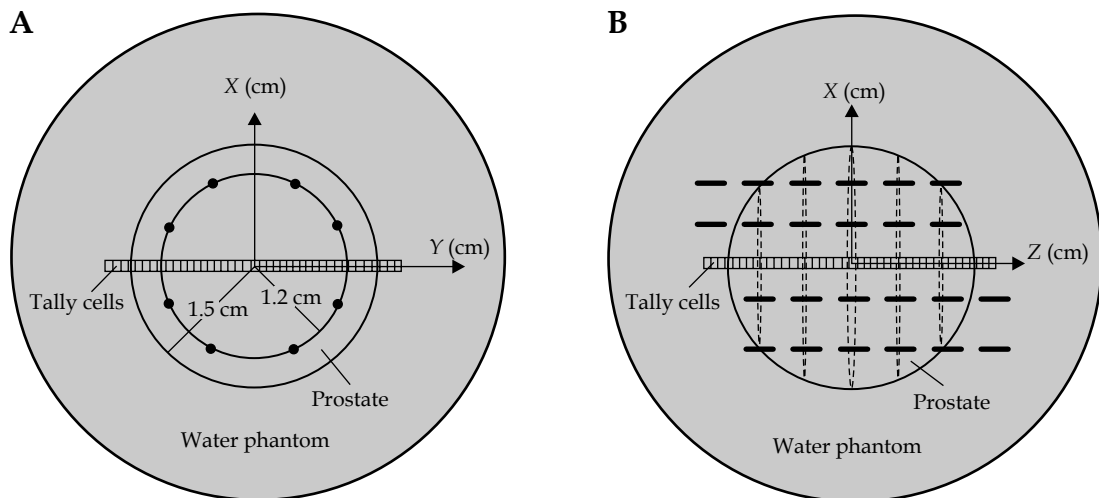


Fig. 2. Prostate and seeds simulated in present study. A) Transverse cross section, B) longitudinal cross section

photon interactions and scoring primary and secondary particles including photons and electrons. A number of 2.0×10^8 , 2.0×10^9 , and 2.0×10^8 photons were run in each input file for the ^{125}I , ^{103}Pd and ^{131}Cs , respectively. The type A statistical uncertainties of all Monte Carlo calculations were less than (or equal to in one case) 2.30% in these programs.

Absolute and relative doses were calculated for this configuration in various points inside and outside the tumor on the central transverse (y -) and longitudinal (z -) axes. The transverse and longitudinal data were extracted from the 2D dose distribution matrix obtained from the above described mesh tally. In relative dose calculations, dose values were normalized on dose on the surface of prostate (at 1.5 distance) on the transverse axis. Dose profiles were obtained on y - and z - axes for the sources in terms of $\text{cGy}/(\text{h.U})$. Isodose curves of 10%, 30%, 50%, 100%, and 150% were plotted while the prescribed dose was at the point located at distance of 1.5 cm from the center of the tumor on the y -axis (on the surface of the prostate). The dose at this point was considered as

the reference dose and the relative doses were calculated as the ratio of dose relative to the dose at this point. It is obvious that the doses at this point were different for the ^{125}I , ^{103}Pd , and ^{131}Cs sources, and for each source the dose at this point with the same source was considered as the reference. Therefore, the contour of 100% covered the surface of the prostate. Finally, the transverse and longitudinal dose profiles, isodose curves for the sources were compared. Advantages and disadvantages of the sources were discussed from dose distribution aspects for use in interstitial prostate brachytherapy as well.

Results

Figure 3 (part A and B) illustrate dose profiles ($\text{cGy}/(\text{h.U})$) determined by the cumulative dose distribution from the multi-seed implant simulations for the ^{125}I , ^{103}Pd , and ^{131}Cs sources in the transverse and longitudinal axes, respectively.

Isodose curves including 10-150% contours are plotted in Figure 4. The contours are located inside and out-

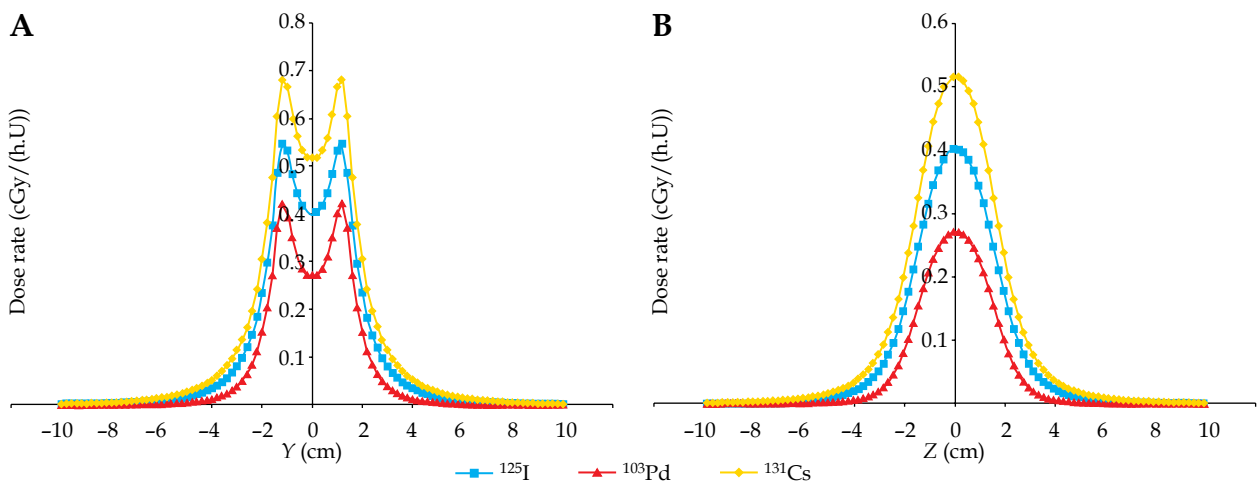


Fig. 3. Dose profiles ($\text{cGy}/(\text{h.U})$) for the ^{125}I , ^{103}Pd , and ^{131}Cs sources in prostate brachytherapy. (A) transverse axis, (B) longitudinal axis

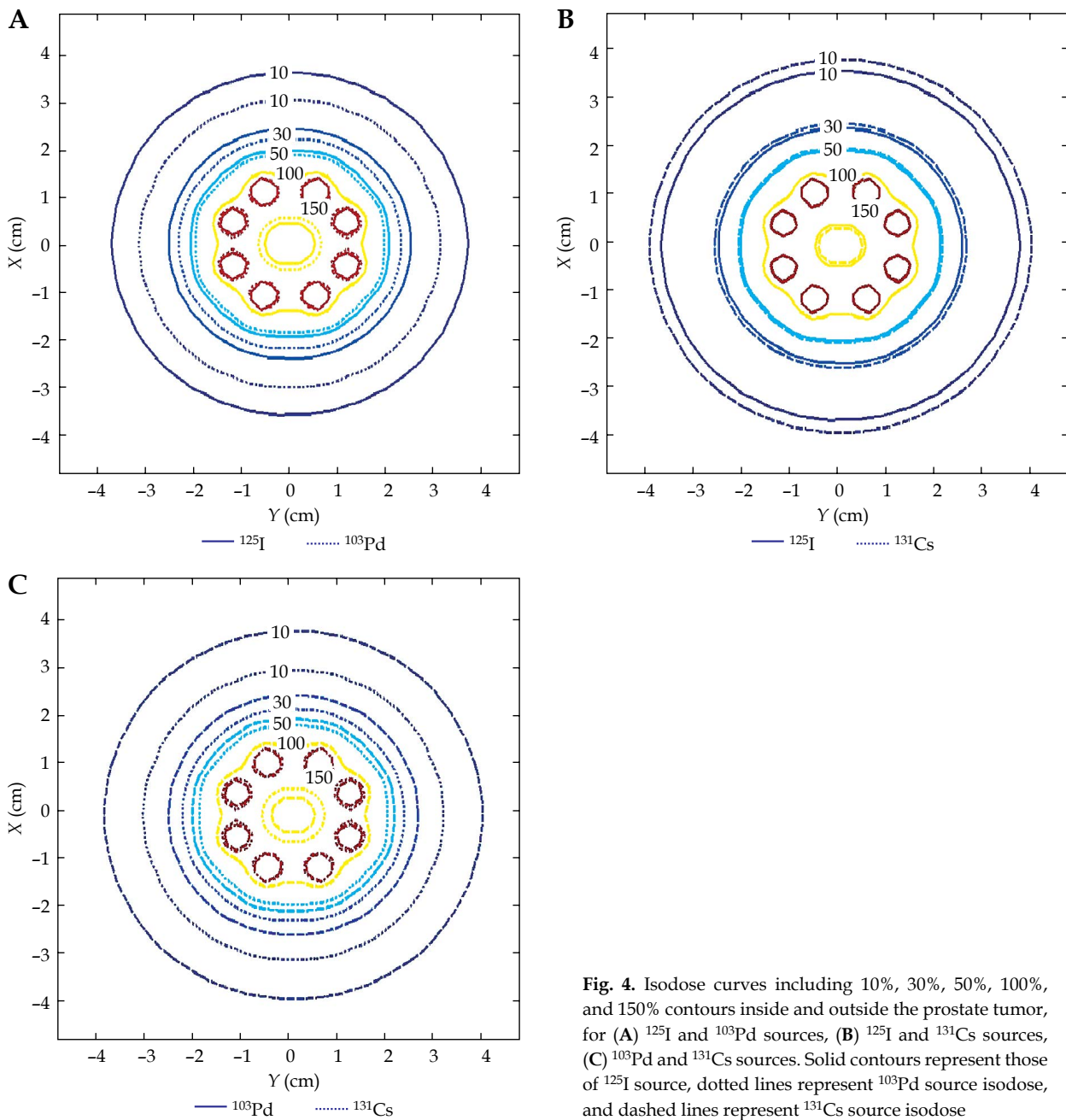


Fig. 4. Isodose curves including 10%, 30%, 50%, 100%, and 150% contours inside and outside the prostate tumor, for (A) ^{125}I and ^{103}Pd sources, (B) ^{125}I and ^{131}Cs sources, (C) ^{103}Pd and ^{131}Cs sources. Solid contours represent those of ^{125}I source, dotted lines represent ^{103}Pd source isodose, and dashed lines represent ^{131}Cs source isodose

side the prostate tumor, and are plotted for the ^{125}I , ^{103}Pd , and ^{131}Cs sources. In this figure, solid lines represent the case for ^{125}I source. The dotted and dashed lines are related to ^{103}Pd , and ^{131}Cs sources, respectively. Doses were normalized to the dose on the tumor surface. In order to have better comparisons, each part in this figure illustrates the dose distribution for two sources. From the top to the bottom, the curves are related to the ^{125}I and ^{103}Pd sources (part A), ^{125}I and ^{131}Cs sources (part B), and ^{103}Pd and ^{131}Cs sources (part C), respectively. Eight circular contours around the sources are isodose contours of 150%. In these simulations, the prostate was defined as a sphere with radius of 1.5 cm and forty-eight sources of each type were distributed in the prostate volume separately.

Figure 5 presents percentage differences between the relative dose values for the ^{125}I , ^{103}Pd , and ^{131}Cs source implants. In this figure, from the top to the bottom, percentages differences are related to the ^{125}I and ^{103}Pd sources (part A), ^{125}I and ^{131}Cs sources (part B), and ^{103}Pd and ^{131}Cs sources (part C), respectively.

Discussion

In this study, a ProstaSeed ^{125}I source and two hypothetical ^{103}Pd and ^{131}Cs brachytherapy sources were simulated with the same geometry of the ProstaSeed ^{125}I source. Then comparison of y - and z - axes dose profiles and dose distributions for the sources inside and outside the tumor was performed in interstitial prostate brachytherapy.

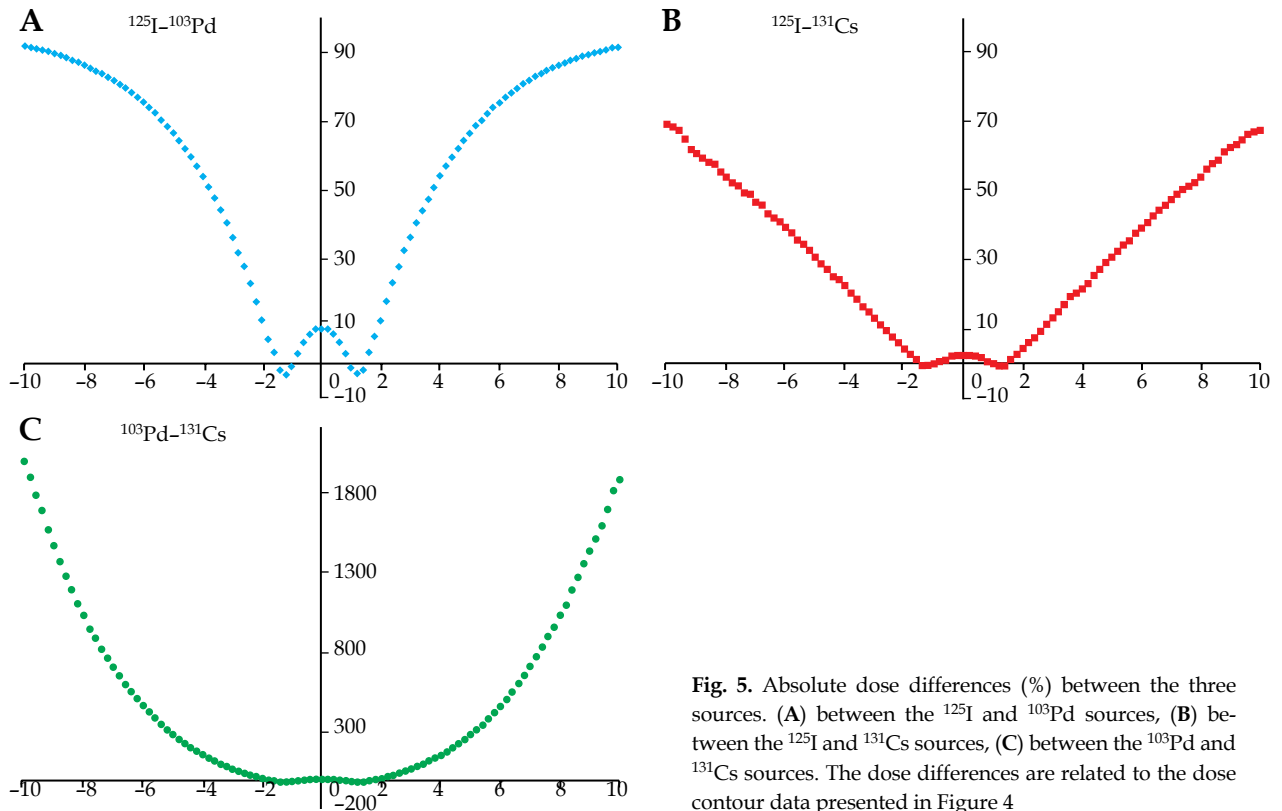


Fig. 5. Absolute dose differences (%) between the three sources. (A) between the ^{125}I and ^{103}Pd sources, (B) between the ^{125}I and ^{131}Cs sources, (C) between the ^{103}Pd and ^{131}Cs sources. The dose differences are related to the dose contour data presented in Figure 4

For the purpose of comparison of various radionuclides in prostate brachytherapy, not only dosimetric and treatment planning aspects but also evaluation of treatment outcome in brachytherapy patients is important. Zhang *et al.* [19] in a systematic review, compared the effectiveness and adverse effects in 1406 patients with prostate cancer treated with ^{125}I and ^{103}Pd brachytherapy sources. Their results have shown that after one or six months following the treatment, there were differences between the adverse effects in the patients treated with ^{125}I or ^{103}Pd sources. However, it was not found significant difference in adverse effects between the ^{125}I and ^{103}Pd groups, following 12 months after source implantation. Finally, it was reported that the effects of brachytherapy with ^{125}I and ^{103}Pd sources for low risk prostate radiotherapy are similar. Nuttens *et al.* [20] determined normal tissue complication probability for urethra in three prostates patients implanted with ^{125}I , ^{103}Pd , ^{131}Cs , ^{103}Pd - ^{125}I , or ^{103}Pd - ^{131}Cs seeds. The large uncertainties in the fitting parameters in the modeling of the urethral normal tissue complication probability, resulted in large uncertainty on this probability value. Therefore, it was announced that application of a model for normal tissue complication probability in permanent brachytherapy is possible, but it is necessary to minimize the uncertainties in the parameters in this model.

As it can be seen in Figure 3 (dose profiles in terms of cGy/(h.U) in the transverse and longitudinal axes), the results show that the dose distribution in terms of cGy/(h.U) are quite different with the ^{125}I , ^{103}Pd , and ^{131}Cs sources. Since the same geometries were defined with these sources, this effect is due to the differences in pho-

ton energy spectra, and photon yields (number of photons per disintegration) of these sources. These differences are incorporated in calculation of air kerma strength (in terms of U) and therefore have their effect on dose distribution in terms of cGy/(h.U). Since TG-43 proposed air kerma strength for characterization of the source strength instead of activity, presentation of dose rate in terms of cGy/(h.U) are of relevance in dose calculation and optimization in treatment planning in prostate brachytherapy. Therefore, based on interpretation of the results in cGy/(h.U) as the reference results (based on the recommendations of TG-43), ^{131}Cs , ^{125}I , and then ^{103}Pd has higher dose rates per U inside and outside the tumor, respectively. This will be accounted as an advantage of ^{131}Cs over the others, however, the higher dose outside the tumor with this source is a disadvantage. In other words, from clinical and radiobiological point of view, a higher dose by ^{131}Cs source will reduce the likelihood of cold spots inside the prostate. On the other hand, this is with the cost of higher dose to organs at risk (rectum and urethra) for a given prostate dose. A higher dose to organs at risk will increase the risk of rectal and urethral complications with this source [20].

Considering Figure 4 (part A), generally speaking, there is no significant difference in hot/cold spots for various sources. When one considers Figure 4, with an accurate assessment of 10% isodose lines, it can be evident that ^{125}I source presents a more suitable dose relative to ^{131}Cs . This is due to the fact that 10% isodose line for ^{125}I is more internal than that for ^{131}Cs . This indicates that ^{125}I delivers less dose than ^{131}Cs outside the tumor. This manner for ^{125}I is advantageous than ^{131}Cs in terms of reduction of dose to the around OAR.

As can be seen in Figure 4 (part B), using ^{103}Pd source, dose decreases outside the tumor faster than ^{125}I source. This is demonstrated obviously with the assessment of 30% and 10% isodose lines. These isodose lines are more internal for ^{103}Pd than the ^{125}I ones, which indicates less dose delivery to outside the tumor. 100% isodose line for the ^{125}I brachytherapy source is more internal than for ^{103}Pd . This is mentioned in some extent as an advantage of ^{125}I source. Regarding little difference between the 100% isodose lines for these two sources, it can be claimed that using ^{103}Pd is more beneficial than ^{125}I .

As it can be seen in Figure 4 (part C) explicitly, 10%, 30%, and 50% isodose lines of ^{103}Pd are more internal relative to ^{131}Cs cold spots. Additionally, considering 100% isodose lines for these two sources, it can be concluded that the 100% isodose line for ^{131}Cs is more internal. There is not a significant difference between hot spots for these two sources. This behavior indicates the usage of the ^{103}Pd source gives advantages relative to ^{131}Cs .

As it is demonstrated in Figure 5, with increase in the distance from the source, the percentages differences between the two-source cases become larger. For distances greater than about 2 cm with ^{125}I - ^{103}Pd and ^{125}I - ^{131}Cs source comparisons, the differences exceeds 10%. There is also an increasing trend of dose differences for ^{103}Pd - ^{131}Cs source comparisons with increase in distance from the center of prostate. This effect may be due to the definition of relative difference. In other words, absolute dose is smaller at larger distances, and when the dose differences are divided to a smaller dose value at larger distances, the relative dose increases. As another effect, as it can be seen from Figure 5, the percentage relative dose differences for ^{125}I - ^{103}Pd and ^{125}I - ^{131}Cs are smaller than the ^{103}Pd - ^{131}Cs sources. This can be related to the differences in photon energy spectra, photon yields, and in-phantom photon attenuations for these three sources.

Since in the current study ^{131}Cs radionuclide in the studied form was proposed as a hypothetical source in brachytherapy, based on assessment of its isodose curves and longitudinal and transverse dose profiles relative to ^{125}I and ^{103}Pd brachytherapy sources, it can be concluded that cold spots for the hypothetical ^{131}Cs source are more external than the other two sources, which may be disadvantageous for ^{131}Cs . This is due to the organs at risk around the tumor receives higher dose relative to the other two sources. Comparing hot spots for hypothetical ^{131}Cs source with ^{103}Pd and ^{125}I brachytherapy sources, there is no significant difference. Therefore, it can be claimed that ^{131}Cs have no significant difference with the other two sources in terms of distribution of hot spots. Actually, 100% isodose lines for hypothetical ^{131}Cs source are more internal than the ^{103}Pd and ^{125}I brachytherapy sources. This effect indicates that ^{131}Cs delivers higher dose to the tumor relative to the other two sources, which can be reported as an advantage of using the ^{131}Cs source in brachytherapy.

Another consideration for these sources is that they are used as permanent implants in prostate brachytherapy. In this modality, the prescription dose is the criteria and is calculated as the total dose during the presence of

the implants inside the tumor. In this case, the total dose is calculated as $1.44 \times \text{half-life} \times \text{initial dose rate (cGy/h.U)}$. In this study, the initial dose rates for these sources were obtained from the Monte Carlo simulations. Therefore, while having the number of seeds (48 seeds), air kerma strength for each source, half-life of each radionuclide, and the initial dose rates, it is possible to calculate the total dose. In the above sections only initial dose rates were as the criteria for comparison of the sources. As examples, initial dose rate per air kerma strength on prostate in the transverse axis for the ^{131}Cs , ^{125}I , and ^{103}Pd sources are 0.54 cGy/(h.U), 0.43 cGy/(h.U), and 0.32 cGy/(h.U), respectively. The corresponding values for these sources on the longitudinal axis are 0.32 cGy/(h.U), 0.25 cGy/(h.U), and 0.15 cGy/(h.U), respectively. It is obvious that with the same number of seeds and initial air kerma strengths, the half-life will have effect on the total dose. The half-lives of the ^{125}I , ^{103}Pd , and ^{131}Cs sources are 59.40 days, 16.991 days, and 9.7 days, respectively. With these half-lives, while having the same number of seeds and initial air kerma strengths, ^{125}I will have a higher total dose due to its longer half-life. In the above discussions, the initial dose rates were the criteria, however, based on the total dose the ^{125}I source has advantage over the others.

In this study we did some simplification in our simulation. For example it was considered the prostate shape as a symmetric sphere but we know that it is not the true shape in reality. It is suggested that the evaluation of this study with more real treatment plans in terms of the asymmetric prostate shape and presence of urethra in this organ asymmetrically. In routine brachytherapy practice, dose volume histograms are applied additionally to dose distribution. A comparison of dose volume histograms by these sources in prostate brachytherapy can be a subject of further research in this field. It is obvious that since all of these sources are not available clinically with the same treatment planning system, this subject can be performed via Monte Carlo simulation of these sources. Furthermore, the same geometries were considered for the three sources. This is beneficial to have comparison between these sources with the same conditions and the dose differences are related to the radiation characteristics of these sources. On the other hand, a comparison of these sources with their own commercially available geometries can be a subject of further research in this field.

In the current study a number of simplifications were used in definition of the geometry of phantom and sources. The prostate was considered as a sphere in a phantom. In the real situation, prostate has not a spherical shape. Additionally, in order to have a precise comparison between various radionuclides, the geometries of ^{103}Pd and ^{131}Cs sources were considered the same as the ProstaSeed ^{125}I source. In other words, the geometries of the ^{103}Pd and ^{131}Cs sources were hypothetical. The simulation of geometries have some differences from the real condition. Additionally, the prostate was composed of four-element soft tissue. In practice, the composition of prostate tumor may differ from the healthy tissue. The comparison of these sources could be completed doing the measurements with real sources in an anthropomorphic phantom,

and with this work there may be very interesting parameters for decision about the correct source for application in brachytherapy treatment. Implication of these issues on the study design and subsequent source comparisons can diminish the accuracy of the results, and these effects can be subjects for future researches.

Conclusions

Considering the transverse and longitudinal dose profiles and isodose contours for the ^{125}I , ^{103}Pd , and ^{131}Cs source in interstitial prostate brachytherapy indicates that with the same geometries, these sources have different dose distributions. The results of dose rates in terms of $\text{cGy}/(\text{h.U})$ show different trends. Therefore, based on the results in $\text{cGy}/(\text{h.U})$ as the reference (in accordance with TG-43 recommendation), a comparison of dose distributions of these three sources indicates that, with the same time duration and air kerma strength, it is possible to deliver a higher dose to the prostate volume with the ^{131}Cs source. However, relative dose rate inside the tumor is higher and outside the tumor is lower for the ^{103}Pd source. ^{103}Pd has more rapid dose falloff outside the tumor, which can be beneficial for the normal tissues outside the tumor. This effect for ^{103}Pd is the advantage of this brachytherapy source. Additionally, the results show the dose distribution in terms of $\text{cGy}/(\text{h.U})$ are quite different and this should be considered in clinical applications of prostate brachytherapy. While having the same number of seeds and initial air kerma strengths, ^{125}I will have a higher total dose due to its longer half-life. Therefore, based on the total dose, the ^{125}I source has advantage over the others.

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Disclosure

Authors report no conflict of interest.

References

1. Nguyen PL, Zietman AL. High-dose external beam radiation for localized prostate cancer: current status and future challenges. *Cancer J* 2007; 13: 295-301.
2. Ghorbani M, Bakhshabadi M, Golshan A et al. Dose enhancement by various nanoparticles in prostate brachytherapy. *Australas Phys Eng Sci Med* 2013; 36: 431-440.
3. Holmgren M. Brachytherapy for cancer of the cervix. 3D dose distributions for new ring applicator using BrachyVision, for clinical use. Master of Sciences Thesis, Medical Radiation Physics Department, Lund University, Lund 2005. <http://lup.lub.lu.se/student-papers/record/2156980/file/2157759.pdf>. Accessed December 19, 2015.
4. Li Z, Palta JR, Fan JJ. Monte Carlo calculations and experimental measurements of dosimetry parameters of a new ^{103}Pd source. *Med Phys* 2000; 27: 1108-1112.
5. Murphy MK, Piper RK, Greenwood LR et al. Evaluation of the new cesium-131 seed for use in low-energy x-ray brachytherapy. *Med Phys* 2004; 31: 1529-1538.
6. Meigooni AS, Awan SB, Rachabattthula V et al. Treatment planning considerations for prostate implants with the new linear RadioCoil ^{103}Pd brachytherapy source. *J Appl Clin Med Phys* 2005; 6: 23-36.
7. Yu Y, Anderson LL, Li Z et al. Permanent prostate seed implant brachytherapy: report of the American Association of Physicists in Medicine Task Group No. 64. *Med Phys* 1999; 26: 2054-2076.
8. Meigooni AS, Hayes JL, Zhang H et al. Experimental and theoretical determination of dosimetric characteristics of IsoAid ADVANTAGE™ ^{125}I brachytherapy source. *Med Phys* 2002; 29: 2152-2158.
9. Heintz BH, Wallace RE, Hevezi JM. Comparison of I-125 sources used for permanent interstitial implants. *Med Phys* 2001; 28: 671-682.
10. Prestidge BR, Bice WS, Jurkovic I et al. Cesium-131 Permanent Prostate Brachytherapy: An Initial Report. *Int J Radiat Oncol Biol Phys* 2005; 63: 336-337.
11. Zhang H, Baker C, McKinsey R et al. Dose verification with Monte Carlo technique for prostate brachytherapy implants with ^{125}I sources. *Med Dosim* 2005; 30: 85-91.
12. Meigooni AS, Luerman CM, Sowards KT. Evaluation of the dose distribution for prostate implants using various ^{125}I and ^{103}Pd sources. *Med Phys* 2009; 36: 1452-1458.
13. Pelowitz D. MCNPX user's manual, LA-CP-07-1473 Version 2.6.0, National Laboratory, Los Alamos 2008.
14. Carleton University (2013). http://www.physics.carleton.ca/clrp/seed_database/I125/ProstaSeed_125SL. Accessed December 19, 2015.
15. Rivard MJ, Coursey BM, DeWerd LA et al. Update of AAPM Task Group No. 43 Report: a revised AAPM protocol for brachytherapy dose calculations. *Med Phys* 2004; 31: 633-674.
16. Rivard MJ. A discretized approach to determining TG-43 brachytherapy dosimetry parameters: case study using Monte Carlo calculations for the MED3633 ^{103}Pd source. *Appl Radiat Isot* 2001; 55: 775-782.
17. Rivard MJ. Brachytherapy dosimetry parameters calculated for a ^{131}Cs source. *Med Phys* 2007; 34: 754-762.
18. ICRU. ICRU Report No. 44. Tissue substitutes in radiation dosimetry and measurement. ICRU, Bethesda 1989.
19. Zhang LL, Ma L, Tian JH et al. ^{125}I versus ^{103}Pd brachytherapy for low risk prostate cancer: a systematic review. *Ai Zheng* 2009; 28: 872-878.
20. Nuttens VE, Nahum AE, Lucas S. An NTCP analysis of urethral complications from low dose rate mono- and bi-radio-nuclide brachytherapy. *Prostate Cancer* 2011; 2011: 128360.