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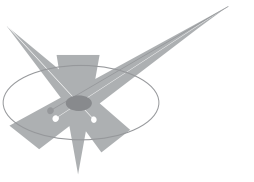

Original Paper

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Real-time brachytherapy for prostate cancer – implant analysis

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background In HDR brachytherapy precision of catheter implantation is crucial for conformal treatment planning as a starting point for better optimization process.

Aim The aim was to investigate differences between virtual and real needle position and the effect of needle displacement on dosimetric parameters as a function of prostate volume for better evaluation of "real" implant with respect to final dose distribution.

Materials/Methods Thirty treatment plans calculated by Nucletron SWIFT™ were randomly selected. Dosimetric data including V100 for prostate gland and D10 for urethra were analyzed as a function of prostate volume and needle displacement.

Needle displacement was determined by measuring the distance between virtual and real positions of respective needles in three sectional images: at the base, apex of the prostate gland and reference image. Dosimetric parameters were determined for consecutive computer plans: virtual (before implantation), live (after implantation and renewed optimization). For the purpose of this study a new parameter, VD (Volume-Dose), was created.

Results VD indicates the quality of "real" dose distribution with respect to "virtual" treatment plan. In order to realize the assumption of virtual plan (VD<1) for a given prostate volume, mean values of needle displacement *r* should not exceed $r_{acceptable}$ according to the formula: $r_{acceptable}(Vp) \propto Vp^2$. For larger glands (above 30cc) final dose distribution is less dependent on needle displacement than smaller ones.

Conclusions The experiment determined maximum values of needle displacement for a given Vp parameter, allowing one to take advantage of optimization algorithms and to improve the final dose distribution.

Key words **real-time brachytherapy • interstitial implant • prostate volume**

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Background

High dose rate brachytherapy has become an incredibly popular method for early-stage prostate cancer [1–3]. In HDR remote afterloading technique the source is positioned inside the catheters in predefined dwell positions. Moreover, the dwell times (time of source stopovers) inside the catheter are individually selected (optimized) for better targeting of the volume of interest as well as sparing normal tissue and organs at risks [4–6]. Additionally, increasingly improved imaging techniques facilitate accurate implantation. "Real-time" HDR brachytherapy based on transrectal ultrasound guidance provides continuous visualization of the prostate during the treatment planning process [1].

However, in brachytherapy, precision of catheter implantation according to pre-planned needle position and patient's anatomy is crucial for conformal treatment planning and in HDR "stepping source" technique is a starting point for better optimization process. There is a lack of reports in the literature on the subject of needle displacement as the distance between preplanned catheter position and its real one after implantation, and its impact on the final dose distribution.

Aim

The aim of this study was to analyze the needle displacement as a function of prostate volume and provide precautions for the needle insertion procedure to improve the quality of the final dose distribution.

Materials and Methods

In the Centre of Oncology – MSC Memorial Institute Branch Gliwice patients with early stage localized prostate carcinoma (T1–T2) were treated with combined external beam therapy and HDR[192] Ir brachytherapy from 2003. Interstitial brachytherapy of the prostate is delivered as a boost during a single treatment session. Treatment plans are based on transrectal ultrasound imaging and calculated with the Nucletron Swift™ treatment planning system, which was designed for "real time" conformal brachytherapy.

On the basis of the transverse US images, taken with 1 mm scan thickness, volumes of interest such as PTV and organ at risk (urethra) are reconstructed. According to 3D VOI contours a "virtual" implant is prepared. Positions of the needles are established with coordinates of the template holes. Dwell positions in each catheter and dwell weights are determined in order to realize the optimal treatment plan. This "virtual" plan (Figure 1A) is evaluated with parameters of the dose volume histogram V_{100} and D_{10}, which define respectively: the volume of prostate covered by 100% isodose surface, and the dose value that is delivered to 10% volume of the urethra.

The implantation procedure is visualized on the live US images, which allow one to control "live" needle placement according to its virtual coordinates. Insertion of needles always begins with upper right horizontally and ends with lower left corner of the template.

Even small differences between prescribed needle position and the real one result in changes in the virtual dose distribution. Therefore, on the basis of real implant geometry, dwell times are recalculated to obtain the final dose distribution ("live" treatment plan) (Figure 1B). The quality of the "live" plan is also evaluated with dosimetric parameters V_{100} and D_{10}.

In this study thirty treatment plans ("virtual" and "live" calculated for each patient) were randomly selected for analysis. For each treatment plan differences between "virtual" and "real" dose distribution caused by needle displacement were estimated by the new parameter VD (Volume – Dose) (eq. 1)

$$VD = \frac{V_{100\ virtual}}{V_{100\ live}} \cdot \frac{D_{10\ live}}{D_{10\ virtual}} \quad (1)$$

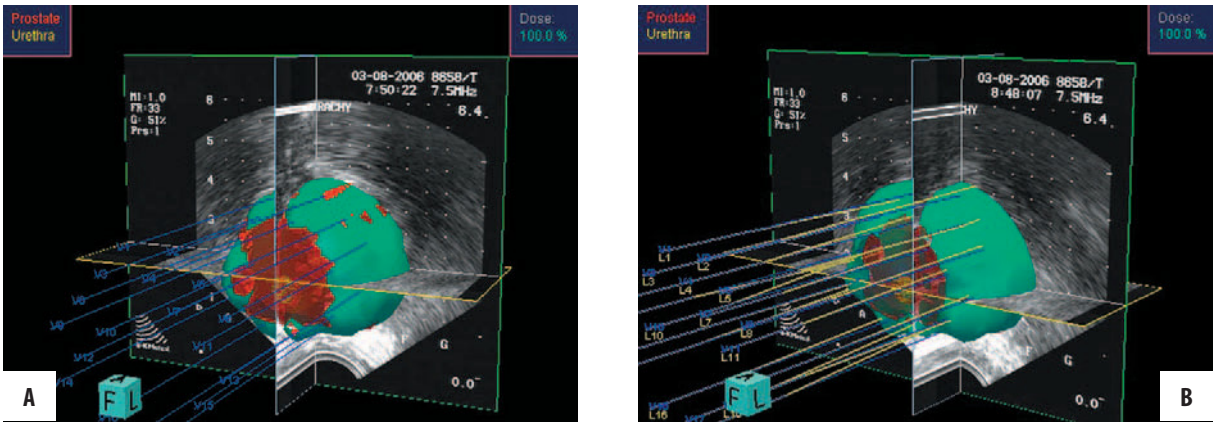

Figure 1. "Real-time" conformal treatment planning for HDR brachytherapy of prostate cancer. (**A**) "virtual" treatment plan before implantation based on pre-planned catheter coordinates and anatomy-based optimization, (**B**) post-implant, final dose distribution calculated for "real" catheter positions and re-optimized for new implant geometry.

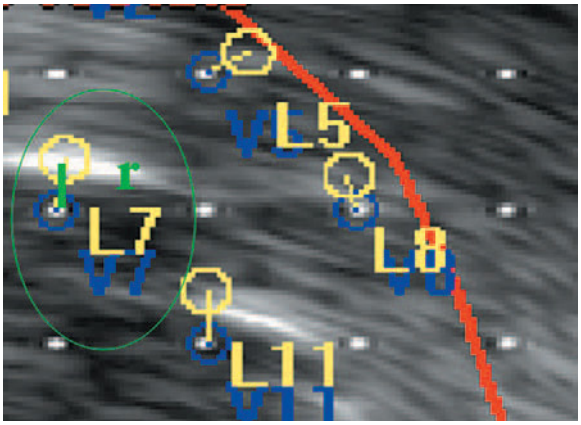

Figure 2. The difference between "virtual" and "real" needle position r in mm measured on the selected axial image define needle displacement.

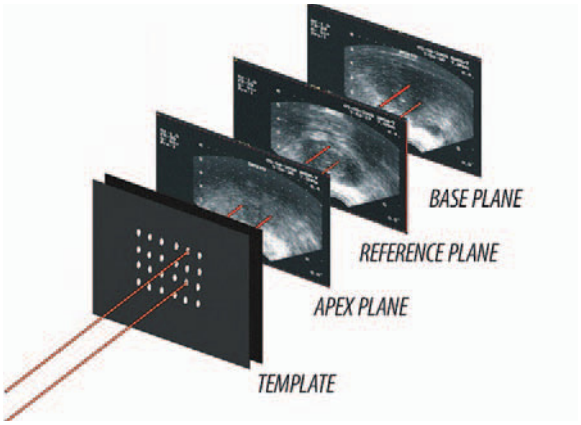

Figure 3. Anatomic plane definition. After image acquisition base, reference and apex planes are defined. Apex refers to the plane that intersects the top of the prostate, while the base is the prostate plane closest to the bladder wall; reference is the middle and the largest cross-section of the gland.

$V_{100\ virtual}$ and $V_{100\ live}$ are fractions of the prostate volume that are encompassed by 100% isodose in the "virtual" and "real" treatment plan, while $D_{10\ virtual}$ and $D_{10\ live}$ are dose values that encompassed 10% volume of the urethra in the "virtual" and "live" treatment plan respectively.

Values of the provided VD formula, which was created for the purpose of our analysis, characterize the final dose distribution with regard to the virtual plan:

When:

a. VD<1 – "real" dose distribution is considered to be better than virtual one for prostate gland and/or urethra,
b. VD>1 – worsening in "real" dose distribution for prostate gland and/or urethra when compared to "virtual" plan,
c. VD=1 – "virtual" and "real" treatment plans are considered to be equivalent.

VD parameter was also designed to compare the differences between "real" and "virtual" treatment plans as a function of needle displacement and prostate volume.

Needle displacement was determined by measuring the distance between "virtual" and "real" positions of respective needles (Figure 2) in three axial images (Figure 3) acquired at the base and the apex of the gland and in the reference image. Mean values of needle displacement were calculated for each plane and for three planes in total.

Results

Needle number, needle displacement and prostate volume

Number of implanted needles varied from 12 to 18 for single "real" treatment plan and the

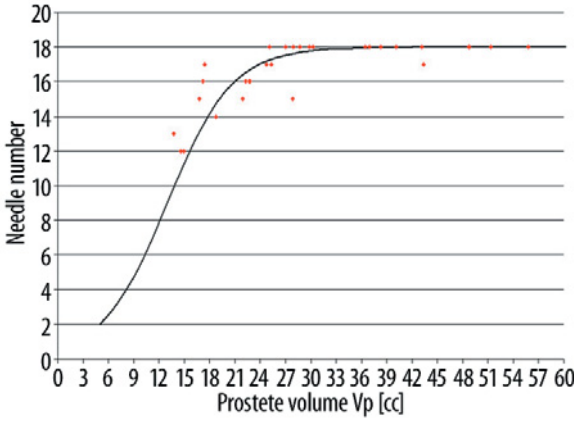

Figure 4. Number of implanted needles depends on prostate volume Vp parameter. Number of needles and their initial coordinates are established with catheter placement option in treatment planning system on the basis of contoured patient anatomy. "Virtual" needle position and its number can be modified manually for better PTV coverage.

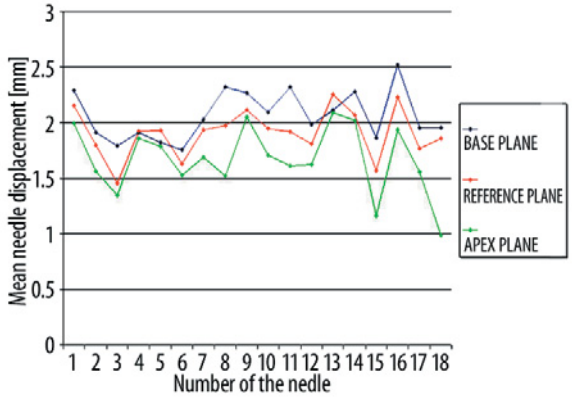

Figure 5. Mean needle displacement for consecutive number of needle calculated for thirty treatment plans in three axial images. The biggest mean needle displacement was observed in the base plane of the prostate.

median needle number was 17.5. Mean prostate volume considered in this experiment was 29.75cc (±11.9cc). Needle number corresponded with prostate volume. Higher prostate volumes were implanted with higher needle number (Figure 4.)

Mean value of the needle displacement r (Figure 2) calculated for thirty "live" treatment plans was 1.8mm (±0.6 mm) and did not depend on implantation sequence but varied depending on the level of transverse imaging: base, apex or reference.

The needle displacement was the smallest for the apex and the biggest for the base plane (Figure 5).

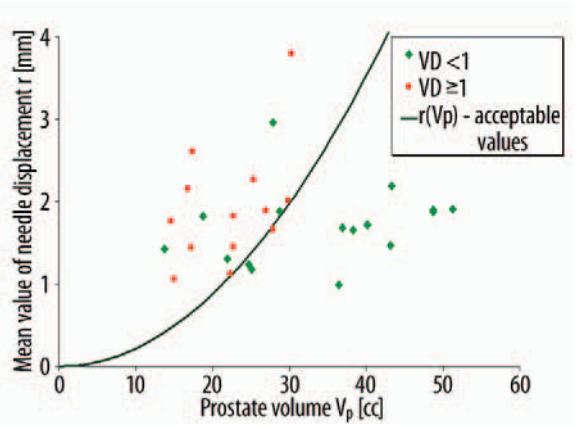

Figure 6. Graph represents the scatter of VD values as a function of prostate volume Vp and needle displacement r. The values of r(Vp) (solid line on the graph) boundary represent the maximum acceptable values of mean needle displacement r_a and are relative to Vp.

Analysis of VD parameter

Influence of mean needle displacement and prostate volume on the final dose distribution was analyzed with VD parameter (Figure 6).

In the group of treatment plans where VD⩽1 mean value of prostate volume was observed to be significantly higher than in the group of VD>1, while needle displacement was statistically equal in both groups (Table 1).

Changes in dosimetric parameters between virtual and live plan depend on needle displacement while prostate volume parameter seems to modulate the extent of dose distribution alteration.

In order to obtain a "real" treatment plan at least equivalent to the "virtual" one, needle displacements for a given prostate volume are required to be equal to or smaller than acceptable, while the acceptable values for a mean needle displacement r are assumed to be determined by the expression:

$$r_{acceptable}(Vp) \propto Vp^2 \qquad (2)$$

Where:
Vp – prostate volume in cc by anatomy based contouring of PTV performed on the acquired US slice before implantation.
$r_{acceptable}$ – prescribed maximum acceptable values of needle displacement for a given Vp value.

The expression led to the conclusion that for smaller glands even slight needle shift from

Table 1. Differences between mean values of geometrical parameters in two groups of VD values.

	VD≤1 n=16	VD>1 n=14	
	mean ± standard deviation		p Mann-Whitney U test
Mean needle displacement r [mm]	1.7±0.46	1.99±0.73	0.28
Prostate volume Vp [cc]	34.25±11.5	24.6±10.45	0.027

pre-planned positions may affect essential changes in virtual dose distribution that cannot be reduced by re-optimization.

Discussion

Modern imaging techniques such as transrectal ultrasounds allow visualization of the procedure of implantation and on-line, "real time" evaluation of the accuracy of needle positioning according to its pre-planned position [7]. Not only for permanent seed implants, careful implant preparation and catheter geometry is an essential part of the treatment planning process in brachytherapy [8,9]. However, the potential tool of dwell time differentiation in HDR stepping source brachytherapy can minimize, to a certain degree, the superfluous underdosed and overdosed volumes resulting from needles' displacement from their pre-planned positions.

The research into the influence of an adequate needle placement regarding its virtual position as a function of prostate volume improves the possibility of predicting the quality of final dose distribution at the time of implantation.

Charra-Brunaud et al. [10] suggested that a higher number of catheters leads to decreasing values of the V_{150} parameter (percentage of prostate volume covered with 150% isodose) that allows large high-dose volumes inside the PTV to be avoided. 15 to 21 needles are an adequate number for preparing an optimal treatment plan. The results seems to be in agreement with our study where the number of implanted needles corresponds with prostate volume and was in the range of 12 to 18, which gave sufficient coverage of PTV by reference isodose in the "virtual" treatment planning phase.

In our study the needle implantation sequence was taken into consideration. We assumed that after implantation of consecutive catheters prostate motion would reduce. According to Lagerburg et al. [2] the use of locking needles results in reduced prostate rotation in the coronal plane and thus improves the implantation accuracy. However, in our experiment no significant differences were observed between needle displacement for first and last implanted needles. Thus, during implantation, the prostate movements were not reduced by the increasing number of implanted needles. Implantation sequence or additional locking needles do not influence the reduction of prostate motion.

The influence of mean needle displacement on dose distribution depends on prostate volume. Changes of the dose distribution calculated for bigger gland volume are less dependent on the needle shift than for smaller prostates (Figure 4). While mean needle displacement is higher than 2mm, final dose distribution for bigger prostate volumes (30cc) can be equivalent or even better than virtual when the renewed optimization procedure was applied to dose distribution calculated on the basis of "real" implant geometry. For prostate volumes lower than 25cc even small differences between "virtual" and "real" needle positions reduce the effectiveness of optimization methods.

If the needle shift exceeds acceptable values for a given Vp parameter, determined by r_a (Vp) function, needle relocation during implantation should be considered.

Optimization algorithms are beneficial for conformal treatment planning in brachytherapy but their usefulness is restricted by insufficient implant geometry.

Conclusions

The calculations demonstrate that final dose distribution depends on needle displacement, which is the distance between "virtual" and "real" needle position, but prostate volume should be taken into consideration. The experiment determined maximal values of needle displacement for a given Vp parameter that still allow one to take advantage of optimizations algorithms to improve the final dose distribution.

However, acceptable values of needle displacement as a function of prostate volume require further research and more complex and multifactorial analysis.

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