Original paper

Benefits of a dual sagittal crystal transducer for ultrasound imaging during I-125 seed implantation for permanent prostate brachytherapy

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Abstract

Purpose: To investigate whether a longer sagittal view and less movement using a dual sagittal crystal probe (DSCP) for trans rectal ultra sound (TRUS) allow for more accurate online-planning in I-125 permanent implant brachytherapy of the prostate, compared to a single sagittal crystal probe (SSCP).

Material and methods: Between March 2008 and March 2010, 50 patients with prostate cancer were consecutively included in the study. The first 25 of these patients had both their pre- and online-planning based on a single sagittal crystal probe (SSCP). The treatment-plans of the other 25 patients were based on a DSCP TRUS. Three weeks after implantation a post-planning was made based on CT. TRUS online and CT post-plan dose-volume histogram (DVH) parameters, D_{90} and V_{100}, were compared for both groups. Also, the post-plan DVH parameters of SSCP were compared to DSCP. The possible factors that might influence the post-plan D_{90} and V_{100} were analysed using Analysis of Variance (ANOVA).

Results: SSCP and DSCP online mean D_{90} and V_{100} were significantly larger than post-plan mean D_{90} and V_{100} ($P < 0.01$). The post-plan mean D_{90} and mean V_{100} were both non-significantly larger for SSCP based post-plans compared to DSCP based post plans ($P = 0.76$ and $P = 0.68$). ANOVA showed significant impact of prostate volume on the post-plan D_{90} and V_{100}.

Conclusions: The advantages of the dual sagittal crystal probe did not lead to more accurate online planning by investigating DVH-parameters. The only factor found to have influence on the DVH-parameters was the prostate volume.

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Key words: prostatic neoplasms, brachytherapy, computer assisted radiotherapy planning, transrectal ultrasound, D_{90}, V_{100}.

Purpose

In permanent I-125 seed implants of the prostate, the quality of the implant depends, amongst other factors, on the quality of the image modality used during implantation. The image modality most frequently used in the Operation Room (OR) is transrectal ultrasound (TRUS), although other modalities like Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) have also been introduced and are still under investigation [1]. TRUS is most often used, because it is available in the OR and it visualizes the prostate, surrounding tissues, the inserted needles and seeds. TRUS makes online-planning possible, while the brachytherapy treatment-planning can be updated continuously, based on the actual placement of the seeds in the prostate. This is useful, because the online treatment plan can be continuously adjusted, with the patient still positioned in lithotomy position and under general anesthesia, until the dose constraints are met. These features cannot be performed with CT based post-planning, because it is too late to instantly correct for an implant of low quality.

These advantages make further improvement of TRUS based treatment-planning possible. For this purpose Ali *et al.* [2], compared pre- and post-implant TRUS and CT based plans for I-125 prostate brachytherapy, using a twister mode. The twister mode acquires longitudinal projections of the prostate by rotating the probe over an angular range. There are several advantages of the twister mode, compared to the stepper mode. The possibility of reconstruction of the slices with variable slice thickness (1 to 5 mm) causes better visualization of the seeds. Another advantage is the rotation of the probe instead of the movement through the rectum. This twister mode enabled evaluation during the implant

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Table 1. Summary of studies

Study	# Pt	# Seeds (activity/ seed)	Prostate volume TRUS	Prostate volume CT	Time between implant and CT	D_{90} post-TRUS	D_{90} CT	V_{100} post-TRUS	V_{100} CT	V_{100} CT
Acher [3]	49	68 (43-128), 28.8 MBq (19.9-39.9)	40 cm^3, mean (SD 14)	40 and 30 cm^3, mean	4 weeks	168 Gy, mean	155.5 Gy, mean	96%, mean	91.5%, mean	91.5%, mean
Kaplan [4]	45		37.7 cm^3 mean (20 pt extra seeds)	35.4 cm^3, mean	4-8 weeks	125.8%, mean	133.6%, mean	97.4%, mean	97.4%, mean	97.4%, mean
			37.3 cm^3 mean (25 pt no extra seeds)	35.5 cm^3, mean		124%, mean	127.5%, mean	96%, mean	96.7%, mean	96.7%, mean
Igidbashian [5]	127, I-125	63 (37-98), 0.45 mCi (0.39-0.65)	38.0 mL (14.0-74.4), median		28 days	172 Gy, median (SD 16.0)	155 Gy, median (SD 27.42)	98%, median (SD 6.82)	94%, median (SD 7.52)	94%, median (SD 7.52)
Chauveinc [9]	450, I-125		35.11 cm^3 (13-80.1 cm^3), mean post implant volume	Mean CT/TRUS volume ratio 1.08 (0.85-2.15)	2 months	183.3 Gy (165-225 Gy), mean	183.5 Gy (115-240 Gy), mean	99.66% (93.15-100%), mean	97.44% (89.45-99.97%), mean	97.44% (89.45-99.97%), mean
Stone [10]	77, Pd-103 I-125	I-125: 116 (72-179)	39.8 cm^3 mean (16.6-87.8)	43.6 cm^3 mean (17.6-95.6)	1 month	110%, mean	113%, mean	83.1%, mean	87.9%, mean	87.9%, mean
Chew [11]	19	73 (55-104)	36.37 cm^3 (mean, postplan TRUS)	31.26 cm^3 (mean)	1 month	165.89 Gy, mean	171.20 Gy, mean	95.04%, mean	90.43%, mean	90.43%, mean
Ohashi [12]	412		22.1 mL, mean (6.2-49.6)	24.7 mL, mean (7.8-53.3)	30 days	118.8%, mean (89.4-143.5) (SD 6.6)	119.2%, mean (79.4-152.1) (SD 11.3)	97.2%, mean (80.7-100) (SD 2.0)	96.8%, mean (73.8-100) (SD 3.1)	96.8%, mean (73.8-100) (SD 3.1)

procedure with soft tissue contrast superior to CT, taking account of oedema and enabling adjustment of the online treatment plan if needed.

Since March 2009 a new TRUS probe is used in the Academic Medical Center (AMC, Amsterdam) for prostate brachytherapy. This probe has two sagittal crystals, with a transversal crystal in between, instead of the conventional single sagittal crystal with a transversal crystal in the front (Fig. 1.). The probe has several advantages. Not only a longer sagittal view of the prostate can be seen with the two sagittal crystals, but the position of the crystals also enables a switching from the transversal to the sagittal mode without moving the probe in craniocaudal direction. These advantages were expected to diminish the movement of prostate and surrounding tissues caused by craniocaudal movement of the probe, enabling better projection of the planning target volume (PTV) and organ at risk (OAR) contours and more accurate seed placement.

A retrospective cohort study was conducted to compare the treatment plans based on a single sagittal crystal probe (SSCP) and based on a dual sagittal crystal probe (DSCP). It was hypothesized that the new probe (DSCP) would improve the quality of the online-planning. As a consequence, CT post-planning was expected to be more comparable with TRUS online-planning with DSCP compared to SSCP. To investigate whether the overall quality of post-planning in the new situation had improved, the CT based plans were also compared for both groups.

The primary objective of this study was to investigate whether DSCP allows for more accurate dose planning in I-125 permanent implant brachytherapy than SSCP. Dose Volume Histogram (DVH) parameters of TRUS online-plans were compared to CT post-plans for both the SSCP and the DSCP groups to investigate the similarity of both plans, assuming CT-based plan evaluation as the quality standard. The secondary objective was to determine whether the post-plan based DVH parameters have improved with the DSCP technique compared to the SSCP technique. The investigated DVH parameters are D_{90} which is the minimal dose received by 90% of the prostate volume and the V_{100} being the volume of the prostate receiving 100% of the prescribed dose.

Material and methods

Our study size was calculated to be 42 patients, to show a significant deviation of more than 20 Gy between online- and post-plan D_{90}. The 20 Gy difference was chosen, because several studies have shown that discrepancies of that magnitude can occur between online- and post-plan D_{90} (Table 1) [3-5]. Our study therefore involved reviewing 50 intra- and post-operative plans of patients who underwent a permanent I-125 implant of the prostate between March 2008 and March 2010. 25 patients were implanted based on the use of a SSCP (Hitachi, Japan) and 25 on the use of a DSCP (Best Medical Systems, USA). Patients were included with histologically confirmed adenocarcinoma of the prostate eligible for I-125 brachytherapy treatment in AMC (see Table 2). No patient had previous antiandrogen therapy. Patients with a metal hip prosthesis were excluded.

Online-planning

In the OR the patients received general anaesthesia and were positioned in lithotomy position with a Foley balloon catheter inserted into the bladder. The TRUS probe was positioned in the rectum and TRUS images were acquired with an axial slice thickness of 1 mm. The clinical target volume consisted of the prostate. The urethra and rectum were delineated without any margins. All volumes were delineated every 5 mm. The treatment-planning program, Permanent Seed Implant Dosimetry 4.2 (D&K Technologies, Germany), was used for preplanning. Dose volume parameters constraints used for treatment-planning were D_{90}-prostate > 168.5 Gy (117% of the 144 Gy reference dose [D_{ref}]); V_{100} > 95% of $V_{prostate}$; $D_{0.1ml}$ urethra < 120% of D_{ref}; $D_{0.1ml}$ rectum < 80% of D_{ref}. Between 32 and 75 I-125 seeds were implanted per patient, with a nominal activity of 18.5 MBq/seed. During the implantation the calculated dose distribution was continuously updated based on the actual seed positions as seen on TRUS. If seeds were difficult to identify, the dose update was based on the position of the needle. The updated plan was considered to be the online-plan. At the end of the procedure, based on the online treatment plan, it was decided whether it was necessary to add one or more seeds at positions where an underdosage was observed.

Post-planning

Three weeks after implantation a CT scan (Lightspeed 16 PRO, General Electric, USA) of the prostate was made, with a slice thickness of 3 mm. No Foley balloon catheter

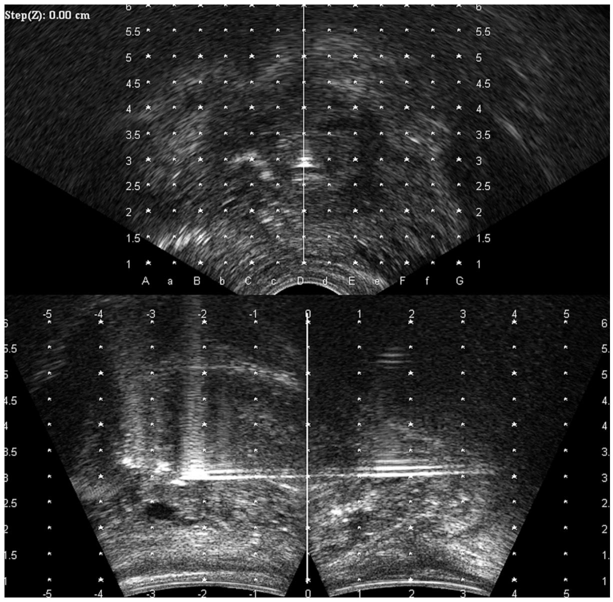

Fig. 1. The long sagittal view shows bladder and prostate. A seed is implanted in basis of the prostate

was used. Between June 2010 and August 2010 all CT scans of the patients being treated between March 2008 and March 2010 were delineated and post-plans were made randomly. Two observers were blinded for treatment date and type of TRUS used for the implant. The prostate and rectum were delineated. Disagreements between the observers were resolved by consensus, to avoid variation in contouring that would influence the result of DVH-parameters calculations. No formal quantitative analysis for disagreement was used, but rather a discussion on the contouring. Seeds were marked and a post operative plan was made. D_{90}-prostate, V_{100}-prostate and $D_{0.1ml}$-rectum were calculated.

Statistical analysis

DVH parameters for both groups were analyzed to see if there was a significant difference between the online- and post-planning, based on the two TRUS probes. A paired *t*-test was used comparing the D_{90} of the online- and post-planning and a non-paired *t*-test was used to compare the

Table 2. Patient characteristics and DVH parameters

	Value, SSCP group	Value, DSCP group
Age at time of treatment, mean (SD)	65.80 years (5.54)	64.12 years (8.77)
Online plan (TRUS) prostate volume, mean (SD)	38.67 cc (9.46)	29.88 cc (8.28)
Post plan (CT) prostate volume, mean (SD)	36.10 cc (8.64)	27.99 cc (8.13)
Number of needles, median (range)	23 (12-29)	18 (15-28)
Number of seeds in online plan, median (range)	59 (44-70)	50 (32-75)
Number of seeds in post plan, median (range)	59 (44-70)	50 (32-74)
D_{90} online plan (TRUS), mean (SD)	170.12 Gy (14.19)	167.94 Gy (11.13)
D_{90} post plan (CT), mean (SD)	149.53 Gy (20.03)	147.64 Gy (23.33)
V_{100} online plan (TRUS), median (range)	99.1% (91.5-99.1%)	99.3% (97.7-99.9%)
V_{100} post plan (CT), median (range)	93.1% (64.7-98.4%)	90.1% (56.8-99.6%)

post-plan D_{90} of the SSCP technique with the post-plan D_{90} of the DSCP technique. The V_{100} values were non-normal distributed and therefore a Wilcoxon signed rank test was used comparing the V_{100} parameters of the online- and post-planning and a Mann-Whitney U test comparing the post-plan V_{100} parameters of the SSCP technique to the V_{100} parameters of the DSCP technique.

Possible factors that could have influenced the post-plan D_{90} or V_{100} were: the prostate volume, number of needles, number of seeds and age. Therefore, patients were divided into three equally sized groups for each of these factors, to facilitate analysis of variance (ANOVA). The analysis started with all factors included and one after another the least significant factor was removed from the model. Statistical analysis was performed with Statistical Package for the Social Sciences 16.0 (SPSS, IL, USA).

Results

Table 2 shows the prostate volume, D_{90} and V_{100} resulting from the online- and post-plan for both SSCP and DSCP. The prostate volumes in the SSCP group are larger than the volumes in the DSCP group. The mean difference is 8.79 ml for the online-plan and 8.11 ml for the post-plan volume. The number of needles and seeds used for implantation depend on the prostate volume and are therefore also a little higher in the SSCP group. The prostate volume had a mean difference of 2.57 ml (SSCP) and 1.89 ml (DSCP) between online- and post-planning, with a larger prostate drawn on TRUS images compared to CT. In six cases one seed from the online-planning could not be identified in the post-planning.

Primary outcomes

Both for SSCP and DSCP, the online mean D_{90} was statistically significantly larger than post-plan mean D_{90} ($P < 0.01$). For SSCP this difference for the D_{90} was 20.6 Gy and for DSCP it was 20.3 Gy. SSCP online- and post-plan mean V_{100} differed 7.4% whereas for DSCP the difference was V_{100} 9.9% (both $P < 0.01$) (Table 2).

Secondary outcomes

The post-plan mean D_{90} and mean V_{100} were both statistically non-significantly higher for the SSCP based post-plans compared to DSCP based post-plans, being 1.89 Gy and 3%, respectively ($P = 0.76$ and $P = 0.68$) (Table 2).

Possible factors that influence post-plan D_{90} or V_{100}

ANOVA showed statistically significant impact of prostate volume on the post-plan D_{90}. Age, number of seeds and number of needles had no significant impact. Post hoc tests showed significant difference between the group with the largest prostate volume in the OR (mean D_{90} of 158.97 Gy) compared to the group with the intermediate (D_{90} of 145.27 Gy) and smallest prostate volume (D_{90} of 141.08 Gy). For prostate volume on CT, the group with the intermediate prostate volume had the highest D_{90} (155.41 Gy), while the group with the smaller prostate volume had a D_{90} of 141.84 Gy, and 148.11 Gy for the larger prostate volume group. ANOVA indicated that prostate volume in the OR was the only factor having impact on the post-plan V_{100}. The post hoc test showed statistically significant difference between the group with the largest (V_{100} of 93.85%) compared to the group with the smallest prostate volume (V_{100} of 86.96%).

Discussion

The advantages of the DSCP, as mentioned in the introduction, were expected to result in improved quality of the online and post-plans. To investigate the impact of DSCP on the implant quality, 50 patients were consecutively selected for this study. The patients were selected in a period when the brachytherapy team performing the implant was stable, with the same group of people making the treatment plans and implanting the prostate. Therefore, the quality of the online-plans was expected to be comparable for all 50 patients. Results for both D_{90} and V_{100} of the online- and post-plan were reported. By using both parameters a representative description of the dose distribution was obtained.

Despite the use of a new TRUS probe, a significant difference between the intra and post operative planning D_{90} and V_{100} was seen for both SSCP and DSCP based treatment plans. When considering the online-plan, the standard deviation (SD) of the D_{90} of SSCP and DSCP were 14.2 Gy and 11.1 Gy and the V_{100} ranged from 91.5 to 99.1% and from 97.7-99.9%, respectively. The post-plan SD of the D_{90} was 20.0 Gy for SSCP and 23.3 Gy for DSCP, respectively, while post-plan ranges for V_{100} were 64.7-98.4% and 56.8-99.6%, respectively. The online-plan D_{90} and V_{100} in the DSCP group were very similar among the patients. However, the post-plans were less comparable among the patients for both the SSCP and the DSCP group, indicating that the differences between the post-plans do not predominantly dependent on the prostate movement during implantation as was hypothesized. Other factors are playing a major role in this respect. Although stranded seeds were used, the seeds might still migrate after implantation [6]. This could be an explanation for the more comparable online-plans with DSCP, but less comparable post-plans.

The use of the DSCP probe not only failed to result in post-plans with less variation among the patients, but also did not lead to a difference in D_{90} en V_{100}-values compared to the SSCP probe. The only factor having significant influence on the DVH parameters D_{90} and V_{100}, was the prostate volume, with larger prostate volumes resulting in higher D_{90} and V_{100} values on the post-planning 3 weeks after the implant. Prostate volume is therefore a more important factor determining the resulting dose to the prostate than the type of TRUS probe used. Prostate movement due to insertion of the needles is another factor influencing the quality of the implant. Because the prostate movement due to insertion of the needles was the same for both types of TRUS probes used, this might explain why no differences in D_{90} en V_{100}-values of the two groups were found.

The retrospective study caused the prostate volumes to be unequally divided over the SSCP and DSCP groups, with the SSCP group containing larger prostates and the DSCP group containing smaller prostate volumes. However, the difference in prostate volume and D_{90} is constant for both the SSCP and the DSCP group between the online and post-plan. Therefore, we do not expect the difference in prostate volume between the two probe groups had influenced the outcome.

McNeely *et al*. [7] found significant differences in dose outcomes in relation to the prostate volume. In patients with prostate volumes smaller than 25 ml, 20% had a D_{90} < 140 Gy and only 7% had a D_{90} > 180 Gy. They suggest that increasing the implanted activity might be considered for this group. Acher *et al*. [3] assessed the agreement between online- and post-planning DVH-parameters. They found online-plan D_{90} and edema to be significantly influencing the post operative D_{90}. They pointed out several factors influencing delineation of the prostate volume. At first the setting in the OR which was different compared to CT, with the patient in lithotomy position, anesthesia causing pelvic muscle relaxation and deformation of the prostate gland by the rectal TRUS probe. Secondly, the circumstances in which the prostate was delineated and seed positions were marked, like edema, hemorrhage, needle artifacts and time pressure in the OR. On CT the patient was in supine position and the prostate was delineated every 3 mm instead of every 5 mm with ultrasound. Also no anesthesia or a rectal probe was used when performing a CT-scan. Ali *et al*. [2] described that both variation in the filling of the bladder and the rectum and the use of the Foley catheter in the OR might have influence on the shape of the prostate.

The differences between online- and post-plan DVH parameters might also be caused by the accuracy of seed localization. In this study seeds with rather high activity were used, compared to others [8]. Because of the high activity the number of seeds used is relatively reduced. If the positions of the seeds are not reconstructed in the actual position in which they were implanted, a difference between online- and post-plan dose volume parameters can be expected and exaggerated. Kaplan *et al.* [4] mention the rapid dose fall-off of the seeds as a reason for large differences between pre and post-planning, because of small differences in planned and actual location of the seeds.

Because of the online information obtained during implantation, it cannot be excluded that even with a moving prostate when using an SSCP probe, high quality implantations are obtained. Small misplacements of seeds and the resulting deviation of dose distribution are automatically corrected with the subsequent seed placements. Therefore the resulting post-plans have been found to be similar to implantations performed with a DSCP probe.

Conclusions

The longer sagittal view and less movement of prostate and surrounding tissues with the DSCP enabled better visualisation in one view, which resulted in more homogeneous online-plans among patients. However, this did not lead to improved DVH-parameters in I-125 permanent prostate implants. TRUS and CT based D_{90} and V_{100} were statistically significantly different and the post-plan based D_{90} and V_{100} did not improve with the DSCP technique compared to the SSCP technique.

The most important factor found to influence DVH-parameters was the prostate volume.

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