Obstructive urination problems after high-dose-rate brachytherapy boost treatment for prostate cancer are avoidable

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Background. Aiming at improving treatment individualization in patients with prostate cancer treated with combination of external beam radiotherapy and high-dose-rate brachytherapy to boost the dose to prostate (HDRB-B), the objective was to evaluate factors that have potential impact on obstructive urination problems (OUP) after HDRB-B.

Patients and methods. In the follow-up study 88 patients consecutively treated with HDRB-B at the Institute of Oncology Ljubljana in the period 2006-2011 were included. The observed outcome was deterioration of OUP (DOUP) during the follow-up period longer than 1 year. Univariate and multivariate relationship analysis between DOUP and potential risk factors (treatment factors, patients’ characteristics) was carried out by using binary logistic regression. ROC curve was constructed on predicted values and the area under the curve (AUC) calculated to assess the performance of the multivariate model.

Results. Analysis was carried out on 71 patients who completed 3 years of follow-up. DOUP was noted in 13/71 (18.3%) of them. The results of multivariate analysis showed statistically significant relationship between DOUP and anticoagulation treatment (OR 4.86, 95% C.I. limits: 1.21-19.61, p = 0.026). Also minimal dose received by 90% of the urethra volume was close to statistical significance (OR = 1.23; 95% C.I. limits: 0.98-1.07, p = 0.099). The value of AUC was 0.755.

Conclusions. The study emphasized the relationship between DOUP and anticoagulation treatment, and suggested the multivariate model with fair predictive performance. This model potentially enables a reduction of DOUP after HDRB-B. It supports the belief that further research should be focused on urethral sphincter as a critical structure for OUP.

Key words: prostate cancer; high-dose-rate brachytherapy boost; late effects; urinary stricture; obstructive urination problems.

Introduction

Several modes of radical local treatment are on disposal for patients with localized or locally advanced prostate cancer. Beside radical prostatectomy, radical irradiation in the form of external beam radiotherapy (EBRT), and permanent brachytherapy (PB) or high-dose-rate brachytherapy (HDRB) are established ways of treatment. Both treatment modalities should be considered as equally effective in the absence of randomized trials. Similar consideration should also be given to different ways of radiation treatment.1,2 When radiation therapy is applied, EBRT could be combined with either form of brachytherapy. The combination of EBRT and HDRB to boost the dose to prostate (HDRB-B) is effective treatment, according to some reports more effective than EBRT alone.3-5 Any of above mentioned treatments could expose patients to late side effects. Especially long-term consequences could be decisive for patients’ determination for one or other treatment. Well
known long-term complications are bladder neck contractures after radical prostatectomy, and urethral strictures after PB or HDRB-B.

In HDRB-B obstructive urination problems (OUP), including urethral strictures, are the most frequent urinary severe late effect. According to results of studies in the past the frequency of only strictures was 1.5–9%. Some recent studies report even considerably higher frequency. Previous transurethral resection of the prostate (TURP), fractionation schedule of HDRB-B with increased risk with higher fractional dose, older age, and hypertension, were considered as potential patient-related risk factors but their role was not clearly defined. Furthermore, there were found no reliable normal tissue absolute dose constraints for urinary toxicity.

This high stricture risk with problems that evolve with stricture formation should be factored into counselling all men who are considering HDRB-B and could curtail patient’s decision for HDRB-B, since with refinement of radical prostatectomy, or PB, the expected frequency of these marked lower urinary tract OUP could be considerably lower.

At the Ljubljana Institute of Oncology HDRB-B was started in October 2006, and up to now, late effects, including OUP and stricture formation, have not been evaluated yet.

Aiming at improving treatment individualization in patients with prostate cancer treated with HDRB-B, the objective of the present study was to evaluate factors that have potential impact on OUP after HDRB-B.

Patients and methods

Patients

In the follow-up study 88 patients, consecutively treated by the author with HDRB-B at the Institute of Oncology Ljubljana in the period 2006–2011, were included.

HDRB-B treatment was primarily offered to patients with intermediate- or high-risk clinically localized or locally advanced prostate cancer (according to D’Amico risk stratification of prostate cancer patients) and to low risk patients refused to get radical prostatectomy, if feasible for brachytherapy. In general, patients were considered eligible for HDRB-B if (i) ultrasound showed no pubic arch interference, (ii) were eligible to undergo regional anaesthesia with spinal block, and (iii) were eligible to perform CT/MRI scan. TURP was considered as a contraindication for the procedure.

Study protocol was approved by the Protocol and Ethical Committee of the Institute of Oncology Ljubljana.

Treatment characteristics

Brachytherapy consisted of ultrasound guided transperineal insertion of 20 or 30 cm long close-end plastic needles (Varian, California, USA) into the prostate, and in selected patients also into the initial part of seminal vesicles. An in-house made template allowing needle fixation was used. Needles were typically placed into prostate periphery. Cystoscopy was performed to control for urinary bladder or urethral puncture. CT or MRI scan was used for planning purposes. Brachyvision planning system (Varian, California, USA) was used for image registration, contouring and dosimetry. Two planning target volumes (PTVs) were routinely defined: PTV1 and PTV2. PTV1 encircled the prostate with additional 3 mm margin around the zone of suspected capsular invasion, while PTV2 encircled peripheral part of the prostate. If visible on the MRI images, also gross tumour volume (GTV) was defined and included in the PTV2.

Initially, prescribed dose was 21 Gy to PTV1 and 22.5 Gy to PTV2, with 7 Gy and 7.5 Gy per fraction, respectively. Later, the dose was reduced to 18 Gy to PTV1 and 19.5 Gy to PTV2, also given in 3 fractions in 2 consecutive days. Urethra was indentified with the urinary catheter. The contour also enclosed additional 1-2 mm margin around the catheter. Contouring of urethra started at bladder base and extended to genitourinary diaphragm inferiorly (always at least 0.5 cm caudally from the last slice of contoured apex of the prostate). Minimal dose received by 90% of the urethra volume (D90urethra volume) was planned to be below 110%, while minimal dose received by 1% of the urethra volume (D1urethra volume) was planned to be below 130% of the prescribed dose. Treatment was delivered with Gammamed plus device (Varian, California, USA) using 192Iridium with the activity of 0.7-1.4 Ci.

EBRT was delivered as 3-dimensional conformal radiation. The details of technique have been described elsewhere. The patients were simulated in supine position with knee and feet fixation device and urethrogram, to define prostatic apex. Clinical target volume (CTV) included prostate and distal 2/3 of seminal vesicles with lymph nodes along external, internal and common iliac vessels in patients with Gleason Score (GS) 8–10 or locally advanced tumours, or if the risk of positive lymph
nodes ($R_{N^+}$) exceeded 15% according to the equation of Roach et al. (Equation 1).23

$$R_{N^+} = \frac{2}{3} \text{PSA} + 10(\text{GS} - 6)$$  \[\text{Equation 1}\]

$\text{PSA} = \text{the pre-treatment prostate-specific antigen}$

$\text{GS} = \text{the pre-treatment Gleason score}$

Uniform 1 cm margin was added to CTV to form PTV. Prior to treatment planning three gold-en markers were implanted into the prostate. If treatment started with HDRB treatment, markers were implanted together with needle insertion. Prescribed dose was 50.4 Gy. The PTVs were required to be enclosed in 95% isodose relative to the prescribed dose. Basically, box technique was used, with additional small fields to homogenize the dose delivery. All patients were treated using 15 MV photons. During treatment prostate position was determined using MV portal imaging and implanted markers. Daily off-line position correction was used.

A constitutive part of treatment was also the androgen deprivation therapy. In principle 3 years of androgen deprivation was advised to high-risk patients and also to some intermediate-risk patients with cancer overgrowth in the majority of biopsy cores or with MRI evidenced infiltration of periprostatic tissue or seminal vesicles. One year of androgen deprivation was advised to the rest of intermediate-risk patients. In low-risk patients androgen deprivation therapy was given either to reduce the prostate volume, or was initiated by the referring urologist after prostate biopsy and continued afterwards until the end of radiation treatment. Patients on androgen deprivation were followed-up every 6 months. After the discontinuation of androgen deprivation, patients were seen yearly, with PSA testing every six months. After the first follow-up visit 3–6 months after treatment, the same way of annual check-ups was used in patients without adjuvant androgen deprivation.

### Study instrument for assessment of obstructive urination problems

An in-house made questionnaire, used already for several years, was used as the study instrument. The questionnaire was discussed with patients at follow-up visits. The aim of the questionnaire was to detect late effects of treatment more precisely as would be by open questions, and to allow to grade late toxicity according to Radiation Therapy Oncology Group (RTOG)24 subjective part of RTOG/EORTC Soma Scales25 and Common Terminology Criteria for Adverse Events Ver. 3.0 (CTCAE). Late urinary toxicity was addressed with regard to dysuria, frequency, haematuria, incontinence and obstruction. In Table 1 the questions addressing OUP are presented. Patients were asked to complete the questionnaire just before the start of the HDRB-B treatment, at first follow-up visit and yearly thereafter.

### TABLE 1. Questions addressing obstructive urination problems in Ljubljana Institute of Oncology questionnaire about adverse health effects of radiation therapy

<table>
<thead>
<tr>
<th>Question</th>
<th>Possible answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did you have a sensation of not emptying your bladder in the previous month</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Did you find stopping and starting again several times when you urinated in the previous month</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Did you have weak urinary stream in the previous month</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Did you have to strain to start urination in the previous month</td>
<td>Yes/No</td>
</tr>
<tr>
<td>If you had any of the problems, how often did they occur</td>
<td>Occasionally At least once a week Daily At every urination</td>
</tr>
<tr>
<td>How big were these problems for you</td>
<td>No problem Very small problem Small problem Moderate problem Big problem</td>
</tr>
<tr>
<td>Did you have to get urinary catheter in the last half of the year</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Were you operated because of the mentioned problems</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Did you still have urinary catheter</td>
<td>Yes/No</td>
</tr>
</tbody>
</table>
Observed outcome

The observed outcome was deterioration of OUP (DOUP) during the follow-up period longer than 1 year, supposing to be a manifestation of late radiation urethral injury. It was defined in several steps.

Firstly, the presence of OUP just before the start of the HDRB-B treatment was established. The problems were graded according to the following scale: 1-occasional (less than weekly), 2-regular (about daily), 3-regular (daily) with at least one episode of urgent urethral catheter placement, 4-regular (daily) with at least one episode of urethral dilatation or endoscopic intervention, 5-refractory obstruction (permanent urinary catheter, supravesical urine derivation).

During the follow-up period the grade of OUP was checked-up in the 2nd, the 3rd, the 4th and the 5th year after the beginning of the HDRB-B treatment.

Finally, the difference in grade of OUP between OUP at the start of the HDRB-B treatment and later follow-up visits was assessed. The following scale was used: 1-major improvement (decrease in OUP for two or more grades), 2-minor improvement (decrease in OUP for one grade), 3-no change, 4-minor deterioration (increase in OUP for one grade), 5-major deterioration (increase in OUP for two or more grades). Since minor and major deterioration were the categories of interest, these two categories were combined in the observed outcome - DOUP (0 = no, 1 = yes).

In order to achieve a sufficiently large number of observed persons, analysis of association between observed outcome and potential risk factors was carried out only in patients who completed 3 years of follow-up. The occurrence of DOUP in the 2nd or in the 3rd year of follow-up was considered.

Risk factors for deterioration of obstructive urination problems

Two groups of risk factors were observed. The first group consisted of HDRB-B and supportive treatment factors, while the second group consisted of patients’ characteristics.

In the group of HDRB-B and supportive treatment factors following factors were observed: number of implanted needles (Nimplemented needles), planning imaging (1 = CT, 2 = MRI), number of interventions (Ninterventions) (0 = 1, 1 = 2+), and dosimetric factors, being PTV1, minimal dose received by 100% of the PTV1 (D100_{PTV1}), minimal dose received by 90% of the PTV1 (D90_{PTV1}), minimal dose received by 100% of the PTV2 (D100_{PTV2}), urethral volume (V_{urethra}), mean urethral dose (DMEAN_{urethra}), D90_{urethra volume}, minimal dose received by 10% of the urethra volume (D10_{urethra volume}), and D1_{urethra volume}. All of dosimetric factors were retrospectively extracted from Dose-Volume Histograms stored in electronic patients’ files. As supportive treatment factor the duration of androgen deprivation therapy was included (0 = < 12 months, 1 = ≥ 12 months).

In the group of patients’ characteristics the following factors were observed: age, co-morbidity (hypertension: 0 = no, 1 = yes, diabetes: 0 = no, 1 = yes, coronary insufficiency: 0 = no, 1 = yes, hyperlipidemia: 0 = no, 1 = yes, history of cerebrovascular insult or peripheral deep venous thrombosis: 0 = no, 1 = yes), and anticoagulant treatment (vitamin K antagonist or antiplatelet drug) (0 = no, 1 = yes). All of them were extracted from patients’ files.

Statistical analysis

All data were first statistically described. Parametric (mean ± standard deviation, minimum and maximum) or nonparametric methods (median, range) for numerical data, or percentages for attributable data were used.

Afterwards the univariate and multivariate relationship analysis between DOUP and potential risk factors (treatment factors, patients’ characteristics) was carried out. Univariate analysis was carried out by using binary logistic regression or Fisher’s exact test (in one variable logistic regression analysis could not be performed due to no observed outcome in one category). In multivariate analysis binary logistic regression was used. All variables that were meaningful for the observed outcome and univariately at least marginally statistically significantly associated with DOUP (p < 0.250) were included in the multivariate model.26 On the basis of logistic regression model, the risk-score (logit) for each participant was calculated (Equation 2) and afterwards converted to the risk estimates (p(x)) for the observed outcome (Equation 3).

\[
\text{logit} = \ln \left( \frac{p(x)}{1-p(x)} \right) = a + b_1 x_1 + b_2 x_2 + ... + b_n x_n
\]  
\[
p(x) = \frac{e^{\text{logit}}}{1 + e^{\text{logit}}}
\]  

Finally, the risk estimate values were put in an ordered series from the lowest to the highest value.
At every value the cut-point was placed, a decision matrix defined taking into account the actual status of presence/absence of observed outcome, and nosological (true-positive, false-positive, true-negative and false-positive rates) as well diagnostic test validity measures (positive and negative predictive values) calculated.27-29 Also the receiver operating characteristic (ROC) analysis was performed (ROC curve constructed and the area under the curve calculated).29 Decision about the best possible cut-point (the cut-point with the highest true positive rate at the highest acceptable false positive rate) was supported by calculating Youden index (the maximum vertical distance between the ROC curve and the diagonal/chance line).30

In all statistical tests p-value 0.05 or less was considered significant. SPSS statistical package for Windows Ver. 21.0 was used for analysis.

### Results

#### Description of the study group

Patients in the study group were aged 67.6 ± 6.1 years, with following tumour characteristics: Gleason score: £ 6 22/88 (25.0%), 7 37/88 (42.0%), ≥ 8 29/88 (33.0%); percent of positive cores: median 50 (range 10–100); PSA: median 10 ng/ml (range 4–60 ng/ml); stage: T1 18/88 (20.5%), T2 40/88 (45.5%), T3 30/88 (34.0%); risk category: low 13/88 (14.8%), intermediate 27/88 (30.7%), high 48/88 (54.5%).

Androgen deprivation treatment was received by 81/88 (92.0%) patients (median duration 24 months (1–60 months); duration less than 12 months: 10/81 (12.3%) patients).

In most patients the comorbidities were present. The most frequent was hypertension (46/86, 53.5%), followed by hyperlipidemia (20/85, 23.5%), coronary insufficiency (17/86, 19.8%), history of cerebrovascular insult or peripheral deep venous thrombosis (11/86, 12.8%) and diabetes (10/85, 11.8%).

During the HDRB-B treatment 22/86 (25.6%) of patients were receiving anticoagulation therapy.

#### Description of the treatment

Regarding the dose to PTV1, 21 Gy was delivered to 27/88 (30.7%) patients, while 18 Gy to 61/88 (69.3%) patients. Target volume was restricted to prostate in 79/88 (89.8%), while in 9/88 (10.2%) of patients it was enlarged to enclose infiltrated parts of seminal vesicles. Dosimetric parameters of HDRB-B applied in the study are summarized in Table 2.

Mean N implanted needles was 15±3, while N interventions was one in 80/88 (90.9%), and two or more in 8/88 (9.1%) patients. CT based planning was used in 30/88 (34.1%), while MRI was used in 58/88 (65.9%) patients.

#### Obstructive urination problems at the beginning of the study

At the start of treatment OUP were declared in 52/88 (63.4%) patients that had complete entry data. In majority of them problems were not significant and were assessed as grade 1 in 46/52 (88.5%). In the rest of patients, problems were more pronounced and assessed as grade 2 in 5/52 (9.6%) and as grade 3 in 1/52 (1.9%) patients.

#### Analysis of deterioration of obstructive urination problems during the follow-up period

The course of OUP after treatment in relation to initial problems is presented as a prevalence rates during the 2nd, the 3rd, the 4th and the 5th year of observation (Table 3). In this time frame the proportion of patients with DOUP after initial increase remained stable. On the other hand it seemed that the proportion of patients that experienced improvement of initial obstructive problems increased (Table 3).
Analysis of association between deterioration of obstructive urination problems and potential risk factors

Analysis of association between observed outcome and potential risk factors was carried out in 71 patients who completed 3 years of follow-up. DOUP occurred in the 2nd or in the 3rd year in 13/71 (18.3%) of patients.

In the group of HDRB-B and supportive treatment factors none of them was statistically significantly associated with the DOUP (Table 4). However, according to predefined criterion PTV1 and D90urethra volume were candidates for entering the multivariate analysis.

In the group of patients’ characteristics also the vast majority of factors did not show statistically significant association with DOUP (Table 5). The only exception was anticoagulation treatment in which association with observed outcome was statistically significant, and thus was a candidate for entering the multivariate analysis. In the majority of patients receiving this treatment, it consisted of acetyl salicylic acid either alone (11/17 patients) or in the combination with warfarin (2/17 patients). Tidapidine was given to 2/17, warfarin to 1/17.

TABLE 3. Prevalence rates of alteration of obstructive urination problems in Ljubljana Institute of Oncology study of late toxicity after high-dose-rate brachytherapy boost treatment for prostate cancer

<table>
<thead>
<tr>
<th>Year of follow-up</th>
<th>N</th>
<th>Major improvement</th>
<th>Minor improvement</th>
<th>No change</th>
<th>Minor deterioration</th>
<th>Major deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd year</td>
<td>80</td>
<td>1 (1.3%)</td>
<td>10 (12.5%)</td>
<td>57 (71.3%)</td>
<td>12 (15.0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>3rd year</td>
<td>71</td>
<td>1 (1.4%)</td>
<td>11 (15.5%)</td>
<td>51 (71.8%)</td>
<td>8 (11.3%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>4th year</td>
<td>45</td>
<td>2 (4.4%)</td>
<td>7 (15.6%)</td>
<td>31 (69.9%)</td>
<td>4 (8.9%)</td>
<td>1 (2.2%)</td>
</tr>
<tr>
<td>5th year</td>
<td>25</td>
<td>0 (0%)</td>
<td>6 (24.0%)</td>
<td>16 (64.0%)</td>
<td>3 (12.0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

TABLE 4. Results of univariate logistic regression analysis of association between deterioration of obstructive urination problems and treatment factors in Ljubljana Institute of Oncology study of late toxicity after high-dose-rate brachytherapy boost treatment for prostate cancer

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Ntot</th>
<th>Ndet/Ncat (%)</th>
<th>OR</th>
<th>95 % C.I. limits for OR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N implanted needles</td>
<td>71</td>
<td>0.89</td>
<td>0.71</td>
<td>1.11</td>
<td>0.305</td>
</tr>
<tr>
<td>Planning imaging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>71</td>
<td>3/25 (12.0%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRI</td>
<td>10/46 (21.7%)</td>
<td>2.04</td>
<td>0.51</td>
<td>8.22</td>
<td>0.317</td>
</tr>
<tr>
<td>N interventions</td>
<td>71</td>
<td>10/63 (15.9%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2+</td>
<td>3/8 (37.5%)</td>
<td>3.18</td>
<td>0.65</td>
<td>15.48</td>
<td>0.152</td>
</tr>
<tr>
<td>PTV1 (ml)</td>
<td>70</td>
<td>1.03</td>
<td>0.99</td>
<td>1.07</td>
<td>0.149</td>
</tr>
<tr>
<td>D100PTV1 (Gy)</td>
<td>71</td>
<td>1.08</td>
<td>0.76</td>
<td>1.53</td>
<td>0.656</td>
</tr>
<tr>
<td>D90PTV1 (Gy)</td>
<td>71</td>
<td>0.93</td>
<td>0.68</td>
<td>1.28</td>
<td>0.673</td>
</tr>
<tr>
<td>V urethra (ml)</td>
<td>70</td>
<td>0.99</td>
<td>0.75</td>
<td>1.31</td>
<td>0.941</td>
</tr>
<tr>
<td>D-MEAN urethra (Gy)</td>
<td>70</td>
<td>1.22</td>
<td>0.55</td>
<td>2.74</td>
<td>0.626</td>
</tr>
<tr>
<td>D-MEAN urethra volume (Gy)</td>
<td>71</td>
<td>1.06</td>
<td>0.84</td>
<td>1.35</td>
<td>0.629</td>
</tr>
<tr>
<td>D90 urethra volume (Gy)</td>
<td>71</td>
<td>1.18</td>
<td>0.95</td>
<td>1.47</td>
<td>0.145</td>
</tr>
<tr>
<td>D100 urethra volume (Gy)</td>
<td>70</td>
<td>1.07</td>
<td>0.87</td>
<td>1.31</td>
<td>0.521</td>
</tr>
<tr>
<td>D1 urethra volume (Gy)</td>
<td>71</td>
<td>1.03</td>
<td>0.86</td>
<td>1.22</td>
<td>0.780</td>
</tr>
<tr>
<td>Androgen deprivation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 12 months</td>
<td>69</td>
<td>2/9 (22.2%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 12 months</td>
<td>11/60 (18.3%)</td>
<td>0.79</td>
<td>0.14</td>
<td>4.31</td>
<td>0.781</td>
</tr>
</tbody>
</table>

N = total number of observations, Ndet = number of patients with deterioration; Ncat = number of patients within the category; N implanted needles = number of implanted needles; N interventions = number of interventions; PTV1 = planning target volume 1; PTV2 = planning target volume 2; D100PTV1 = minimal dose received by 100% of the PTV1; D90PTV1 = minimal dose received by 90% of the PTV1; D100PTV2 = minimal dose received by 100% of the PTV2; V urethra = urethral volume; D-MEAN urethra = mean urethral dose; D90 urethra volume = minimal dose received by 90% of the urethra volume; D100 urethra volume = minimal dose received by 100% of the urethra volume; D1 urethra volume = minimal dose received by 1% of the urethra volume.
while acenocoumarol to 1/17 patients. In the group of 6 patients with DOUP, anticoagulation treatment consisted of acetyl salicylic acid in 4 patients, a combination of acetyl salicylic acid and warfarin in one, and warfarin alone in one patient.

All data necessary to perform multivariate analysis were present in 68/71 patients (95.8%). The results of the logistic regression model showed that anticoagulation treatment not only remained statistically significantly associated with observed outcome but even increased (the odds for DOUP were about 4.9-times higher in patients on anticoagulation treatment). In addition, D90\textsubscript{urethra volume} came closer to the border of statistical significance (for a one-Gy increase in D90\textsubscript{urethra volume}, about 23% increase in odds of experiencing observed outcome could be expected). All other results are presented in Table 6.

Finally, the risk of DOUP was estimated for each patient. The values varied between 0.02509 and 0.62421, with the median value 0.10973. The value of area under ROC curve was 0.755, indicating fair predictive performance of the model. The best cut-point was placed at value 0.16441 (true positive rate: 9/12 or 0.750; false positive rate: 16/56 or 0.286; true negative rate: 40/56 or 0.714; false negative rate: 3/12 or 0.250; positive predictive value: 9/25 or 0.360; negative predictive value: 40/43 or 0.930; Youden index: 0.464).

### Discussion

The main results of the study

The most prominent result of present study was strong association of DOUP after HDRB-B with anticoagulation treatment. Based on the available literature this association has not been reported yet up to now. Generally, patient-related risk factors, with exception of age and prior TURP, were only

### Table 5

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>N\textsubscript{tot}</th>
<th>N\textsubscript{det}/N\textsubscript{cat} (%)</th>
<th>OR</th>
<th>95% C.I. limits for OR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>70</td>
<td></td>
<td>1.05</td>
<td>0.94</td>
<td>1.17</td>
</tr>
<tr>
<td>Hypertension</td>
<td>No 69</td>
<td>5/32 (15.6%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>7/37 (18.9%)</td>
<td>1.26</td>
<td>0.36</td>
<td>4.44</td>
</tr>
<tr>
<td>Diabetes</td>
<td>No 68</td>
<td>12/62 (19.4%)</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>0/6 (0.0%)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>No 68</td>
<td>8/52 (15.4%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>4/16 (25.0%)</td>
<td>1.83</td>
<td>0.47</td>
<td>7.14</td>
</tr>
<tr>
<td>CVI</td>
<td>No 69</td>
<td>10/62 (16.1%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>2/7 (28.6%)</td>
<td>2.08</td>
<td>0.35</td>
<td>12.26</td>
</tr>
<tr>
<td>Coronary insufficiency</td>
<td>No 69</td>
<td>8/54 (14.8%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>4/15 (26.7%)</td>
<td>2.09</td>
<td>0.53</td>
<td>8.22</td>
</tr>
<tr>
<td>Anticoagulation treatment</td>
<td>No 69</td>
<td>6/52 (11.5%)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>6/17 (35.5%)</td>
<td>4.18</td>
<td>1.13</td>
<td>15.48</td>
</tr>
</tbody>
</table>

N\textsubscript{tot}=total number of observations, N\textsubscript{det}= number of patients with deterioration; N\textsubscript{cat}= number of patients within the category; NA = not applicable; * = Fisher exact test results; C.I. = confidence interval; CVI = history of cerebrovascular insult or peripheral deep venous thrombosis; OR = odds ratio

### Table 6

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>OR</th>
<th>95% C.I. limits for OR</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV1 (ml)</td>
<td>1.02</td>
<td>0.98</td>
<td>1.07</td>
</tr>
<tr>
<td>D90\textsubscript{urethra volume} (Gy)</td>
<td>1.23</td>
<td>0.96</td>
<td>1.57</td>
</tr>
<tr>
<td>Anticoagulation treatment</td>
<td>No</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>4.86</td>
<td>1.21</td>
</tr>
</tbody>
</table>

D90\textsubscript{urethra volume} = minimal dose received by 90% of the urethra volume; OR = odds ratio; PTV1 = planning target volume 1; OR = odds ratio
exceptionally considered in the studies of OUP after HDRB-B. In the available literature only one study that considered patients’ characteristics could be found. In this study hypertension was identified as an independent predictor of urinary tract obstruction grade 2 or more according to CTCAE after HDRB-B, but anticoagulation treatment was not considered. Anticoagulation treatment, however, was found to be, together with total dose, the most important predictive factor for 5-year risk of global urinary toxicity in a large study of 965 patients who received definitive EBRT. One of the conclusions of the study was that urinary toxicity might be more related to patients’ risk factors than dose parameters. A similar conclusion can be drawn on the basis of results of present study. They pointed out that perhaps higher dose sensitivity of urethral sphincter region in comparison to the urethra, as already suggested by Hindson, is further increased with anticoagulation treatment (with almost 5-times higher odds of DOUP in patients receiving either vitamin K antagonists or antiplatelet agents in present study). One can only speculate about exact etiology of this increased radiosensitivity. Since anticoagulation treatment is as a rule considered in patients with vasculopathy, poor circulation could be the underlying cause. However, other parameters that implicate this mechanism and were considered in present study (hypertension, diabetes, hyperlipidemia, history of cerebrovascular insult and deep venous thrombosis) did not show significant association with the observed outcome.

Other important results of the study

Additionally, study offered other results that could be interesting. Urethra is, as suggested by Hsu, with regard to late urinary toxicity, a dose limiting structure. In present study \( D_{90u} \) expressed the strongest, although statistically only marginal, association with observed outcome. This relation of dose applied to the major part of urethra to OUP seems to be reasonable as the location of stricture formation is at or beyond the prostatic apex, which is at the margin or beyond the contoured urethra. Apparently, this is in the area of external urethral sphincter. This way it is more likely that the dose applied to the major part of urethra is a better representative of the actual sphincter dose than are dose parameters that represent high doses to small parts of (contoured) urethra. Some similarity can be found between the significance of the \( D_{90u} \) and the minimum dose to bulbomembranous urethra which was found to be (with regard to maximum prostatic urethral dose, the mean, maximum and minimum bulbomembranous urethral doses, and bulbomembranous urethral doses 10 and 15 mm from apex) the strongest predictor of stricture formation in a large study of patients treated with PB. However, in two studies that addressed whole range of dose-volume histogram urethral data, and related them to late urinary toxicity grade 2 or higher according to CTCAE, or late urinary toxicity grade 3 or higher according to RTOG, small urethral volumes and high doses were emphasized. In the study of Ischiyama this was the volume that received minimal 13 Gy per fraction with the prescribed dose of \( 57.5 \) Gy, and in the study of Hsu multiple dose levels above 110% of the prescribed 19 Gy in 2 fractions. Although in 8/12 patients with grade 3 toxicity in the study of Ischiyama was due to stricture formation, studies that focused only on strictures, failed to prove the value of high-dose urethral volumes. In the study of Hindson this was the minimal dose received by the «hottest» 10% of the urethral volume, and in the study of Ghadjar the minimal dose to the urethral volumes that received at least 100%, 120%, 125% of the prescribed target dose and the minimal dose received by the «hottest» 1% urethral volume. Both were negative as no significant association was found with 5-year stricture-free survival in the study of Ghadjar, and no correlation was recorded within dose groups of 18 Gy in 3 fractions, 20 Gy in 4 fractions, 19 Gy in 2 fractions, or 16 Gy in 2 fractions between \( D_{10u} \) and stricture risk in the study of Hindson. Nevertheless, low-dose urethral volumes were decisive for obstructive or any other urinary toxicity after HDRB-B. We can only speculate that with analogy to EBRT data, different dose-volume histogram parameters should be emphasized for different grades of toxicity. In all of patients that were included in the present study, OUP would either be missed if RTOG criteria were used, or graded as grade 1 morbidity according to CTCAE. As it is suggested by the results of present study, low-dose parameters may be crucial for this low-grade urinary toxicity.

Another parameter that was included in predictive model in present study was PTV1. It was also only marginally significantly associated with observed outcome and was included in the final model primarily due to results of other studies that reported positive correlation between late genitourinary toxicity and PTV. Additionally, the study of Pinkawa et al. showed that PTV may relate to the length of prostatic urethra that is also predictive for late genitourinary toxicity.
The importance of the study results for clinical practice

The study stresses the importance of clinical patients’ data in the evaluation of late toxicity after HDRB-B. Considering clinical patients’ data together with treatment and dosimetric parameters it is possible to estimate toxicity of HDRB-B more precisely and also give better opportunity to alleviate side effects. The implementation of results of presented study can hopefully reduce OUP after HDRB-B, and can perhaps also reduce stricture formation that requires surgical intervention.

Possibilities for further research in the field

Further research in the field should be focused in improvement of safety of HDRB-B treatment. For improvement of safety in terms of late adverse effects it is vital to recognize structures which could be at risk for certain type of toxicity. It seems that the critical structure for OUP may be urethral sphincter. However, it is needed to confirm a relation between urethral sphincter, potential risk factors and OUP. Among potential risk factors also anticoagulation treatment should be considered.

Conclusions

Treatment factors as well as patients’ characteristics that are associated with OUP, and can predict it, and eventually prevent overt stricture formation after HDRB-B, are not sufficiently known. The study emphasizes the relationship between DOUP and anticoagulation treatment and suggests a fair predictive performance of the model which includes its high negative predictive value. It supports the belief that further research should be focused on urethral sphincter as a critical structure for OUP.

References


20. Grabec D, Kragelj B. The sigmoid colon and bladder shielding in whole pelvic irradiation at prostate cancer (forward planned IMRT from Institute of oncology Ljubljana). *Radiother Oncol* 2009; **43**:56-64.


