Setup error and its effect on safety margin in conformal radiotherapy of the prostate

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Background. *In radiotherapy, setup errors in positioning the patients influence the size of safety margin and thereby also the size of irradiation field and toxicity of radiotherapy.*

Methods. *The setup errors were calculated by evaluating the deviations from the measured distance between the irradiation field margin and the bony pelvis.*

Results. *The research was performed on 23 patients. With respect to lateral, craniocaudal and anteroposterior axis, the observed systemic error ranged from -5 to + 9 mm, -4 to +5 mm, and from -4 to +4 mm, respectively, whereas the observed random error ranged from 0 to 7.5 mm, 0 to 3.6 mm, and from 0 to 4.2 mm, respectively. The safety margin, with the 90% probability to cover clinical target volume (CTV) and allowing for the prostate position variability, measured 9 mm, 9.5 mm, 7 mm, and 10 mm in the respective lateral, craniocaudal, anterior and dorsal direction.*

Conclusions. *Irradiation of the prostate with a 7 mm dorsal safety margin, allowing for 90% coverage probability of CTV, was feasible in 22/23 patients on condition that the gross systemic error (>3mm) was eliminated.*

Key words: prostatic neoplasms; radiotherapy, conformal

Introduction

Due to acute and particularly chronic postirradiation complications in radiotherapy of the prostate, the dose application, and consequently also the irradiation effect, are restricted. The incidence and grade of acute and chronic complications depend upon the dose and volume of the surrounding organs involved in the irradiation area.[1-4]

As the restrictions on dose application should in no way be disregarded, the irradiation of the prostate can be performed on condition that the beam is aimed as accurately at the target volume as possible. The size of the irradiation field is dependent on the width of safety margin around the target volume that ensures that the area to be irradiated is actually or most probably irradiated. However, the more the safety margin is extended, the

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greater is the exposure of the surrounding organs to irradiation and consequently also the risk of therapy-related complications.

In the radiotherapy of prostate cancer, the safety margin width is dependent upon the prostate motion and patient positioning errors. The aim of our research was therefore to estimate the setup errors, and from the obtained results, determine an optimal safety margin.

Methods

Patients

The patients who were irradiated at our Institute in the period from September 2004 to March 2005 were included into the study. These patients were given radiotherapy as a unique treatment or as adjuvant treatment after primary prostatectomy.

Irradiation technique

Irradiation was performed by a 15-MeV linear accelerator (Varian, Clinac 2100 C/D), using the four-field technique, at the angles of 0, 90, 180, and 270 degrees in the sense of 3D conformal radiotherapy. Irradiation simulation was carried out on Philips CT MX 8000 multislice simulator. Target volumes were mapped using the program CMS Focal, whereas the program CMS Xio 4.2.0 was used for irradiation planning that was carried out by beam-eye-view technique. The fields were framed by multileaf collimator.

The patients were irradiated in supine position with the feet resting on a support cushion (Sinmed Feetfix support cushion) and the knees provisionally supported. The isocenter was defined by three spots – one on the abdominal wall and two lateral spots. The position of each patient was additionally marked on the isocenter plane by four lines (with respect to the patient's axis, three longitudinal lines and one transversal line).

Irradiation area

Clinical target volume (CTV) included the prostate, seminal vesicles, and in the patients at high risk, also regional lymph nodes. The safety margin determining the planned target volume (PTV) was 1.5 cm wide; in the closing phase of radiotherapy, in which only the prostate was exposed to irradiation, the safety margin was reduced to 1 cm, and on the dorsal side, to 0.7 cm.

Irradiation precision

Irradiation precision was tested by amorphous silicon-based portal imaging system (EPI). The image was additionally processed by Varian's vision software, version 6.1 that allows a precise computerized reconstruction of irradiation field borders.

The setup error in patient positioning was calculated by comparing the distance between the field margin and selected bony pelvic structures of the digitally reconstructed radiographs (DRRs) obtained from the planning CT data and EPI. The display and comparison of images as well as measurements were made by computer program Multiaccess, version 8,00J0, Impac Medical Systems.

Methods

The setup error in patient positioning was defined by the deviations along the craniocaudal, anteroposterior and lateral axis. All deviations in the cranial direction, to the right and anterior were marked as positive and the deviations in the caudal direction, to the right and dorsum were marked as negative. In order to eliminate errors in deviation measurements, more measurements were performed yielding a higher mean value. Therefore, in final evaluations of safety margins, the inaccuracy of measurements was neglected.

From the above measurements, a systemic (SE) and a random setup error (RE) with respect to each of the three axes was calculated for each individual patient. Systemic error was defined as a mean deviation of a patient positioning from the isocenter and random error as a deviation of each individual measurement from the mean value. The size of random error was marked as 1SD. The systemic and random setup errors were then calculated for the entire group of patients. The systemic error for the entire group (SEeg) was defined as arithmetic mean of all individual systemic errors.

In calculating the random error for the entire group (REeg), random deviations of individual SE from SEeg were also taken into account. The size of the random component of SE was estimated by 1 SD (SDse) and derived from an even distribution of individual SE around SEeg. The size of RE was also considered and was derived from an even distribution of individual RE around arithmetic mean of individual RE (AM RE). The size of individual RE deviations from AM RE was also defined as 1 SD (SDam). Adding AM RE and 1.63 SDam, SDre was obtained with 95% probability that all RE were comprised in SDre. In the calculation of REeg, SDse and SDre were considered as independent parameters. REeg, expressed as 1 SD, was obtained by the square root of SDse2+ SDre2.[5]

From the obtained systemic (SEeg) and random (REeg) setup errors, the size of safety margin was calculated in order to compensate for the errors in positioning the patient along each of the axis. Because of relatively high prevalence and severity of late rectal radiation toxicity, the anterior and posterior safety margins along the anteroposterior axis were calculated separately.

The safety margin calculation by adding SEeg and 1.5 SD REeg was based on Goitein's estimation[6] that 1.5 SD is a sensible compromise between the risk of underdosing the target volume and of excessive overdosing of the surrounding healthy tissue. This complies well with 90% confidence interval of random deviation in any of the directions. In further calculations of safety margin, the prostate position variability was taken into account in addition to the setup error. For the assessment of the position variability of the prostate, Zelefsky's data were used.[8] The safety margin was calculated by adding the arithmetic mean of the prostate movements and SEeg and 1.5 SD of the combined random error, calculated according to Rudat's recommendations, taking into account the random setup error as well as the random prostate movement error. The calculations of safety margins were made for each axis and separately for anterior and posterior directions.

Results

The research was performed on 23 patients in whom altogether 95 measurements were made for evaluating the position of a patient during irradiation. In each patient, three to maximum five positioning measurements were carried out.

The deviations along the lateral axis ranged from -10 to +12 mm, along the craniocaudal axis from -7 to 6 mm, and along the anteroposterior axis from -11 to +5 mm. The systemic error along the lateral axis was within the range of -5 to 9 mm, along the cranio-

Table 1. The range of the set up errors and the systemic and random components of the setup errors with respect to the direction of the positioning deviation

Deviation - direction	Lateral	Craniocaudal	Anteroposterior
Setup error-range (mm)	-10 do +12	-7 do +6	-11 do +5
Systemic error (mm)	-5.0 do +9.0	-4.2 do +4.8	-4.4 do +4.2
Random error (1SD in mm)	0 do 7.5	0 do 3.6	0-4.2

Table 2. Systemic (SEeg) and random (REeg) setup errors with respect to the entire group of patients (23) and the direction of pisitioning deviation by presenting SEeg, AMRE, SDam, SDre

Deviation - direction	**Lateral (**mm)	**Craniocaudal** (mm)	**Anteroposterior** (mm)
Systemic error (SE eg)	**+0.53**	**+0.17**	**-0.87**
SDse (1SD)	2.9	2.3	2.5
Random error (REeg)	**5.1**	**4.1**	**4.9**
AMRE	2.6	1.9	2.3
SDam	1.6	1.0	1.2
SDre	4.3	3.5	4.2

caudal axis -4.2 to +4.8 mm, and along the anteroposterior axis -4.4. to +4.2 mm. The random error with the size of 1SD varied along the lateral axis from 0 to 7.5 mm, along the craniocaudal axis from 0 to 3.6 mm, and along the anteroposterior axis from 0 to 4.2 mm (Table 1).

The calculated systemic error for the entire group along the lateral, craniocaudal, and anteroposterior axis was +0.57 mm, +0.17 mm, and -0.87 mm, respectively. The random error for the entire group in the lateral, craniocaudal, and anteroposterior axis was 5.1 mm, 4.1 mm and 4.9 mm, respectively. The two errors (SEeg and REeg) as well as SDse, AM RE, SDam, and SDre are presented in Table 2. The safety margin (SM) that would, with a 90% probability, cover an inaccurate positioning of a patient with respect to the lateral and craniocaudal axis is 8.2 mm and 6.3 mm, respectively, and with respect to the anteroposterior axis, 6.5 mm towards the anterior and 8.3 mm posteriorily. The safety margin that would, in addition to the setup errors, compensate also for the prostate position variability (SM total) along the lateral and craniocaudal axis with the same confidence interval is 9.2 mm and 9.5 mm, respectively, and along the anteroposterior axis, 6.7 mm towards the anterior and 10.3 mm posteriorily (Table 3).

Discussion

The aim of this study was to determine an adequate safety margin that would allow an acceptable exposure of a target area to irradiation. The difficulties of the prostate cancer patient radiotherapy that make this therapy unreliable are the prostate position variability as well as inaccuracy in all subsequent repositionings of the patient in the initial pose.

Monitoring the variability of prostate position is an exacting task, and so far, it has not been performed at our Institute. So, the size of safety margin, and thereby also the precision of irradiation, is dependent merely on the precision in repositioning the patient in the initial irradiation position. In comparing our data on the patient repositioning precision to the published data, it may be concluded that our precision was tolerably satisfactory. As reported by Rudat,[5] the random error along the lateral, craniocaudal, and anteroposterior axis was 3.1 mm, 5.4 mm, and 4.9 mm, respectively. In our patients, the random error calculated by using a similar method, was 3.9 mm, 2.9 mm, and 3.5 mm, respectively. In the study by Song, the data on the deviations greater than 5 mm in 40% of repositionings of his patients[9] also speak in favor of the satisfactory precision in repositioning of our patients.

Table 3. Safety margin depending on the setup error (SM) in conjunction with the prostate position variability (SMtotal)

Direction	**Lateral**	**Craniocaudalni**	**Anterior**	**Posterior**
SM (mm)	8.2	6.3	6.5	8.3
SM total (mm)	9.2	9.5	6.7	10.3

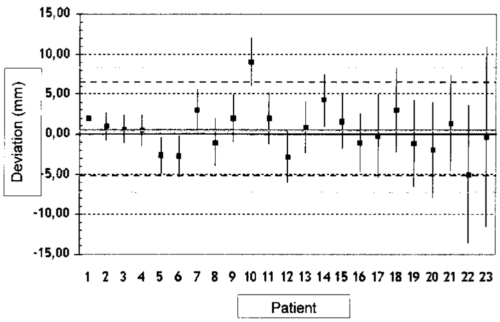

Figure 1. Systemic and random setup errors (1.5 SD) along the lateral axis in the patient positioning and safety margin at which CTV should have been included in the irradiation field with 90% probability.

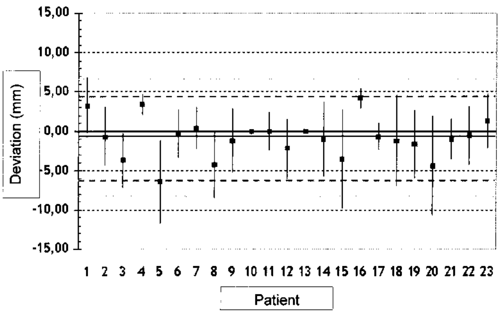

Figure 3. Systemic and random setup errors (1.5SD) along the anteroposterior axis in the patient positioning and safety margin at which CTV should have been included in the irradiation field with 90% probability.

The safety margin was calculated from the measurements of setup errors (in positioning of our patients) and from the data published on the prostate position variability. Our calculated safety margin – approximately 1 cm in all directions – is similar to the margins reported by various authors of the studies on prostate irradiation, except for the margin on the dorsal side, which was allowed to be smaller than 1 cm.[10] However, if the safety margin of less than 1 cm is not coordinated with the prostate position variability and setup error, the coverage of CTV may not be sufficient - according to Zelefsky, in the patient in prone position and at a safety margins of 1 cm in the anterior lateral and craniocaudal directions and of 0.6 cm at the dorsal side, the coverage of CTV at the dorsal side is 85 % before and 96% after the corrections for setup error and prostate displacement.[8] In our patients, the coverage of CTV can be evaluated only indirectly, by assessing the involvement of CTV dependent exclusively on the setup errors. The results are shown in Figures 1-3.

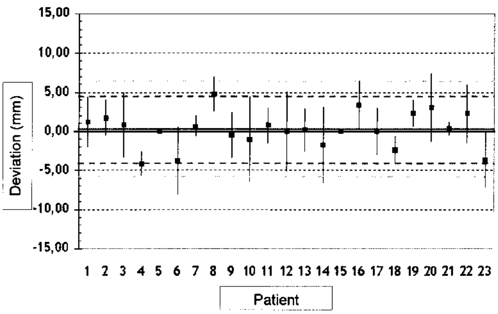

Figure 2. Systemic and random setup errors (1.5SD) along the craniocaudal axis in the patient positioning and safety margin at which CTV should have been included in the irradiation field with 90% probability

The 90% probability of CTV coverage of the irradiation field at the safety margin of 1 cm along the lateral axis is achieved in 91% of patients, and in cranial and caudal directions in 91 % and 87% of patients, respectively, and on the anterior and posterior side in 96 % and 78 % of patients, respectively on side. By reducing the dorsal margin to 0.7 cm, the 90% probability of CTV involvement in the irradiation field would be obtained only in 74% of patients.

The irradiation precision may not be improved either by changing the patient position or by additional support using various positioning aids. The prone position during irradiation may helps to reduce the exposure of the rectum to irradiation;[8,11] however, there is no data proving that this position can improve the positioning precision, given that it somehow deprives the patient of comfort during irradiation. Additional disadvantage of the prone position is that, in this position,

Table 4. Systemic and random setup errors in patients with less than 90 % probability of CTV coverage and the direction of the setup errors

Direction	Patient's no.	Systemic error mm	Random error mm
Right	16	9	2
	19	0.3	7.5
Left	15	5.0	5.8
	19	0.3	7.5
Cranial	8	4.8	1.5
	20	3.0	2.9
Caudal	6	3.8	2.9
	14	1.8	3.3
	23	3.7	2.3
Anterior	1	3.2	2.4
Posterior	5	6.4	3.5
	15	3.5	4.2
	20	4.4	4.2
Posterior	3	3.7	2.3
(0.7cm)	8	4.2	2.9
	18	1.2	3.9

urethrography is hard to perform and, hence, the apex of the prostate cannot be reliably located. Considering the precision of the patient positioning, even the use of support cushions may be questionable. Comparing different support systems, Song reported that a similar percentage of most evident errors, approx. 40%, was made in positioning the patients by using any type of support as in positioning them with no support at all.[9]

On the other hand, a better irradiation precision may be achieved by eliminating most apparent systemic errors (Table 4). By determining the systemic and random positioning errors, it is possible to asses an appropriate safety margin and, by eliminating the systemic error, the probability of CTV involvement into the irradiation field may increase. By correcting the systemic error, due to which the probability of involving CTV along one of the axes during the positioning was lower than 90%, an adequate CTV coverage may be obtained along the lateral axis in 96% of patients, in the cranial and caudal directions, in 100% and 96%, respectively, and along the anteroposterior axis, in 100% of patients. In cases when the dorsal safety margin is reduced to 0.7 cm, the correction of the most evident systemic error may help to achieve an adequate exposure of CTV to irradiation in as much as 96% of patients. In that case, the correction of isocenter would be required in 10/23 patients.

From the estimates of systemic and random error, it is possible to identify the patients in whom CTV would have been included in the irradiation field with 90% probability provided that the systemic error had been eliminated and the patients in which the estimated exposure of CTV to irradiation would have been obtained only by increasing the safety margin. By redefining the isocenter, which would be required in almost half of our patients, an optimal exposure of the most critical part of the prostate to irradiation, i.e. of the dorsal part, would be obtained in 22/23 patients, even though the safety margin was reduced to 0.7 cm.

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