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FIELD DISPLACEMENT DURING EXTERNAL RADIOTHERAPY IN PROSTATIC ADENOCARCINOMA TREATED WITH RADIOACTIVE ^{198}Au IMPLANTS AND EXTERNAL IRRADIATION

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The purpose of this work was to study displacement error and internal movements of the prostate during external beam radiotherapy. Verification films in the frontal (n = 194) and lateral (n = 64) portals were investigated in 14 patients treated with radioactive ^{198}Au implants. Displacement errors of two implants were investigated. In seven patients, filling of the rectum and the bladder with contrast medium or isotonic saline was performed during CT investigation for planning purposes to detect movements of the prostate. Most (95%) of the displacement errors were less than 10 mm in the frontal portal and less than 15 mm in the lateral portals. No correlation to the patient's weight was found. The displacement errors were randomly distributed. The spatial relations between the implants were not altered during the treatments. Small movements of the prostate were observed. To conclude, the positioning system employed at present (laser) can be sufficient for the margins used (2 cm). In lateral portals, however, the system did not have the ability to detect a possible systematic displacement error from simulator to accelerator. The intention is to decrease the margins to 1 cm, which will necessitate a better positioning system.

Successful radiotherapy of prostatic adenocarcinoma depends on biological, physical and technical factors. Of most importance is to define and deliver a lethal irradiation dose in the target and, at the same time, to spare the patient as much morbidity as possible in other organs and structures. A most important issue is the exactness obtained in the positioning of the daily fields. Divergences from the ideal position are usually called displacement errors.

In 1978, Byhardt et al. (1) reported displacement errors of up to 4 cm when treating targets in the pelvic region and since then additional studies have been presented (1–10). Richards & Buchler (8) found that displacement errors increased by the weight of the patient and Haken et al. (11) have shown that the motion of the prostate itself can be of a considerable magnitude and cause underdosage in the target volume. These factors indicate that external radiation of a prostatic adenocarcinoma can be associated with large displacement errors of the portals relative to the target.

The importance of local control has been stressed by several authors (12–14) and shown to be dose-dependent (15). Consequently, there is a tendency today to increase the total dose in the target in radiotherapy of prostatic adenocarcinoma. The disadvantage, however, is that side-effects will increase if the treatment is not modified.

Modern conformal field techniques (16), such as the use of multi-leaf collimators, reduce the irradiated volumes in the surrounding risk organs or structures and it is assumed that this will decrease the dose-related complications. A significant additional decrease in dose in risk organs can be achieved by shrinking the margins around the tumour. However, this will make further demands on the accuracy of the positioning of the patient (9).

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In order to detect field displacement during the external radiotherapy of prostatic adenocarcinoma, 14 consecutive patients (T2–3N0–1M0) with ^{198}Au implants in the prostate (17, 18) were investigated with verifications of the anterior-posterior fields 3–5 times a week and of the lateral fields once to twice a week. The study took advantage of the fact that the gold implants are clearly visible on both frontal and lateral verification films and that these implants monitor the total movement of the target relative to the accelerator field with a high degree of accuracy. The positions of the implants were checked during the investigation, and no movement were detected. The stability of the positions of the implants have been documented in x-rays in other patients several years after treatment completion. Similar techniques have been presented by others (19–20).

In a separate part of the study, 7 patients were examined with CT with rectum and bladder filled with different media. The purpose was to evaluate the internal movement of the gland.

The aim of the present study was to investigate the motion of the target volume relative to the initially applied portals during therapy simulation and to the fields delivered during the entire course of the treatment, and to assess the practical limitations of the positioning system used at our department when target in the pelvic area are irradiated.

Material and Methods

Patients and treatments

Fourteen consecutive patients with a mean age of 67 years (range 50–73) and localized T2–T3 N0–1 (17) prostatic adenocarcinoma were investigated (Table 1).

The patients underwent combination radiotherapy, which comprised initial treatment with radioactive ^{198}Au implants and subsequent external conformal therapy with high-voltage photons.

The planning and treatment with ^{198}Au implants followed the technique described by Scardino & Carlton (18). The volume of the prostate was determined during an ultrasound investigation. Number of implants and activity depended on volume of the prostate. The implants were positioned by means of a special device at an open surgical procedure, when the prostate gland had been completely freed from surrounding structures and could be held in its entirety between the fingers of the operating urologist. The calculated dose in the tumour was estimated at a minimum of 30–35 Gy. The number of implants varied from 5 to 16 (mean 11) per patient.

During laparotomy, lymph node sampling of loco-regional stations was performed for staging. Three weeks after laparotomy, all lymph node negative patients underwent computed tomography of the pelvic region for planning of external beam radiotherapy (21). Contiguous, 8 mm thick slices were taken of the prostate gland and seminal vesicles: these slices formed the basis for the external therapy plans, for which the TMS RADIX 3-D dose-planning system (Helax, Uppsala, Sweden) was used. The distance between two slices was 16 mm. The target volume was defined as the prostate gland and seminal vesicles with 2 cm margins.

The patients received a total external dose of 46 Gy in the central axis, with daily fractions of 2 Gy, 5 times a week with an isocentric 4-field conformal therapy technique with 100%, 50% and 25% weight factors for the anterior, lateral and posterior fields respectively.

Table 1

Patients, clincial TNM status, prostate volumes as determined by ultrasonography, body mass index (BMI), and number of observation in lateral and frontal protals

Patient no.	Age years	TNM stage	Prostate volume (cm^3)	BMI	Number of obs. front/side
1	72	T2N0M0	66	22	24/8
2	50	T3N0M0	44	23	44/18
3	68	T3N0M0	157	23	24/6
4	72	T2N0M0	28	24	28/6
5	66	T3N0M0	57	24	24/4
6	64	T3N0M0	21	26	24/12
7	63	T2N0M0	30	26	30/12
8	73	T3N1N0	70	26	18/8
9	57	T3N0M0	41	27	28/8
10	63	T2N0M0	23	27	24/8
11	64	T3N0M0	40	30	38/4
12	69	T3N0M0	65	31	24/8
13	59	T3N0M0	95	31	22/14
14	73	T3N0M0	55	33	36/12
Total					388/128

Verification of treatment

The portals and the laser marker crosses were marked on the patient's skin while on the simulator. No fixation methods were used. A pillow was placed under the patient's knees if this was more comfortable. The arms were placed above the patient's head. The positions of the laser markings and all portals except for the posterior one were checked before each treatment and the positioning of the patient was not altered after this primary check had been carried out.

The simulator used was an Oldelft Simulix-Y which was equipped with a standard hard table-top. With the exception of one patient, (No. 2 in Table 1), all were irradiated on a Scanditronix Microtron with a multi-leaf collimator and an Atlas treatment table-top (Precitron, Uppsala, Sweden). Patient No. 2 was treated on a Philips MEL 20 linear accelarator, equipped with a standard Philips table-top.

Verifications of the anterior-fields were carried out 3–5 times a week during treatment on the linear accelerator whereas the lateral fields were radiographed on the simulator once or twice a week since no satisfactory images could be obtained on the accelerator.

The radiograms obtained during simulation (before start of the treatment) formed the references with which the verification images exposed during treatment were compared. The displacements in positions of 2 implants, located as far as possible from each other, per patient in each field dimension were assessed. The positions were digitalized on two axes (X and Y) on a high resolution digitizer board (Digi-Pad PC) and the relative displacements (relative to the simulator film) in millimetres and the rotation to one decimal position were calculated according to the following formulas:

$$\text{Displacement error (mm)} = \sqrt{(\Delta x^2 + \Delta y^2)} \quad [1]$$

$$\text{Rotation } (^\circ) = [\tan^{-1}(\Delta y/\Delta x)] \times C \quad [2]$$

were Δy and Δx are the differences between the coordinates of the implants on the simulator and the verification films and C is a constant for the conversion from radians to degrees.

The accuracy of the digitizing system was found to be within ± 0.5 mm.

As earlier reports indicate large displacement errors with increasing patient weight (8), three subgroups were formed based on the body mass index (BMI) of the patient (22). A BMI above 25 is considered to be representative of a patient of normal weight and one above 30 an obese patient. The interval 25–30 is used for patients with varying degrees of overweight.

CT-based evaluation of motion

Seven patients with T2–T3, N0, M0 prostatic adenocarcinoma and treated with ^{198}Au were included in a separate study. A quantitative measurement of prostate gland movement was calculated from CT scans obtained after separate filling of the rectum and the bladder (Table 2).

Prior to the CT performed for dose-planning purposes, one Foley catheter was placed in the rectum and one in the urinary bladder. CT scanning was performed from the shaft of the penis to the top of the bladder with a Siemens Somatom DR2. The slice thickness was 8 mm and the table increments 8 mm. After an initial scan with both the bladder and the rectum empty, subsequent scans were obtained without altering the patient position, after the bladder and the rectum had been filled. The bladder was filled with 300–600 cm^3 of isotonic saline and the rectum with 300 cm^3 of a 2.5% solution of diatrizote (Gastrografin; Schering). Movements in implants position and movements of the seminal vesicles were calculated in three dimensions.

Table 2

Comparison of displacement errors in different studies

Author (ref. No.)	Region	Displacement error	
		Mean	Max
Richards et al. (8)	Pelvis	–	6% more than 30 mm
Byhardt et al. (1)	Pelvis	15 mm	40 mm
Rabinowitz et al. (7)	Pelvis	5.6 mm	24 mm*
Kihlén et al. (3)	Pelvis	–	6 mm
Griffiths et al. (2)	Pelvis	0.8–3.3 mm	9–17 mm[1]
Soffen et al. (10)	Pelvis	3.3–8 mm^2	7–15 mm^2
Rosenthal et al. (9)	Pelvis	4–6 mm^2	14–21 mm^2
Gilderslave et al. (6)	Pelvis	2–4.3 mm^3	6.4–11 mm^3*
Own study	Pelvis	5.4 mm	27 mm

Note: In the study by Richards & Buchler (ref. 8), no mean displacement errors were presented and the data were separated into intervals, e.g. > 30 mm. 1) with or without laser positioning, 2) with or without cast fixation and 3) with or without on-line portal verification. * = value taken from a figure.

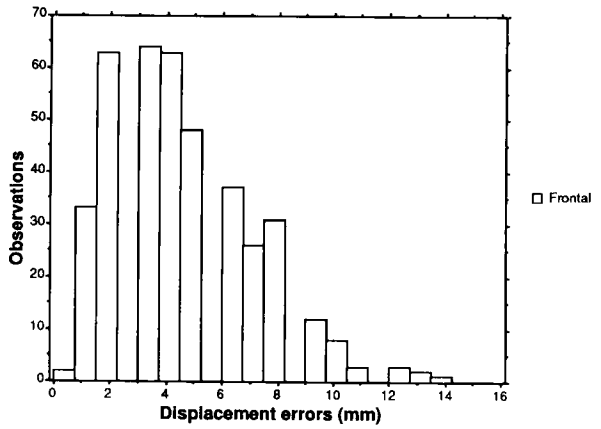

Fig. 1. Frequency distribution of displacement errors in mm for the frontal portal. Total number of observations was 388.

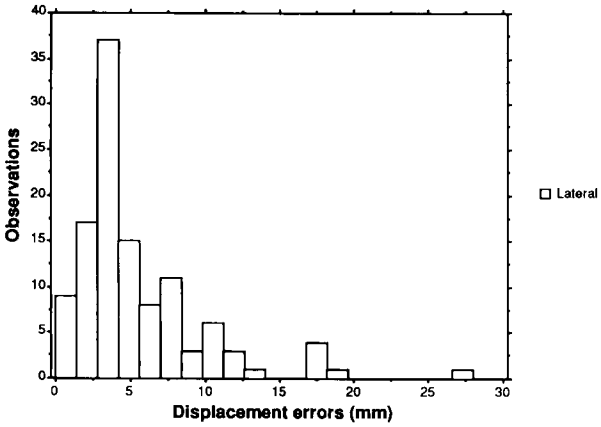

Fig. 2. Frequency distribution of displacement errors in mm for the lateral portal. Total number of observations was 128.

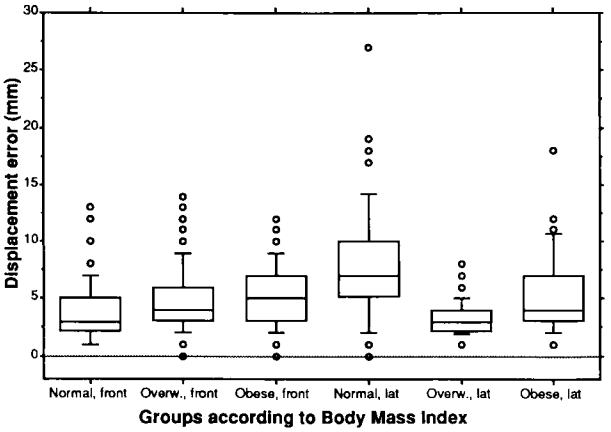

Fig. 3. Box and whiskers plots of displacement errors in the different groups according to the body mass index and the lateral and frontal portals. BMI < 25 was regarded as normal, BMI > 30 as obese and IBM 25–30 as overweight. The boxes entail the middle 50% of the material, the whiskers 10%–90% and the circles are extreme values.

Results

A total of 64 lateral and 194 frontal films and treatments were investigated, giving 128 observation of the lateral portal projections and 388 of the frontal portal projections.

In Figs. 1 and 2, the frequency of the displacement error are presented. As can be seen, the displacement errors are around 4–5 mm. The mean displacement errors were 4.5 mm in the frontal portal projections and 5.4 mm in lateral protals. Extreme displacement error were unusual.

The displacement errors registered in the different groups of patients and their BMIs are presented in Fig. 3 and Table 1. There were no statistically significant differences between the three categories in the lateral and A–P fields as regards the means or the spread of the data. This study could not confirm any correlation between displacement errors and patient weight. Nor did any increase or decrease in displacement errors occur during the entire treatment course. The directions and the displacement errors on the X- and Y-axes were also randomly distributed.

The distribution of the rotational displacement are centered around 0° (no data presented) with some extreme rotations of 20°. The evaluation of the rotational displacement can be harzardous, see 'Discussion'.

The alterations in implant positioning in the 7 patients examined with CT after the rectum and urinary bladder had been filled with different media were small. A displacement in the anterior-posterior direction was observed in only one patient after filling of the rectum (2 mm). In four patients, a caudo-cranial displacement was observed after bladder filling (4–8 mm). In 5 patients, the seminal vesicles were displaced more than 8 mm cranially after filling of the rectum.

Discussion

If the margins around the tumour are reduced to 10 mm in an effort to minimize complication frequency, this will increase the number of displacement errors to 1 out of 8 observations (12.5%) in the lateral portals which is unacceptable.

Assuming that the maximum acceptable number of target misses during a treatment course is 1 out of 20 (5%), then the margins required around the target volume should be 10 mm in the frontal portal and approximately 15 mm in the lateral portals (23). In an extreme situation, with maximum displacement errors in the X-, Y- and Z-axes, these movements may result in a displacement error of 18 mm, according to Formula 1, which is therefore the necessary margin.

Table 2 shows the average and maximum displacement errors presented by other authors. The maximum values differ considerably but the extreme values are usually few. However, one or two misses of the planning target volume

during a treatment course may result in an insufficient dosage of the target volume (23).

Haken et al. (11) have investigated the internal motion of the prostate gland by filling the rectum or the urinary bladder with different media and have thereby observed movements of up to a maximum of 8 mm. The present study demonstrates an internal movement of the prostate gland of only a few millimeters. A relatively small degree of movement has also been found by Balter et al. (24), in whose study the patients had had an operation in the prostatic region and this may have produced fibrosis which rendered the prostate immobile. Haken et al. (11) observed a large amount of movements in unoperated patients with values ranging from 0 to 20 mm. This has also been demonstrated in a study Beard et al. (25).

In the current study, which comprised operated patients, the seminal vesicles were displaced more than 8 mm in 5 of the 7 patients; in other respects, the movements of the prostate were small in the anterior-posterior direction (0–2 mm) and more frequent and greater in the caudo-cranial direction (4–8 mm). With a slice thickness of 8 mm and an 8 mm table increment, the actual resolution was, in fact, 16 mm. This can be increased by comparing different anatomic and implant features in the scans but is, of course, a disadvantage of this investigational technique.

As can be seen in Figs. 1 and 2 the total displacement errors are centred around 4–5 mm and not around zero. This might be an indication of a systematic error in the positioning routine and has also been found in other studies (7).

The differences in physical properties between a simulator and an accelerator have been suggested as one of systematic errors. If this were only cause, the lateral observations in this study ought to be centered around zero. However, as can be seen in Figs. 1 and 2, the lateral portal groups do not differ from the frontal groups in this respect.

Other contributory causes may be the fact that the extraordinary circumstances in being a radiotherapy patient entail a consequent involuntay tension of different muscles groups. On the other hand, there was no tendency towards a decrease of displacement errors during the treatment course. Large errors were discovered at both early and late stages of the treatment.

The present study has shown that the positioning system used for external radiotherapy of prostatic adenocarcinoma at our department entails displacement errors that do not significantly exceed the margins around the tumour. It is difficult to assess whether the treatment can be considered satisfactory since a possible systematic error between the simulator and the accelerator in the lateral fields could not be detected. Nevertheless, despite the limitations of simulator-produced verification films, it is notable that errors not centred around 0 mm occur.

Two rotational axes, viz. the anterior-posterior and the lateral-to-lateral, were calculated in this study. It is important to note that a small error in the calculation of implant coordinates can result in a large rotational error since the difference between X- and Y-coordinates is small. Furthermore, a rotation in the third axis in a cranio-caudal direction can influence the rotation of the two other axes. It is a disadvantage that the verification systems are not able to calculate the displacement errors in two orthogonal directions at the same time. The rotations presented are therefore difficult to evaluate.

It is important to remember that studies of displacement errors are only an approximation of reality. In a complicated plan with several fields, the displacement error in one field can both compensate and aggravate the insufficient dosage in the target volume caused by a displacement error in another field.

It is proposed that reduced margins around the tumour will lead to a reduction in the frequency of complications. However, the present study clearly shows that additional positioning or fixation systems must be developed if one is to implement margins of approximately 10 mm.

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