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ORIGINAL ARTICLE

Comparison of conventional and virtual simulation for radiation treatment planning of prostate cancer

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Summary

Purpose: *Radiotherapy is widely used to treat patients with prostate cancer. Using conventional x-ray simulation is often difficult to accurately localize the extent of the tumor, to cover exactly the lymph nodes at risk and shield the organs at risk. We report the initial results of a study conducted to compare target localization with conventional and virtual simulation.*

Methods: *Fifty patients with prostate cancer underwent target localization for radical prostate radiotherapy using conventional and virtual simulation. The treatment fields were initially marked with a conventional portal film on LINAC, plain x-ray film and available diagnostic imaging. Each patient then had a computed tomography (CT) and these simulated treatment fields were reproduced within the virtual simulation planning system. The treatment fields defined by the clinicians using each modality were compared in terms of field area and implications for target coverage.*

Results: *There was significantly greater clinical tumor volume coverage using virtual simulation compared with conventional simulation and less normal tissue volume irradiated ($p<0.001$).*

Conclusion: *CT localization and virtual simulation allow for more accurate definition of the clinical target volume. This could enable a reduction in geographical misses, while also reducing treatment-related toxicity.*

Key words: conventional simulation, virtual simulation, prostate cancer

Introduction

During the past two decades, advances in radiologic imaging and computer technology have significantly enhanced our ability to achieve separation of dose-response curves for local tumor control and normal tissue complications [1].

In 3D-conformal radiation therapy (3D-CRT) the treatment planning process begins with treatment simulation which entails setting up the patient on the conventional simulator or on the CT unit in the treatment position. The first step in simulation is immobilization of the patient in the treatment position to facilitate accurate reproduction of patient position during both CT image acquisition and multifunction treatment delivery.

Thus, with the patient immobilized in the treatment position, CT images are acquired. From these images the radiation oncologist delineates both target and non-target structures. The delineation of anatomical volumes is usually done directly on a computer display of transverse CT images using standard computer graphics options.

Once all relevant tissues have been delineated and beam directions specified, the design of treatment portal shapes and selection of radiation beam directions are usually determined via a specialized type of computer display denoted as beams eye view (BEV) which shows the patient's anatomy from any desired direction [1].

From CT data digitally reconstructed radiographs (DRRs) are produced which can be used for comparison with conventional simulator films.

In conventional simulator, treatment fields are initially marked using fluoroscopy, plain x-ray film and available diagnostic imaging [2].

Among the most popular techniques for radia-

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tion therapy of prostate cancer included is the four-field box technique. This conventional, non-conformal technique, uses open square fields that are based on bony landmarks.

The aim of this study was to compare the radiotherapy fields between virtual simulation and conventional simulation in prostate cancer based on anatomical data.

Methods

Study population

The study included 50 patients with high risk prostate cancer admitted for radical radiotherapy. In the tumor volume, besides the prostate and seminal vesicles, pelvic lymph nodes were also included.

Simulations

All 50 patients underwent conventional portal images on LINAC and virtual simulation. The conventional simulation fields were compared with DRRs produced from the CT data. The treatment fields defined by the clinician using each modality were compared in terms of field area (superior, inferior, left and right lateral borders of the anteroposterior field, anterior and posterior border of the lateral fields) using anatomical landmarks. Anatomical landmark for definition of the superior treatment field border was the middle of the 5th lumbar vertebra (L5) body. Anatomical landmark for definition of the inferior treatment field border was the inferior border of the ischial tuberosities.

Anatomical landmark for definition of the lateral (left and right separately) treatment field border was the widest bony margin of the true pelvic side walls. The symbols (+) and (–) defined the superior and inferior borders, respectively, above and below the referred anatomical landmarks. The definition of lateral borders was made by the distance beyond the widest bony margin of the true pelvic side walls. Anatomical landmark for definition of the anterior treatment field border in lateral fields was the anterior edge of the pubic symphysis. Definition of the anterior border of lateral treatment fields was made by the distance from/in front of the anterior edge of pubic symphysis. Anatomical landmarks for definition of the posterior border of lateral treatment fields were S2-S3 interspace and posterior sacral margin.

Statistical analysis

The statistical difference between different measurements concerning the anatomical limits of the fields was assessed using the Wilcoxon non-parametric test. The analysis was performed with the SPSS package (v 10, Chicago, IL).

Results

Data analysis of the comparative study of radiotherapy treatment fields between conventional and virtual simulation demonstrated

In the anterior-posterior treatment field

i) In virtual simulation the superior border of the treatment field ranged from 1.5-3 cm above the middle of the L5 body (middle of the L5 body = 0 cm) (Figure 1A).

In conventional simulation the superior border of treatment field was set at the superior margin of the body of L5, set at 1.5 cm above the middle of the body of L5 (Figure 1B).

ii) In virtual simulation the inferior border of the treatment field ranged from –0.7 to +0.57 cm above and below the ischial tuberosities.

In conventional simulation the inferior border of treatment field was set at the ischial tuberosities.

iii) In virtual simulation the right lateral border of the treatment field ranged from 1.06 to 4.9 cm beyond the widest bony margin of the true pelvic side walls.

In conventional simulation the right lateral treatment field border was set 1.5 cm beyond the widest bony margin of the true pelvic side walls.

iv) In virtual simulation the left lateral border of the treatment field ranged from 1.13 to 5 cm beyond the widest bony margin of the true pelvic side walls.

In conventional simulation the left lateral treatment field border was set 1.5 cm beyond the widest bony margin of the true pelvic side walls.

In the right lateral treatment field

i) In virtual simulation the anterior treatment field border ranged from 0 to 2.9 cm in front of the anterior edge of the pubic symphysis (Figure 2A).

In conventional simulation the anterior treatment field border was set 1 cm in front of the anterior edge of the pubic symphysis (Figure 2B).

ii) In virtual simulation the posterior treatment field border ranged from the S2-S3 interspace to behind the posterior sacral margin. In conventional simulation the posterior treatment field border was set at the S2-S3 interspace.

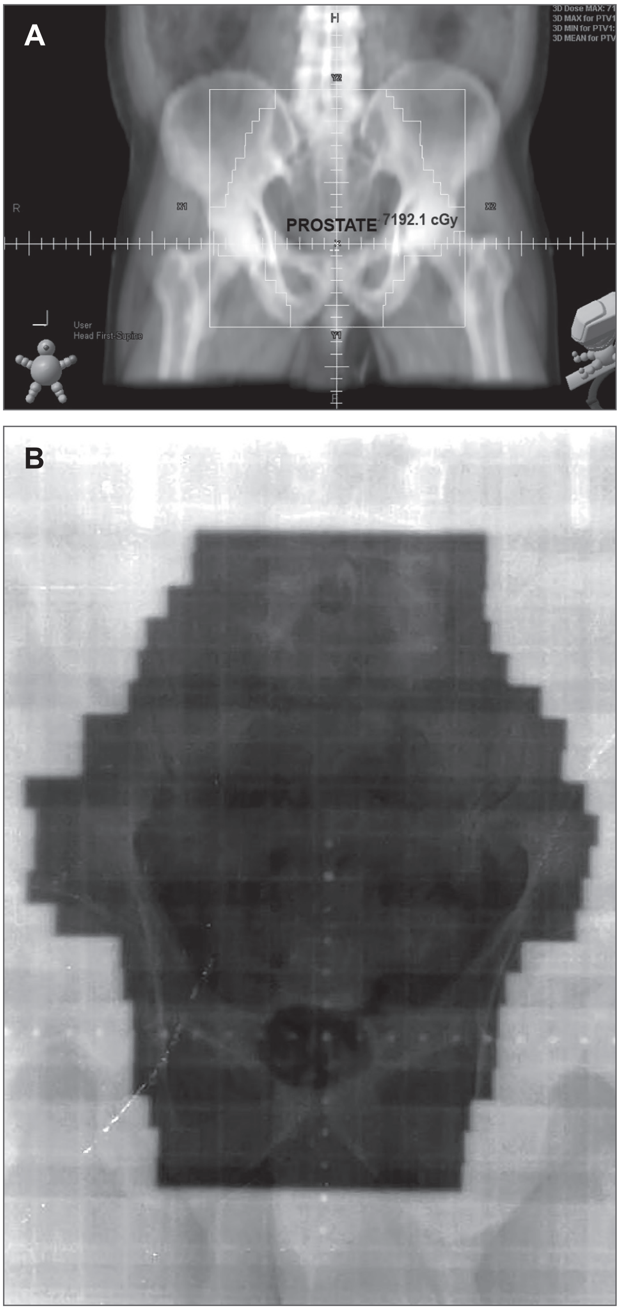

Figure 1. A: In virtual simulation the right and left lateral borders of the treatment field were 2.76 cm and 2.83 cm beyond the widest bony margin of the true pelvic side wall, respectively. In conventional simulation the lateral treatment field borders were set 1.5 cm beyond the widest bony margin of the pelvic side wall. The inferior treatment field border in virtual simulation was 0.7 cm above the ischial tuberosities. **B:** In conventional simulation the inferior treatment field border was set at ischial tuberosities. The superior treatment field border both in virtual and conventional simulation field was set at the superior margin of the body of the L5, set 1.5 cm above the middle of the L5 body.

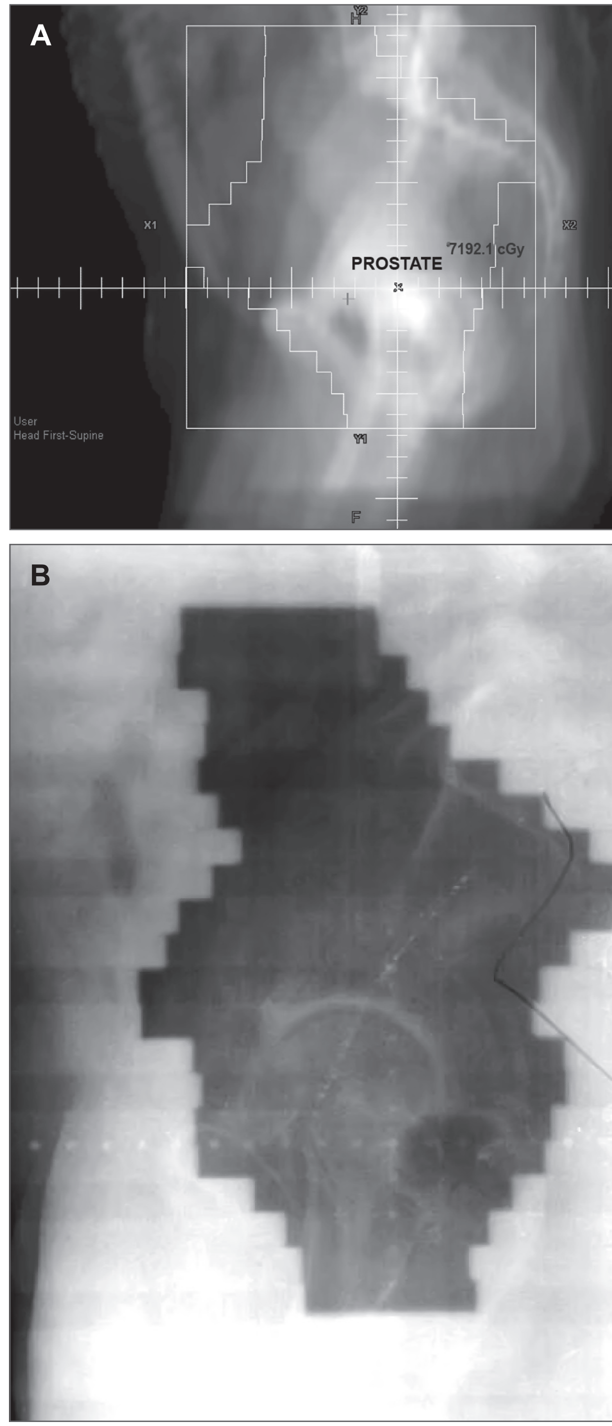

Figure 2. A: In virtual simulation the anterior border of the treatment field was 3 cm in front of the anterior edge of the pubic symphysis. **B:** In conventional simulation the anterior treatment field border was set 1cm in front of the anterior edge of the pubic symphysis. The posterior treatment field border in virtual simulation was set at S4-S5 interspace and in conventional simulation at S2-S3 interspace.

In the left lateral treatment field

i) In virtual simulation the anterior treatment field border ranged from 0 to 3 cm in front of the anterior edge of the pubic symphysis. In conventional simulation the anterior treatment field border was set 1 cm in front of the anterior edge of the pubic symphysis.

ii) In virtual simulation the posterior treatment field border ranged from the S2-S3 interspace to behind the posterior sacral margin. In conventional simulation the posterior treatment field border was set at the S2-S3 interspace. The results are shown in detail in Tables 1 and 2.

The comparative study of the radiation field borders revealed statistically significant differences concerning the two evaluated methods of simulation. The superior field border of the anteroposterior treatment field differed significantly between the two methods of simulation ($p<0.001$). The same applied for the left and right lateral borders of the anteroposterior treatment field ($p<0.001$). For the inferior border of the anteroposterior treatment field, statistical analysis revealed significant difference but in the range of $p<0.038$. As for the lateral treatment field borders, statistical analysis revealed significant differences ($p<0.001$) for the anterior and posterior border between virtual and conventional simulation ($p<0.001$).

Table 1. Anterior-posterior radiation field borders

Ant-post field upper margin (cm)	*Ant-post field lower margin (cm)*	*Ant-post field left margin (cm)*	*Ant-post field right margin (cm)*
+2.2	0	3	3.1
-1.5	0	2.2	2.3
-1.5	0	1.3	2.5
+1.5	0	3.3	3.8
+1.5	0	2.76	2.8
+1.5	0	1.42	1.35
+1.5	0	2.68	3.8
+3.27	0	2.1	2.7
+1.5	0	3	2.4
+1.5	0	2.4	2.7
+1.5	0	3.6	3.6
+1.5	+0.7	2.12	1.91
+1.5	0	2	1.78
-1.5	+0.7	4	3
+1.5	+0.64	3.33	4.18
+1.5	0	1.13	1.06
+1.5	+0.85	3.04	3.4
+1.5	+0.4	4.3	3.26
+1.5	0	1.85	1.56
+3	0	1.13	1.9
+1.5	+0.36	2	2.5
+2.5	0	2.05	2.69
+1.5	+0.5	2	2.2
+3.5	0	2.93	3.3
+3	-0.7	2.12	1.7
+1.5	0	2.27	1.77
+2.5	+0.85	3	2.5
-1.5	0	3.47	2.2
+1.5	0	1.98	2.48
+1.5	0	3.27	2.19
+1.5	0	1.2	1.77
+1.5	0	1.63	1.84
+1.5	+0.45	3	2.4
+1.5	0	3	2.8
+1.5	+0.44	5	4.9
+1.5	0	3.68	3.47
+3	-0.58	3.25	3.38
+1.5	0	3.2	3.3
-1.5	+0.7	3.47	2.9
+2.5	+0.7	2.76	2.9
-1.5	+0.5	2.3	1.91
+1.5	0	2.05	2.05
+2.5	0	2	2.6
+1.5	0	3.19	2.8
+1.5	-0.7	2.83	2.76
0	+0.57	2.83	1.72
+1.5	0	2	1.7
+1.5	0	2.5	2.61
+1.5	0	3.85	4.18
+1.5	0	2.35	3

Discussion

For no other common primary solid neoplasm has been learned more in the past 15 years, especially in terms of radiation therapy, than prostate cancer. The increase in knowledge has improved our ability to select the most appropriate therapies for subsets of such patients and to better define the efficacy of radiation therapy in the management of clinically localized prostate cancer [3]. Local failure rate following conventional radiation therapy is likely to be due mainly to tumor-related factors and partly to technical factors of the radiation therapy [3]. Recent studies have demonstrated that older conventional techniques were associated with inadequate coverage of the target volume in at least 20-41% of the patients treated [3,4]. In comparing the two methods of simulation, studies have shown important differences between them. Results are reported for different treatment sites. The primary objective of a double-blind randomized trial by McJury et al. [5] was to determine the differences in target volumes contoured using both techniques. Comparison of the fields defined in each study arm showed a major or complete mismatch in coverage between fields in 70% of the cases. The use of virtual simulation resulted in field sizes 25% smaller on average than conventional simulation. Senan et al. [6] also found that the use of CT-simulation allowed for smaller planning target volumes in radical lung cancer radiotherapy. Differences in field sizes have also been reported for maxillary cancer favoring the use of CT-simulation with a corresponding reduction in long-term side effects by Nagata et al. [7]. Schiebe and Hoffman [8] demonstrated the reliability and accuracy of virtual simulation for different treatment regions in comparison to conventional simulation. Dinges et al. [9] in a study of 10 patients diagnosed with Hodgkin's lymphoma and 5 patients with non-Hodgkin's lymphoma demonstrated that virtual simulation for radiation

Table 2. Latero-lateral radiation field borders

Left lat-lat field lateral margin (cm)	*Left lat-lat field posterior margin*	*Right lat-lat field anterior margin (cm)*	*Right lat-lat field posterior margin*
1.47	Behind the sacral vertebra	1.1	Behind the sacral vertebra
0.92	S4S5	0.5	S4S5
0.5	S2S3	0	S2S3
1.06	Posterior margin S5	2	Posterior margin S5
0.5	Posterior margin S5	1.49	S4S5
0.75	S4S5	1.2	S4S5
2.5	Posterior margin S5	2	Posterior margin S5
0.9	Behind the sacral vertebra	0.9	Behind the sacral vertebra
2.8	Behind the sacral vertebra	2.12	Behind the sacral vertebra
1.2	S4S5	1.2	S4S5
2.5	S4S5	2.2	S4S5
1.77	S4S5	2.9	S4S5
1	S4S5	0.5	S4S5
2.5	S4S5	2.5	S4S5
1.5	Posterior margin S5	2.34	Posterior margin S5
0.57	Behind the sacral vertebra	0.57	Behind the sacral vertebra
0.78	S4S5	0.8	S4S5
2	Behind the sacral vertebra	2	Behind the sacral vertebra
0	S4S5	0	S4S5
0.7	Behind the sacral vertebra	0.7	Behind the sacral vertebra
1	Posterior margin S5	1.2	Posterior margin S5
1.98	Posterior margin S5	1.77	Posterior margin S5
0.92	S4S5	1.13	S4S5
1.87	Behind the sacral vertebra	1.9	Behind the sacral vertebra
0.3	Posterior margin S5	0.3	Posterior margin S5
1.5	S4S5	0.85	S4S5
1.33	S3S4	1.56	S3S4
1.2	Posterior margin S5	1.6	Posterior margin S5
0.85	Posterior margin S5	0.85	Posterior margin S5
2.3	Posterior margin S5	2.3	Posterior margin S5
0	S4S5	0	S4S5
0.43	S4S5	0.5	S4S5
0.64	S4S5	1.2	S4S5
0.78	Behind the sacral vertebra	1.35	Behind the sacral vertebra
3	S4S5	2.67	S4S5
1.5	Behind the sacral vertebra	2	Behind the sacral vertebra
1.47	S4S5	1.16	S4S5
1.9	Posterior margin S5	1.77	Posterior margin S5
1	Behind the sacral vertebra	1.5	Behind the sacral vertebra
2.62	S4S5	2.05	S4S5
0.2	S4S5	0.5	S4S5
1.49	S3S4	1.42	S3S4
2	Behind the sacral vertebra	1.98	Behind the sacral vertebra
0.78	Behind the sacral vertebra	1.35	Behind the sacral vertebra
1.5	S4S5	1.49	S4S5
2.05	Behind the sacral vertebra	2.76	S4S5
0.5	Behind the sacral vertebra	0.5	Behind the sacral vertebra
1.69	S3S4	1.6	S3S4
2.5	S4S5	2.62	S4S5
1.7	S4S5	1.63	S4S5

treatment planning of malignant lymphoma allowed for more information about soft tissue structures than conventional treatment planning and therefore it allowed for a more precise coverage of the target volumes and better shielding of organs at risk. Dobbs et al. [2] also demonstrated improved tumor volume coverage using virtual simulation for a small group of patients in a comparative study of conventional and virtual simulation for palliative lung radiotherapy. Especially for prostate cancer Baker showed significant reduction of target volumes and field sizes with virtual simulation compared to conventional simulation [10]. The use 3D-CRT techniques is advancing radiation oncology by providing the opportunity for both more conformal dose distributions and more complete and thorough safety systems. However, it must be stressed that the skills of the radiation oncologist, radiation physicist, dosimetrist and radiation technologist can never be entirely replaced by technological advances. The radiation oncology team must be constantly vigilant because no technology can fully compensate for a team members' error in judgment, misunderstanding of physical concepts or technologic limitations or unsatisfactory planning and delivery of radiation therapy [11].

In conclusion, this study demonstrated significant differences in the borders of treatment fields (anteroposterior and lateral fields) between conventional and virtual simulation. CT localization and virtual simulation allow for more accurate definition of the clinical target volume. This could enable a reduction in the geographical misses, reducing also treatment-related toxicity at the same time.

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