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Conventional versus virtual simulation for radiation treatment planning of prostate cancer: final results

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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 on the results of a study comparing target localization with conventional and virtual simulation.*

Methods: *One hundred prostate cancer patients underwent both conventional and virtual simulation. The conventional simulation films were compared with digitally reconstructed radiographs (DDRs) produced from the computed tomography (CT) data.*

All patients underwent target localization for radical prostate radiotherapy. The treatment fields were initially marked with a conventional portal film on linear accelerator (LINAC), plain x-ray film and available diagnostic imaging. Each patient then had a 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: *Virtual simulation showed significantly greater clinical tumor volume coverage and less normal tissue volume irradiated compared with conventional simulation (p <0.001).*

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

Key words: conventional simulation, prostate cancer, radiotherapy, treatment planning, virtual simulation

Introduction

During the past two decades, advances in radiologic imaging and computer technology have significantly enhanced the ability to achieve separation of dose response curves of 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].

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From CT data DRRs are produced, which can be used for comparison with conventional simulator films.

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

The most popular techniques for radiation therapy of prostate cancer include the use of a "four-field box" technique. This conventional, non-conformal technique uses open square fields that are based on bony landmarks.

In a previous study we presented the preliminary results of conventional vs. virtual simulation for radiation treatment planning of prostate cancer [3]. In the present we present the final results based on 100 high-risk prostate cancer patients.

Methods

Study population

The study included 100 patients with high-risk prostate cancer admitted for radical radiotherapy. High-risk patients need prophylactic irradiation of pelvic lymph nodes. In the tumor volume, besides the prostate and seminal vesicles, pelvic lymph nodes were included.

Methods

All 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 clinicians 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. The anatomical landmark for the definition of the superior treatment field border was the middle of the 5th lumbar vertebra body. The anatomical landmark for the definition of the inferior treatment field border was the inferior border of the ischial tuberosities.

The anatomical landmark for the 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. Lateral borders were defined from the distance beyond the widest bony margin of the true pelvic side walls. The anatomical landmark for the definition of the anterior treatment field border in lateral fields was the anterior edge of the pubic symphysis. The anterior border of the lateral treatment fields was defined by the distance from/in front of the anterior edge of the pubic symphysis. The anatomical landmarks for the definition of the posterior border of the lateral treatment fields were the S2-S3 interspace and the 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 (version 10, Chicago, IL).

Results

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

α) In the anterior-posterior treatment field

1) The superior border of the treatment field in virtual stimulation showed a range of variation from –1.5 to +3.5 cm above the middle of the body of the 5th lumbar vertebra (L5); 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 L5 body (set at 1.5 cm above the middle of the L5 body). 2) The inferior border of the treatment in virtual simulation showed a range of variation from –1 to + 0.85 cm above and below the ischial tuberosities. In conventional simulation the inferior border of treatment field was set at the ischial tuberosities (Figure 1B). 3) The right lateral border of the treatment field in virtual simulation 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. 4) The left lateral border of the treatment field in virtual simulation ranged from 1.06 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.

b) In the right lateral treatment field

1) The anterior treatment field border in virtual simulation ranged from 0 to 2.9 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. 2) The posterior treatment field border in virtual simulation ranged from the S2-S3 interspace to behind the posteri-

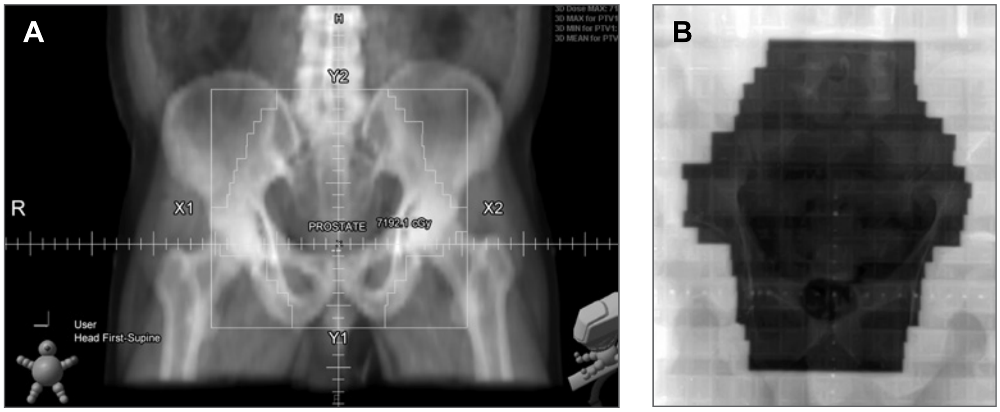

Figure 1. Anterior-posterior field borders. **A:** In virtual simulation the right and left lateral borders of the treatment field were 2.76 cm and 2.83 cm beyond the widest bony margin of the true pelvic side wall, respectively. **B:** In conventional simulation lateral treatment field borders were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

or sacral margin. In conventional simulation the posterior treatment field border was set at the S2-S3 interspace.

c) In the left lateral treatment field

1) The anterior treatment field border in virtual simulation ranged from 0 to 3 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). 2) the posterior treatment field border in virtual simulation ranged from the S2-S3 interspace to behind the posterior sacral margin (Figure 2A). In conventional simulation the posterior treatment field border was set at the S2-S3 interspace (Figure 2B).

Results are shown in detail in Tables 1 and 2.

The comparison study of the radiation field borders revealed statistically significant differences concerning the 2 evaluated methods of simulation. The superior field border of the anteroposterior treatment field differed significantly between the 2 methods of simulation ($p<0.001$). The same applied for the left lateral and right lateral borders of the anteroposterior treatment field ($p<0.001$). For the inferior border of the anteroposterior treatment field, statistical analysis also revealed significant difference ($p<0.038$).

With regard to the lateral treatment field borders, statistical analysis revealed significant differences for the anterior and posterior border between virtual and conventional simulation ($p<0.001$).

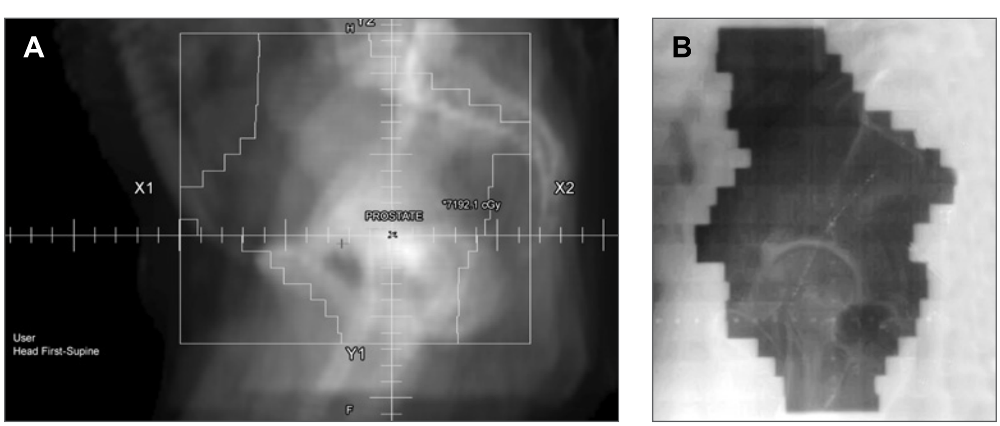

Figure 2. Latero-lateral radiation field borders. **A:** In virtual simulation the anterior border of the treatment field was 3 cm in front of the anterior edge of the pubic symphysis. **B:** In conventional simulation the anterior treatment field border was set 1 cm in front of the anterior edge of 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.

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
+1.5	0	3.6	3.6
–1.5	0	2.4	1.8
+1.5	0	2.68	3.8
+2.2	0	3	3
+1.5	+0.7	2.12	1.91
+1.5	+0.4	4	3.3
–1.5	0	2.2	2.3
+1.5	0	1.8	1.55
–1.5	0	1.3	2.5
+1.5	+0.35	2	2.4
+1.5	0	2	2.4
+1.5	0	2	1.7
+1.5	+0.5	2	2.2
+1.5	0	3.3	3.8
+2	0	2.5	2.6
+1.5	0	1.42	1.35
+3.27	0	2.1	2.7
+1.5	0	2.76	2.8
+1.5	0	2.05	2.69
+1.5	0	2.05	2.05
+1.5	+0.64	3.33	4.18
+3.25	0	2	2.7
+1.5	0	2.3	2.6
+1.5	0	3	2.4
+2.5	+0.44	5	4.9
+1.5	–0.5	3.7	3.3
+3.5	0	2.9	3
+1.5	–1	3	2.9
+1.5	0	2	1.78
+2.5	–0.7	4	2.7
+1.5	+0.8	3	3.2
+2.4	0	4.2	3.9
+2.5	0	3.3	3.4
+3	0	1.12	1.14
+1.5	0	2.67	4
– 1.5	+0.7	4	3
+1.5	+0.5	2	2.1
0	0	3	2.3
+1.5	+0.7	3.2	3.67
+1.5	–0.85	3.3	3.4
+1.5	0	4	3.47
+1.5	–0.8	2.4	3.3
0	0	2.6	2.3
0	0	2.3	2.67
+1.5	0	2.7	3
+1.5	+0.63	3.3	4.14
0	+0.5	3	4
+1.5	–0.45	1.06	1.06
+1.5	0	3.54	3.33
0	0	3.04	2.97

Discussion

For no other common primary solid cancer has more been learned 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 patients and to better define the efficacy of radiation therapy in the management of clinically localized prostate cancer [4]. Local failure rate following conventional radiation therapy is likely to be largely due to tumor-related factors and in part to technical factors of the radiation

Table 2. Latero-lateral radiation field borders

Left lat-lat field anterior 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 vertabra
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
1.87	S4S5	1.54	S4S5
0.5	Posterior margin S5	0.5	Posterior margin S5
0.9	S4S5	0.5	S4S5
0.8	S4S5	0.8	S4S5
1.84	Posterior margin S5	1.77	Posterior margin S5
0.75	S4S5	1.2	S4S5
1.49	S3S4	1.42	
1.5	Posterior margin S5	2.34	Posterior margin S5
1.05	Posterior margin S5	2	Posterior margin S5
1.2	Posterior margin S5	1.2	Posterior margin S5

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Left lat-lat field anterior margin (cm)	*Left lat-lat field posterior margin*	*Right lat-lat field anterior margin (cm)*	*Right lat-lat field posterior margin*
0.55	Behind the sacral vertebra	0.57	Behind the sacral vertebra
2.8	Behind the sacral vertebra	2.12	Behind the sacral vertebra
0.7	Behind the sacral vertebra	0.7	Behind the sacral vertebra
0.8	Behind the sacral vertebra	0.9	Behind the sacral vertebra
3	S4S5	2.67	S4S5
1.6	Behind the sacral vertebra	2	Behind the sacral vertebra
1.3	Behind the sacral vertebra	1.25	Behind the sacral vertebra
0.5	Posterior margin S5	1.4	S4S5
1.1	Behind the sacral vertebra	2	Behind the sacral vertebra
0.3	Posterior margin S5	0.3	Posterior margin S5
2.5	S3S4	2.58	S3S4
2.3	S4S5	1.6	S4S5
0.5	S2S3	0	S2S3
3.5	S4S5	2.5	S4S5
1.6	S3S4	1.6	S3S4
3	Behind the sacral vertebra	2.35	Behind the sacral vertebra
2.1	S4S5	2.2	S4S5
1	S3S4	0	S4S52
2.5	Posterior margin S5	2	Posterior margin S5
1.7	Behind the sacral vertebra	1.5	Behind the sacral vertebra
1.3	S4S5	1.4	S4S5
1	S3S4	1.4	S3S4
1.6	S3S4	1.4	S3S4
2.6	Behind the sacral vertebra	2.12	Behind the sacral vertebra
1.87	S4S5	1.87	S4S5
0.7	S4S5	0.72	S4S5
2	Behind the sacral vertebra	2	Behind the sacral vertebra
2	Posterior margin S5	1.6	Posterior margin S5
0	S3S4	0	S3S4
1.7	S4S5	2.5	S4S5
1.2	S3S4	1.49	S3S4
1.91	S3S4	1.49	S3S4
1.2	S4S5	1.2	S4S5
1.95	Posterior margin S5	1.75	Posterior margin S5
1.2	S4S5	1.2	S4S5
2.5	S4S5	2	S4S5
0	S4S5	0	S4S5
1	S4S5	0.5	S4S5
1.5	Posterior margin S5	2.2	Posterior margin S5
1.45	Behind the sacral vertebra	1.1	Behind the sacral vertebra

therapy [5]. 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 [5,6]. 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 the 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 therapy. Differences in field sizes have also been reported for maxillary cancer 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 treatment planning allows 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. Driver et al. [2] also demonstrated improved tumor volume coverage using virtual simulation for a small group of patients in a comparison 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 3DCRT 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 therapist 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 geographical misses, reducing at the same time treatment-related toxicity.

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