Immersive Visualization with Automated Collision Detection for Radiotherapy Treatment Planning

J W WARD [a], R PHILLIPS [a,1], T WILLIAMS [b], C SHANG [b], L PAGE [a], C PREST [a], A W BEAVIS [c]
[a] *Department of Computer Science, University of Hull, Hull, UK*
[b] *Boca Raton Community Hospital, Florida, USA*
[c] *Princess Royal Hospital, Hull and East Yorkshire NHS Trust, Hull, UK*

Abstract. Intensity modulated radiotherapy (IMRT) is a technique for treating cancer tumours using external delivery of radiation. To create a treatment plan the directions of the external radiation beams (typically 5 to 9) need to be specified. Normally the beams are all coplanar due to the added complexity of planning and patient set-up for non-coplanar beams. RTStar provides a virtual environment of a radiotherapy (RT) treatment room that provides a range of views and visualizations that aid a treatment planner to choose non-coplanar beam directions efficiently. RTStar also automatically warns the planner when a collision would occur during patient set-up. A study was conducted on 8 prostate IMRT cancer patients using RTStar to create RT plans using non-coplanar beams. The study demonstrated that these IMRT prostate plans with non-coplanar beams had a dosimetric advantage over their coplanar conterparts.

Keywords. Visualization, radiotherapy planning, collision detection.

1. Introduction

Intensity modulated radiotherapy (IMRT) [1] is a technique for treating cancer using external delivery of radiation. The radiation field is delivered from a number of beam directions (typically 5 to 9) by a linear accelerator. The shape of each radiation beam is matched to the shape of the tumour and the intensity of radiation is modulated across the cross section of the beam via collimation. A challenging task for the treatment planner is choosing the best set of beam directions. Once chosen an inverse planning optimisation algorithm computes the dose intensity across each beam taking into account dose constraints for the tumour and surrounding critical organs (known as organs at risk). Typically, all the beams of the plan are coplanar (i.e. they all lie in the same plane, normally the axial plane of the patient). This coplanar approach guarantees that the rotating gantry of the linear accelerator does

[1] Corresponding author: Roger Phillips, Department of Computer Science, University of Hull, Cottingham Road, Hull, East Riding of Yorkshire, UK, HU6 7RX; E-mail: r.phillips@hull.ac.uk

not collide with the patient. Use of non-coplanar beams has been reported [2] but the possibility of a collision and additional set-up complexity reduces their use. We have developed a visualization software, RTStar, that can be used with a commercial radiotherapy planning system to create IMRT plans with non-coplanar beams. RTStar features an interactive immersive environment of a radiotherapy (RT) treatment room. This environment contains the patient and it provides automatic detection of potential collisions between the patient and surrounding equipment. Section 2 describes RTStar's facilities that support RT planning. Sections 3 to 5 present a prostate study where RTStar was used to create IMRT plans with non-coplanar beams. These showed a dosimetric improvement over coplanar plans.

2. Tools and Method

The software application RTStar provides a range of simulations and visualizations based on a virtual RT treatment room. RTStar's initial use was for education and interactive immersive training of RT [3,4]. This paper reports how RTStar was extended to support RT planning and its application to plan non-coplanar beams.

The approach adopted for non-coplanar planning of beams is that the RT treatment is first planned using a set of coplanar beams via a commercial RT treatment plan review system (in our case CMS Focal - see www.cms-stl.com). The treatment plan is then uploaded into RTStar. Using RTStar's flexible visualization and automated collision detection facilities, the RT planner manually adjusts one or more beams to achieve a better position. The objectives in seeking an improved beam direction are typically to obtain a better heterogeneous dose distribution to the planned tumour volume (PTV) or provide better dose sparing to the organs at risk, for example by reducing dose to the dose hot spots.

These revised beam directions are then entered back into the RT planning system and a new treatment plan and its dose is computed.

2.1. Visualization Facilities

The virtual environment created by RTStar contains models of the patient, the RT plan, the treatment couch and linear accelerator, all set within a treatment room. This is known as the *room view* (Figure 1). The elements of the RT plan that can be visualized include the image data sets (typically CT / MRI), segmented volumes for the tumour (CTV, PTV, etc) and surrounding organs at risk (e.g. bladder, rectum), dose distribution for the treatment site, radiation beams and their constituent segments, etc. The models of the couch and linear accelerator are geometrically precise and match the equipment actually used for RT treatment. This as important in order to predict collision between the patient on the couch and the gantry of the linear accelerator. Full interactive articulation of the couch (3 DOFs) and gantry (2 DOFs) is provided to the planner. Dose visualization of the existing plan is provided by the display of various isodose surfaces and a dose colour-wash on the surface of the tumour and organs at risk (Figure 2). This dose visualization enables the planner to locate the hot and cold spots of dose for the current plan and to adjust a beam position to reduce their effect.

Figure 1. Room view of all segmented anatomy with skin hidden.

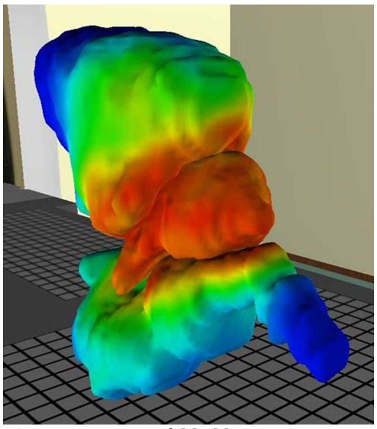

Figure 2. View of bladder (top), tumour (middle) and rectum (bottom) with dose colour-wash on surface of structures.

Visualization controls allow the display of the gantry, couch, image study sets, organs etc to be turned on and off and the transparency and colour of the anatomy and dose can be varied at will.

In addition to the room view, RTStar provides a *beam's eye view* (BEV), i.e. a view formed by looking down the central axis of the beam towards the treatment site. This view is particularly useful in determining the extent of overlap between the tumour and the organs at risk within a beam. This view helps the planner to adjust the beam direction to minimise such overlap.

RTStar uses a dual monitor set-up, with one being a 19" auto-stereo 3D monitor, and the other a conventional 2D monitor. The room view and BEV are divided over these two monitors. The room view can be displayed in stereoscopic 3D, which provides the planner with greater depth perception of the treatment site. The planner is able to navigate around the room view with ease and zoom-in on structures, fly between structures and even view inside structures as required.

Together, the above visualization facilities of RTStar allow the planner to assimilate quickly the juxtaposition between the tumour, surrounding critical organs, the radiation beam and its associated dose distribution and to efficiently and conveniently make adjustments to the beam directions.

2.2. Collision Detection Facilities

Potential collision between the patient, couch and the linear accelerator's gantry is detected automatically by RTStar as the planner adjusts the beam position. This avoids creating RT plans that can not be delivered in the actual treatment room.

Currently RTStar provides a visual warning (i.e. the gantry goes red) when a collision is about to occur between the gantry of the linear accelerator and the couch and patient. This is achieved by creating bounding volumes around the gantry and couch. For prostate and thorax cancer sites a bounding volume for the patient is created from the CT dataset and is extended to cover the whole patient. The bounding volumes include a margin to account for minor variations in actual patient set-up.

3. Prostate Study

The purpose of the study was to investigate the dosimetric advantages of using non-coplanar beams in IMRT plans compared to existing coplanar plans. For the study 8 IMRT prostate cases whose treatment had already been planned at the Boca Raton Community Hospital were randomly selected. Revisions to these existing plans aimed to achieve dosimetric advantage by choosing beam directions that would reduce the radiation dose to the rectum and the bladder.

For these 8 cases the coplanar 7-beam IMRT plans were normalised by setting the prescribed dose constraint that 95% of the tumour volume (D95) be at least 45 Gy. For all cases the 7 gantry angles were evenly spread from 35º to 325º.

Aided by RTStar's visualization facilities the heuristics for selecting better beam positions were established. Using the BEV it became evident that for the two most posterior beams, more than 75% of the rectum intersected the beam targeted on the PTV. Therefore to reduce the rectal dose, these two most posterior beams were rotated anteriorly until the overlap of the PTV on the anterior rectal lumen was reduced to 50% of the visible rectal cross section. This determined the limits of the two most posterior gantry angles for posterior oblique beams. The remaining 5 beams were then evenly arranged between these limits. To reduce the bladder dose, the two anterior beams either side of the AP beam were rotated inferiorly by about 40° to reduce the bladder overlap (Figure 3). Inferiorly tilting the AP beam would further reduce dose to the bladder, however it exposes the penile bulb to radiation which is highly undesirable [5], thus no adjustment was made to the AP beam.

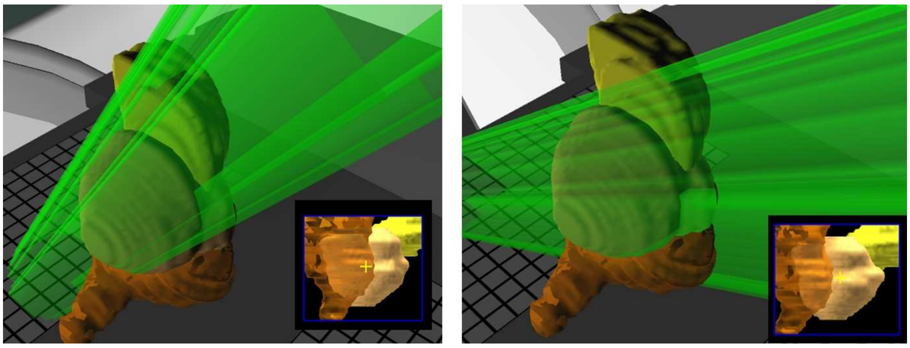

Figure 3. On the left, the view of the original right anterior oblique beam shows that almost the entire bladder overlaps the beam. On the right, a larger portion of the bladder is spared by inferiorly tilting the beam to create a non-coplanar beam. Inset shows the beam eye view (BEV) of the treatment site.

4. Results of Study

Dose homogeneity for the tumour was compared by analysing the global maximal dose (D Global Max) and the average dose of the 5% of the PTV that received the highest dose (D high 5%). A significant reduction in both indicators was observed in the test group as shown in Table 1.

Table 1. Comparison of dose homogeneity for the planned tumour volume (PTV)

	D high 5%			D Global Max		
	Control	Test	Difference	Control	Test	Difference
Max	5115	5025	-140	5416	5373	-191
Min	4828	4780	-5	4960	4864	-23
Mean	4958	4898	-60	5149	5065	-84
SD	108	86	58	146	156	56
t-test (2 sided)	**0.022**			**0.004**		

For the organs at risk, i.e. the rectum and the bladder, the mean dose (D mean) was determined. In addition, hot spots of radiation within each organ were analysed. For the rectum, the 10 cc of the rectum that received the highest dose (D 10cc) was determined. Similarly for the bladder the highest dose for 30 cc (D 30cc) was determined. The results for the rectum and bladder are given in Tables 2 and 3.

Table 2. Comparison of dose for the rectum (an organ at risk).

	D mean			D 10cc		
	Control	Test	Difference	Control	Test	Difference
Max	2573	2408	-231	4479	4437	-290
Min	1789	1885	180	3330	3150	20
Mean	2200	2185	-15	4053	3960	-93
SD	234	189	150	421	463	108
t-test (2 sided)	**0.708**			**0.044**		

Table 3. Comparison of dose for the bladder (an organ at risk).

	D mean			D 30cc		
	Control	Test	Difference	Control	Test	Difference
Max	4078	3991	-873	4770	4583	-425
Min	1084	838	231	3618	3408	-3
Mean	2767	2412	-356	4329	4159	-169
SD	1084	1037	324	405	409	125
t-test (2 sided)	**0.017**			**0.006**		

For the rectum there was no significant difference between the mean dose for the two groups. However, there was a significant reduction for the test group in lowering the mean radiation to the 10 cc hot spot.

For the bladder there was a significant reduction of the mean dose for the test group. Furthermore, there was also a significant reduction for the test group in lowering the mean radiation to the 30 cc hot spot. Together these two statistics indicate that for the bladder there is a significant dosimetric advantage for the test group.

5. Discussion

In the original IMRT plans with their coplanar beam setups, the structures adjacent to the PTV, including a large portion of the rectum and the bladder are exposed to the beams. By tilting two of the anterior oblique beams away from their coplanar positions to provide better dose sparing, a portion of the radiation dose was in fact shifted from the inferior portion of the rectum to its superior section. This contributed to there being no significant change to the mean rectal dose. However the rectal 10 cc high dose region showed a significant improvement due to this dose shifting. Not achieving a significant reduction to the mean rectal dose was rather unexpected as intuitively one would expect a reduction of rectal overlap to give a reduction of mean rectal dose,

However for the bladder, the BEV of these two non-coplanar beams clearly showed that the volume of the bladder in the beam was reduced (Figure 3). Consequently there was both a significant reduction for the test group of both the bladder mean dose and mean dose to the bladder's high 30 cc dose region.

This study also showed an improvement to dose homogeneity within the PTV.

We believe that non-coplanar beam arrangement is the sole factor for these dose improvements. As the two inferiorly tilted beams are further apart from their adjacent beams in terms of entrance point, this creates a more favourable pre-condition for dose intensity modulation.

6. Conclusions

The study reported has demonstrated that non-coplanar beam arrangement for prostate treatment can give better dose sparing to the bladder and reduce the high dose region of the rectum. The virtual simulation facilities of RTStar played a key role in developing and individualising the new set of optimal beam orientations.

The investigators of the reported study found the user-friendly visualization and collision detection facilities very important for IMRT planning with unconventional beam settings, including non-coplanar beam orientation. These facilities provided additional visual information that assisted the evaluation of the spatial relationship between the PTV and adjacent critical structures and helped analyse those organs at risk that intruded into a specific beam. RTStar is now being used to establish heuristics for including non-coplanar beams in plans for other treatment sites.

RTStar is being further developed to allow automatic collision detection for all treatment sites. Ongoing work is investigating creation of a full body model of a patient from PET images, including models of treatment aids, fitting a generic patient model to real patient data, adjustable collision margins, etc.

A software prototype has also been developed where the facilities of RTStar are seamlessly integrated into CMS's Focal RT plan review system.

References

[1] Webb S, *Intensity-modulated radiation therapy*, Institute of Physics Publishing, Bristol, 2000.

[2] Price Jr RA, et al, *Advantages of using non-coplanar vs. axial beam arrangements when treating prostate cancer with intensity-modulated radiation therapy and the step-and-shoot delivery method*; Int J Rad Onc Biol Phys 2002, Vol. 53:236-243

[3] Phillips R, Ward JW, Beavis AW, *Immersive Visualization Training of Radiotherapy Treatment*, Proceedings of Medicine Meets Virtual Reality 13, pp 390-396, Jan 26-29 2005, Long Beach.

[4] Phillips R, Ward JW, Bridge P, Appleyard RM, Beavis AW, *A Hybrid Virtual Environment for Training of Radiotherapy Treatment of Cancer*, Proc. Electronic Imaging Science & Technology: Stereoscopic Displays & Applications, San Jose, USA, Jan 2006, SPIE Vol 6505, pp 6055008 1-12.

[5] Steenbakkers RJHM, et al, *Reduction of dose delivered to the rectum and bulb of the penis using MRI delineation for radiotherapy of the prostate*; Int J Rad Onc Biol Phys 2003, Vol. 57:1269-1279.