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Image Guided Radiotherapy Workflow for Localized Prostate Cancer : A Hybrid Solution for A Better Therapeutic Outcome

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ABSTRACT

Image guided radiotherapy (IGRT) workflow was introduced to manage localized prostate cancer treatment by hybridizing treatment planning and dose delivering optimization. Seven main challenges were examined over a four year period with simple hybrid tailor-made solutions and workflow protocols formulated with limited resources. These techniques significantly improved the therapeutic ratio by safely reducing the large target margins and enhanced the possibility for dose escalation. However, clinical implementations were explored cautiously and a comprehensive dosimetric evaluation done to address uncertainties in workflow.

Keywords : Image Guided Radiation Therapy, Prostate Cancer, Workflow Protocol, Image Fusion.

I. INTRODUCTION

A three dimensional conformal radiotherapy (3D CRT) is used routinely in prostate cancer radiation treatment in an effort to maximize its therapeutic ratio. Its successes rely on the accurate delivery of escalated dose to the targets and minimal dose to surrounding normal tissues. Temporal variations either by patient/organ geometry or dose-response related [1] were the predominant sources of treatment uncertainties with numerous imaging studies confirming this [2, 3, 4]. Conventional methods to compensate for these variations typically involve adding a large margin around the target while limiting the tumor dose prescription. Encouraging results in dose escalation trials for localized prostate cancer [5, 6, 7] establish a better method of safely escalating doses without unduly compromising the treatment volume. This workflow involves fused images from a dedicated computed tomography (CT) and magnetic resonance imaging (MRI) scanners. CT scans solely used for delineation tends to overestimate the prostate volume and underestimate the prostate to rectum distance, in comparism to CT-MRI fusion-based treatment planning [8]. Another study [9] shows the dose-volume histogram (DVH) from CT-MRI fusion is possible to spare a mean 10% of rectal volume and approximately 5% of bladder and femoral heads. In IGRT prostate treatments [10, 11, 12] portal images and digitally reconstructed radiographs (DRRs) are the most frequently used image-guidance systems to monitor patient setup and verification. Several factors contribute to the accuracy of the delivered dose to patients; and in-vivo dosimetry is highly recommended [13]. Recently developed concepts of image-guided adaptive radiotherapy (IGART) workflow can lead to improved matching between planning and treatment [14] by considering an idea workflow. The main goal of this manuscript is to outline the evolution of an IGRT workflow generated

over the years with limited resources to deliver very high standard therapeutic outcome for localised prostate cancer patients.

II. METHODS AND MATERIAL

A. Patient pre-scan preparations for CT/MRI simulation:

Patients are instructed to take 10mg of dulcolax three days prior to CT/MRI scanning to empty their bowels. The bladder is kept comfortably full by drinking 200ml of water mixed with 18ml Gastrografin and intravenous (IV) contrast 30 minutes prior to the scan. These are reproduced by the patient continuing with the dulcolax and taking 200ml of water 30 minutes before daily treatment. Three fine gold markers are implanted transrectally into the prostate guided by an ultrasound, and this is verified before the scanning.

B. CT/MRI fusion for targets and OARs delineation:

Patients are scanned supine with both CT and MRI simulations done on customized flat couches to mimic that of the treatment unit. Dicom images are exported unto the TPS and later imported and fused based on bones and soft tissues. The two image series are registered before fusion. The implanted gold markers give an idea of the size and location of the prostate relative to other OARs. The gross tumor and clinical targets volumes (GTV and CTV) and OARs (bladder, rectum and femoral heads) are then drawn as region of interest (ROI) for onward planning. Fig.1 shows a fusion of CT/MRI images using a rigid alignment of patient contours.

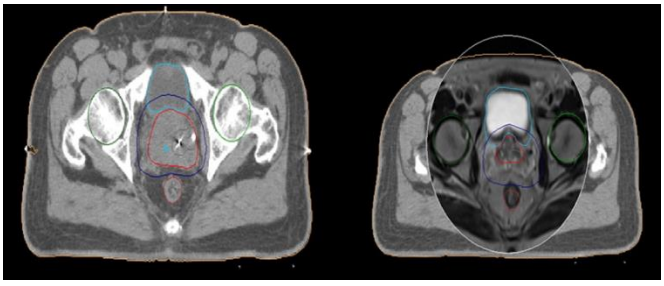

Figure 1. MRI scans overlying a CT scan showing differences in targets and OARs definitions

C. Gold marker implantation and enhancement of its artefacts on isodose lines and imaging:

Each patient had three cylindrical gold markers inserted into the prostate (to serve as a surrogate for the prostate) before CT/MRI scans. These markers are critical in image guided radiotherapy. However, they produce uncertainty in the dose calculation during treatment planning because of gold's (Au) higher photon mass attenuation coefficient than that of normal tissue. The immediate tissue around the fiducial markers was contoured and its density changed to 1.00 g/cm^3 (density of water). The geometric reliability of the digitally reconstructed radiographs (DRRs) generated by Oncentra Master Plan treatment planning system (TPS) are assessed and adjusted accordingly to give better images.

D. Daily online target verification and shift protocols:

To verify the treatment position of the prostate, portal images representing the displacements are acquired with an iView imaging device. For inter-fraction prostate position corrections for both systematic and random errors, an on-line correction procedure is applied. After manual alignment of the marker annotations onto the portal images, the set-up deviations and required corrections are displayed on iView matching software [15].

E. In vivo diode dosimetry: After satisfactory patient set up, diodes are placed on the crosswire at isocenter. The diodes placed are based on the energy and type (photons or electrons) of radiation used for the treatment. Commercial diodes and Apollo 5 electrometer are used for the in vivo measurement. Diode readings are taken for all fields for the first two fractions unless prescribed by the physicist

III. RESULTS AND DISCUSSION

This workflow was developed over the years as a result of a careful and meticulous inter-departmental approach and contribution. Clinical implementations were carefully incorporated after cautiously exploring these new techniques and comprehensive dosimetric evaluation done to address uncertainties. It involves a treatment plan based on 3D volumetric CT/MRI imaging fusion, a strict pre-scan preparation protocol and a highly conformed 3DRT 78Gy in 39 fractions plans. Densities of implanted gold markers are changed in the TPS during dose calculation to obtain accurate isodose and DVHs. Without density correction, the minimum coverage to the PTV was 85.54% but went up to 100.05% when the density was changed. This is a true reflection of the dose coverage to the PTV leading to a more coherent DVH table. Superior DRRs are also generated to clearly distinguish the fiducial markers from intraprostatic calcifications (IPCs) and bones for image verification using the iView imaging system. CT based scans delineation overestimated the prostate volumes by approximately 30% thereby irradiate normal tissues around the prostate. These uncertainties in delineating the targets and OARs were compensated for by giving 2 cm margins around targets and a restriction on the total dose to 68Gy.

The introduction of multi-imaging technique presented a unique challenge for the evolution of the workflow. The two imaging devices had different shaped couches; a flat surface for the CT and a cradle-shaped for the MRI. These differences introduced anatomical variations during fusion and setup errors due to table sag. A home-made flat wooden table top was designed (without metallic and artefact producing objects) to be inserted inside the MRI cradle of the existing table. This made it very easy to fuse both images perfectly. The default DRRs generated by the TPS were of a poor quality and very difficult for matching portal images during imaging verifications. These default image qualities were enhanced by generating customized TPS DRR settings for all prostate cancers patients with gold marker implants. Few patients also presented with IPCs which when during image verification mimic the gold marker implants and very difficult to distinguish as shown in Fig. 2 (A). Matching on wrong objects will lead to wrong shifts and wrong target treatment compromising on the prostate target and OARs. A simple but a very effective way was to draw blocks around the gold markers during planning as in Fig. 2 (B). The TPS provides a very distinct and clearly defined gold marker DRRs for imaging verification.

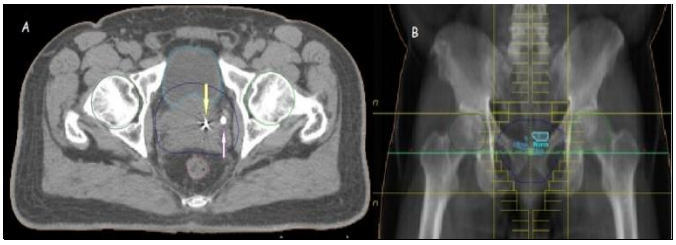

Figure 3. (A) Problem in distinguishing Gold marker implants from intraprostatic calcifications in the prostate (yellow arrow is gold marker and white arrow an IPC), (B) blocks on gold markers during treatment planning

The benefit of following pre-scan instructions as shown in fig.3 is the reduction of rectal volume dose. The shape of the rectum changed with this current workflow to achieve a V50Gy ≤50%, V60Gy ≤40% and V75Gy ≤15% constraint tolerance levels set by the department.

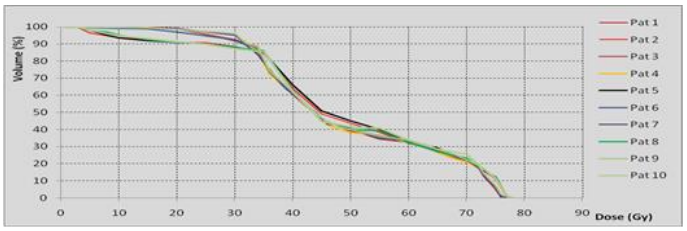

Fig.3. Variation of rectum DVH for new workflow

It was noted that, systematic errors reduced from an average of 4.34 mm to 2.92 mm and random errors from 3.95 mm to 2.68 mm with our gold marker

protocol. Approximately 39.6% of observed patient positioning setup (using gold markers) needed corrections prior to treatments as compared 56.8% when matched on bony anatomy. The rectal dose was significantly reduced in CT-MRI fusion-based plan. For online image guidance, The MV EPID has been a valuable tool to acquire image with patient in treatment position. The main obstacle limiting this workflow from wide clinical implementation is the time management challenge and resource allocation. Many components in this process require considerably increased cost to time and staff resources compared to old treatment technique.

IV.CONCLUSION

Implementation of this image guided radiation therapy workflow for prostate cancer patients required an in-house approach with limited resources. This workflow protocol was tailored specifically to maximize prostate cancer treatment therapeutic outcome whiles sparing the healthy surrounding organs. However, such workflow protocol requires substantially added cost and time to the clinical schedule. The accuracy with which the targets and organs at risks are contoured reduces target margins whiles daily volume imaging also reduces setup and treatment errors. There is no superior or inferior workflow; because a radiotherapy centre should adopt the most suitable workflow, as dictated by its resources (the equipment and personnel available). When this is done, it will maximize efficiency, reduce the possibility of treatment errors and invariably, increase the quality of the treatment offered by the radiotherapy centre. Continous efficient workflows are required to enable frequent adaptive interventions regardless of available resources.

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