Journal of Radiotherapy in Practice

Journal of Radiotherapy in Practice 1999
1, 103–108

Original Article

The role of Digitally Reconstructed Radiographs in the verification process

N. S. Stanley

Radiotherapy Department, Cookridge Hospital, Leeds, UK

Abstract

This article reviews the development and potential impact of Digitally Reconstructed Radiographs (DRR's) in the planning and verification of radiotherapy treatments. It explores the requirements for the creation of usable DRR's their integration into current verification methods and it highlights some of the factors that may influence the routine use of DRR's. Continuing developments in radiotherapy techniques demand increasingly accurate verification methods. DRR's provide an efficient and effective representation of planned treatments for comparison with both simulator and portal images, encompassing the digital imaging technology which is the future of radiotherapy treatment verification.

Keywords

DRR's; conformal radiotherapy; verification; simulator; portal imaging

INTRODUCTION

The advent of 3D conformal radiotherapy (3D CRT) has led this department to assess current techniques in terms of accuracy and reproducibility. Conformal techniques require a high degree of accuracy to ensure the planned volume is within the high dose area for each fraction. Traditional verification methods are being adapted and digital imaging technology utilised to give more accurate information about target volumes and field placement.

It is widely accepted that CT planning is the method of choice for the planning of complex radiotherapy treatments because of its ability to deliver a more detailed anatomical picture compared to a conventional radiotherapy simulator. However, the CT images are not beams eye view (BEV) and consequently not directly comparable to megavoltage images (MVI's). Therefore, the role of the simulator is to produce images of the proposed fields for verification prior to the patient starting treatment and for these to be used for comparison with images from the linear accelerator. Using a 3D planning system or virtual simulator, the CT data can now be reconstructed to form Digitally Reconstructed Radiographs (DRR's) which represent the treatment portals.

This discussion is not technique specific, although clinical practice with DRR's in the radiotherapy department at Cookridge at the time of writing only involved the conformal prostate technique. This article explores the feasibility of these images being incorporated into the planning and treatment processes.

THE PRODUCTION OF DRR'S

A DRR is defined by Webb[1] as a 'Planar radiograph constructed by ray-tracing from the position of the X-ray source through the 3D matrix of CT data'. These were first presented for use in radiotherapy by Goitein.[2] Although the image quality was poor,

Correspondence to: N. S Stanley DCR(T), Imaging Research Radiographer, Radiotherapy Department, Cookridge Hospital Leeds LS16 6QB, UK

he did note that contrast enhancements could be used to define structures where it is possible to use only the high CT numbers to create an image showing bone and contrast.

The CT numbers are derived from the voxels, which in turn are determined by the slice thickness and interslice spacing, directly impacting upon the quality of the image.

The DRR's for radiotherapy are produced by the new generation of 3D planning computers. The planner can select the structures to be highlighted in the DRR depending on what it will be compared to, e.g. MVI.

CT scanner

To plan 3D treatments, a full CT dataset is required. A full dataset consists of large numbers of CT slices so that the reconstruction for planning purposes is accurate. Research has shown that between 50 and 100 slices are necessary to give accurate critical organ volume delineation and good quality DRR's.[3] Using a conventional CT scanner, this has resulted in longer scan times, with the consequences that the patient can find it difficult to hold the treatment position for the length of time required to perform the scan. Movement during the scan results in inaccurate reformatted data.[3] The dose to the patient is also increased which may be considered insignificant given the dose about to be received from the radiotherapy, but is an issue that should be addressed when deciding whether to use DRR's.

Spiral scanning has helped to overcome this problem since in spiral CT both the X-ray tube and couch are moving continuously throughout the scan with the result that the transmitted beam traces a spiral over the surface of the patient. This eliminates the delay time, which is necessary on conventional scanners to reposition the scanner mechanism and allow cooling of the X-ray tube. Dual slice scanning has been studied[4] and concluded that '...the dual slice scan permits the same volume to be scanned in half the time without generating extra degradation in image quality'. This technology applied 'dual slice technology to spiral scanning'[4] where instead of one arc of detectors as in conventional spiral scanners there are two, side by side parallel arcs which produce a double spiral. Whether the technology could be applied to radiotherapy planning and still produce usable DRR's is not known. However, spiral CT scanning has been successfully applied to radiotherapy with the latest CT scanners designed specifically for radiotherapy (CT simulators) using the spiral scanning technology. The CT simulator has the further advantages over the conventional diagnostic scanner in that they have the flat couch top and large aperture vital to enable the patient to be scanned in the desired treatment position.

Whilst these CT scanners provide the ideal, our department currently utilises a diagnostic spiral scanner on a sessional basis with a custom-built flat couch top. CT planned techniques have been tailored to ensure that the patient can be scanned in the treatment position, e.g. thoracic techniques where the patient's arms are placed above the head. This implies that to an extent our techniques are dependent, not only on the ability to reproduce the set-up accurately, but also on the limitations of the CT scanner.

Planning system

A 3D treatment planning system (TPS) or virtual simulator are a necessity to utilise the 3D matrix of data from CT to produce the DRR's.

The TPS gives the planner a degree of control over the DRR in the manipulation of contrast and enabling the selection of structures. However, this constitutes fine-tuning since, as discussed previously, the CT slice thickness has the most bearing on the quality.

Conway and Robinson[5] are of the opinion that 'Virtual simulators are designed to produce rapid high-resolution DRR's, in contrast to 3D planning systems where the quality and speed are limited'. The value of sub-second over 5–10 second DRR production for most purposes is negligible; both are quicker than film processing. However, for some techniques, the clinician may need to examine a series of DRR's using different window settings to highlight different structures. In this situation, there is a definite time advantage to having fast reformatting capabilities. The quality of the DRR using the Picker Acqusim™ described by Conway and Robinson appears to be similar to those produced by the Helax™ TPS used in this department.

https://doi.org/10.1017/S1460396999000187 Published online by Cambridge University Press

IMAGE QUALITY

The quality of the DRR is dependant on the equipment used, the user and the technique to be planned. Galvin et al[3] concluded that the DRR could not match the resolution of the simulator film and also determined that the CT hardware was holding back the DRR quality. Valicenti et al.[6] state that 'DRR's are now of sufficient quality to provide detailed anatomic comparison with portal film and may substitute for diagnostic simulator radiographs'. They agreed with Galvin et al's conclusions that the DRR's cannot match the resolution of the simulator radiograph but concluded that they are good enough for comparison with megavoltage images.

CT scanning produces images of far superior anatomical detail to conventional radiographs and therefore these images are used to plan treatments. What is lacking is a direct comparison between the CT, simulator and MVI. The scout view is used for the AP verification, but this is non-divergent in the cranio-caudal direction, laterally the slice at the isocentre has to be used. It is therefore difficult to judge if the set up on the simulator accurately (within 2/3 mm) reproduces the CT set up. The DRR's have filled this gap, but only if they are good quality. 3–5 mm slices are required to give reasonably good resolution, 1.5–2 mm through the head and neck gives improved resolution for these images.[3]

A research study[7] tested the accuracy of 3D volume reconstruction for CT slices of thickness 2 mm, 4 mm and 8mm. This study was experimental and performed using a cylindrical phantom. The conclusion that 8–10 mm slices are adequate for conformal radiotherapy, where the target diameter is >4 cm, was reached by considering the contrast of the reconstructed objects and the time taken for contouring and isodose calculation. Cost-benefit was raised, however the use of data to create DRR's was not addressed. When contemplating the use of conformal radiotherapy, selecting an accurate means of verification is vital. DRR's can provide this, and potentially replace a simulator session, perhaps overcoming the cost effectiveness issue. As mentioned previously, 3–5 mm slices are required for acceptable resolution, therefore if DRR's are to be used 8–10 mm slices are not adequate. Recent technological advances where planning systems are capable of interpolating contours saves time during volume definition, e.g. Plato VSS™, although this facility is not available on all systems. Where it is available, the implication is that the time advantages of 8–10 mm slices are reduced. Departmental experience has indicated that contouring 30, 5 mm slices for conformal prostate planning is acceptable and preferable for both accuracy of organ definition and DRR quality when compared with 8 mm slices.

One point to note is that with the Helax™ system, any slices that are not contoured are deleted from the study and not available for digital reconstruction, which means that for image quality it may be necessary to contour on slices not needed for dosimetry purposes. This may then alter the opinion that the time spent contouring is acceptable.

The Helax™ TPS is used to create DRR's for prostate treatments with the enhancement set to bone. This has produced DRR's adequate for comparison with electronic portal images (EPI's) from an Elekta *i*view™ electronic portal imaging device (EPID), thus confirming the findings of Valicenti et al. DRR's have the further advantage that they can show the multileaf collimator (MLC) positions, which the current simulator used here cannot. Simulator film is still used and MLC leaf positions are drawn on by overlaying the film on a hardcopy DRR. From personal experience this has not proved particularly practical for several reasons:

1. Difficulty in overlaying anatomy due to the unsharpness of the DRR hardcopy.
2. Subjectivity.
3. Simulated centre and open field edges do not always match the DRR because of set-up inaccuracies.
4. Time taken to print out hard copies (approximately 1 hour for 4 DRR's).

The necessity for hardcopy images in state of the art radiotherapy is decreasing. The CT data is transferred to the TPS along a network link for images to be viewed on screen. DRR's and EPI's are now being used clinically, with the EPID providing the 'lightbox' facility to allow the images to be compared either quantitatively or subjectively depending on the image registration software available.

https://doi.org/10.1017/S1460396999000187 Published online by Cambridge University Press

In the verification of complex treatments, there is a need for quantitative image registration since, through software based image registration techniques more accurate results of field placements can be gained than comparison by eye.[8] An image registration tool, Portal Image Processing System (PIPS), is in clinical use in our department and has been used for the image registration of both scanned portal films and *i*view images with both DRR's and simulator film. Early clinical use with prostate treatments suggests that since the DRR image is more comparable in terms of image quality to the MVI, it is slightly easier to work with, in that the DRR and the MVI both highlight the same areas of dense bone. The use of DRR's at other sites is currently under evaluation.

APPLICATIONS IN THE CLINICAL SETTING

A report by Kolitski et al[9] issued guidelines regarding the equipment requirements for conformal radiotherapy. The report states, 'Pre treatment verification should be performed by means of either (i) a conventional simulator and subsequently verified on the machine by portal imaging or (ii) DRR and beams eye view (BEV) functions, if both are available with the treatment planning system, verified on the machine with portal imaging'.

Traditionally, a simulator film has been used as a direct comparison for the MVI. The most obvious use for the DRR is to cut out the need for physical simulation.

The technology available with virtual simulators and 3D TPS mean that the anatomy can be visualised from a BEV, which essentially is what the simulator film would do.

It can be argued that the DRR represents only a 'snapshot' of the patients' position during the scan and can never be reproduced exactly either on simulator or linear accelerator. However, the 'snapshot' argument can just as easily be applied to the simulator radiograph, since it too only represents a single set up. This becomes more significant in techniques where organ motion and filling create reproducibility problems, e.g. in thoracic techniques lung movement has long been a problem in achieving reproducibility and is being addressed in studies examining the use of breathing control.[10] For these techniques, the use of fluoroscopy will remain a vital verification tool, protecting the role of simulator. However the use of fluoroscopy images for image registration requires specialist software to correct for distortion (such as that available in PIPS pro or simulator software packages). This use of distortion corrected fluoroscopy images has been studied,[11] quantifying CT/planning – simulator error in isocentric 3D head and neck treatment, and found to be a precise and reliable method to reduce field placement errors at simulation. There is potential to use this for other sites where bony anatomy is easily identifiable.

The snapshot argument can also be applied to pelvic techniques. In this department the prostate patients are scanned supine with a full bladder and requested to have emptied their bowels prior to attending and avoid beans/pulses for 48 hrs pre scan. This means that the bladder and rectal wall can be defined on the CT slices and 'accurate' Dose Volume Histogram's for the rectum and bladder calculated. However, this degree of accuracy currently is not repeated for treatment because of the obvious difficulties associated with timing! A novel method of overcoming this, looking at the timing of the patient's appointment is currently under investigation in this department.

One way of minimising the effect of the 'snapshot' is to have a reproducible technique, which is easily maintained for the duration of the CT scan. If there is concern over organ motion then perhaps inter fraction CT scanning may provide useful information, although this could create workload problems. We are currently in the process of installing a simCT; a potential use of this equipment is to take slices (e.g. superior, centre and inferior) for comparison to the planned CT images. To reduce the impact on workload, the DRR would be used as the direct comparison for the MVI with simulator only being used for inter-fraction verification. Inter treatment CT[8,12] has been used to measure the location and orientation of whole organs relative to bony anatomy and to quantify the organ motion during CRT of the prostate. Correlations between rectal filling, leg motion and prostate motion were quantified. Bladder filling was found to have much less influence on prostate movement.

https://doi.org/10.1017/S1460396999000187 Published online by Cambridge University Press

Matching the DRR to the simulator radiograph by registering the images in digital format using PIPS has been useful. It has indicated that the simulator set up does not always match the CT set-up, even if all parameters have appeared to align well. These errors could be caused by reproducibility problems, or classed as random or systematic error.

Defining random or systematic errors at simulation is difficult, particularly with a prostate patient where the patient's position, bladder and bowel status can have a significant impact. When set-up errors have been encountered on simulator, the course of action has been to start the radiotherapy, take EPI's of all fields and reassess. If the same error is apparent then an isocentre movement is made. In all cases, the DRR has been taken as the gold standard.

In non-coplanar techniques, DRR's may provide the only portal image record. The set-up cannot be reproduced on the simulator because the physical bulk of the intensifier prevents it and treatment machines produce distorted images because the film cassette holder or EPID cannot be placed in the same plane as the beam. Whilst verification of 3D CRT using MVI has been restricted to 2D analysis a system for 3D quantification of set up using CT data and two simulator or portal images has been devised.[13] This method offers a solution to the problem of defining out of plane set up errors. This system can be applied at simulation to establish whether the CT set-up can be reproduced, which contradicts the concept that DRR's can replace the simulator. However, each site would have to be assessed individually to determine the value of such a method.

For coplanar techniques, the use of DRR's in the short term may come down to the availability of 3D planning facilities and CT data. Careful consideration must be given to the choice of sites if it is not feasible to include all of them. Conway and Robinson[5] covered the issue of sites with respect to virtual simulation. Their opinion, in terms of DRR quality, points towards their use in head and neck and breast work. They do not comment on the quality of prostate DRR's, although they consider the use of CT simulation for conformal prostate treatment to be crucial. For many departments, prostate treatment has been the 'guinea pig' for conformal radiotherapy and satisfaction with the quality of the DRR's has been documented.[6,12]

Localisation

Whilst the main use of DRR's appears to lie within treatment verification, a technique using thin tissue DRR's aimed at reducing the time spent contouring the CT slices in the localisation of pelvic anatomy for CRT of the prostate has been presented.[14] The study used 3 mm slice thickness at 3 mm separation and pelvic organ opacification. Utilising Picker Acqsim™ software the 'thin tissue' DRR's were generated by restricting the volume of interest (VOI) to a thin (1.0–1.5 cm) slab of tissue through the target. This has the potential to be extended to other techniques, e.g. seminoma, but is restricted to areas with midline structures because of the need for a single VOI. The opportunities for thin tissue DRR use in localisation needs further study, although it does offer a workload solution to the clinician's problems of having many images to review and contour.

CONCLUSION

DRR's can potentially be used at several stages in the planning process. The DRR's provide the gold standard for comparison with other images, since they are a direct representation of the planned treatment position. For non-coplanar techniques, DRR's will be a vital tool.

However, their role within the verification process needs to be assessed for individual techniques, with protocols to ensure the correct usage. They are a fairly new concept and as technology advances, so the use of the DRR develops further. Lack of resources may mean choices have to be made. To stop using them in conformal prostate treatment may prove to be difficult. However, this does not necessarily mean that prostate treatment should take precedence over other techniques, if it can be proven that they would be more useful for other sites.

In our department, we need to have confidence in the reproducibility of our techniques before we can eliminate the use of simulator. This is currently being addressed as part of the work towards 3D CRT with studies ongoing in head and neck, thoracic and pelvic techniques.

https://doi.org/10.1017/S1460396999000187 Published online by Cambridge University Press

We also need to be convinced of the quality and suitability of the DRR. To use DRR's in conjunction with simulator radiographs would give us the confidence in the use of a new system alongside the old one. It will help define if DRR's should replace simulator radiographs or whether they should be used as complementary tools.

It would be interesting to look at utilising the simulator at different stages in the verification process if replacing its conventional purpose with DRR's. We have recently purchased a simCT and there is the potential for this to be used for inter-treatment verifications.

What this assignment has highlighted is that we have been used to using the highest quality images available. The DRR's are not necessarily the best in terms of quality, but in terms of the information about planned field placements, for some techniques they are superior to simulator film.

References

1. Webb S.The Physics of 3D Radiotherapy. IOP Publishing Ltd., 1993: 344
2. Goitein M, Abrams M, Rowell D, Pollari H, Wiles J. Multi-Dimensional Treatment Planning: II. Beams Eye-View, Back Projection And Projection Through CT Sections. International Journal of Radiation Oncology Biology and Physics 1983; 9: 789–797
3. Galvin JM, Sims C, Dominiak G, Cooper JS. The Use of Digitally Reconstructed Radiographs for Three-Dimensional Treatment Planning and CT-Simulation. International Journal of Radiation Oncology Biology and Physics 1997; 31 (4): 935–942.
4. Liang Y, Kruger RA. Dual-slice spiral versus single-slice spiral scanning: Comparison of the physical performance of two computed tomography scanners. Medical Physics. 1996; 23 (2): 205–220.
5. Conway J, Robinson MH. CT virtual simulation. British Medical Journal 1997; 70: (special issue) 106–118.
6. Valicenti RK, Waterman FM, Corn B, Curran WJ. A prospective, randomized study addressing the need for physical simulation following virtual simulation. International Journal of Radiation Oncology Biology and Physics 1997; 39 (5): 1131–1135.
7. Somigliana A, Zonca G, Loi G, Sichirollo AE. How Thick Should CT/MR Slices be to Plan Conformal Radiotherapy? A Study on the Accuracy Of Three-Dimensional Volume Reconstruction. Tumori 1996; 82: 470–472
8. Van Herk M, Bruce A, Kroes AP, Shouman T, Touw A, Lebesque JV. Quantification of organ motion during conformal radiotherapy of the prostate by three dimensional image registration. International Journal of Radiation Oncology, Biology, Physics 1995; 33 (5): 1311–20.
9. Kolitski Z, Dahl O, Van Loon R, Drouard J, Van Dijk J, Ruden BI, Chierego G, Rosenwald JC. Quality Assurance in Conformal Radiotherapy: DYNARAD Consensus Report on Practice Guidelines. Radiotherapy and Oncology 1997; 45: 217–223.
10. Wong J, Sharpe M, Jaffray D. The use of active breathing control (ABC) to characterize and minimize breathing motion in radiation therapy. Extracts from Estro Conference Proceedings, 1997
11. Lohr F, Schramm O, Schraube P, Sroka-Perez G, Seeber S, Schleppe G, Schlegel W, Wannenmacher M. Simulation of 3D-treatment plans in head and neck tumours aided by matching of digitally reconstructed radiographs (DRR) and on-line distortion corrected simulator images. Radiotherapy and Oncology 1997; 45: 199–207.
12. Dawson LA, Mah K, Franssen E, Morton G. Target Position Variability Throughout Prostate Radiotherapy. International Journal of Radiation Oncology Biology and Physics 1998; 42 (5): 1155–1161.
13. Gilhuijs, KGA, Van De Ven, PJH, Van Herk, M. (1995). Automatic three–dimensional inspection of patient setup in radiation therapy using portal images, simulator images, and computed tomography data. Medical Physics 23 (3): 389–399.
14. Valicenti RK, Waterman FM, Croce RJ, Corn B, Suntharalingham N, Curran WJ. Efficient CT simulation of the four field technique for conformal radiotherapy of prostate carcinoma. International Journal of Radiation Oncology Biology and Physics 1997; 37 (4): 953–957.