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INTENSITY MODULATED RADIATION THERAPY: OVERVIEW OF JOURNEY FROM CONVENTIONAL TO DASSIM-RT.

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Abstract

Intensity modulated radiation therapy (IMRT) is a technique to deliver a highly conformal radiation dose distribution, that too with wide spectrum ranging from conventional IMRT, through Volumetric Modulated Arc Therapy (VMAT) to most advanced form called Dense Angularly Sampled and Sparse Intensity Modulated Radiation Therapy (DASSIM-RT). The article intends to overview the current status of the technology.

INTRODUCTION

Since the introduction of the idea of IMRT by Anders Brahme in 1988, we have come through a long journey of methodology for the treatment of cancer by radiation. IMRT was developed to meet the challenge of producing and efficiently delivering highly conformal (radiation) dose distribution. The quality of IMRT depends on beam configuration and intensity modulation. But it is limited by the available dose optimization and appropriate delivery techniques.

Intensity Modulated Arc Therapy (IMAT) with dynamic multileaves collimator was first brought up by Dr. Cedric Yu in 1995. It was an alternative to tomotherapy. In IMAT, intensity modulation is created by overly arcs. This IMAT system then lead to volumetric modulated arc therapy (VMAT) for IMRT treatment delivery that achieve high dose conformity by optimizing the dose rate, gantry speed and collimation by motion of the dynamic multileaves. VMAT is more effective and more efficient technique but, has more variable parameters. It is a rotational approach to IMRT that can provide highly conformal dose distribution and improve the IMRT efficiency significantly.

Recently a novel form of treatment planning and delivery for IMRT called Dense Angularly Sampled and Sparse Intensity Modulated Radiation Therapy (DASSIM-RT) has been introduced as a mean of improving dose distribution.[1]

Up till now little effort has been devoted to investigate systematically the role of beam angular sampling and the interplay between this and intensity modulation. Superiority of DASSIM-RT over VMAT and conventional IMRT is still being debated.[2]

DISCUSSION

IMRT is an advanced form of three dimensional conformal radiation therapy (3-D CRT) technique in which a computer aided optimization process is used to determine customized non-uniform intensity distribution through inverse planning to attain certain specified dosimetric and clinical objectives.

With an advanced radiotherapy techniques, we expect homogeneity of dose, conformity to complex shape target volume and steep dose gradients between tumor and the surrounding normal tissues. We have come so far from forward planning of 3D-CRT to inverse planning in intensity modulated RT, from uniform beam fluence to non-uniform beam fluence, from no optimization to optimization, from convex dose distribution to concave dose distribution, from no compensation for missing tissue to the compensation of normal tissue and further even to the simultaneously integrated boost of the radiation dose delivery.

IMRT opts inverse planning, that is from dose distribution to the field definition. In this the goals are specified first and then the computer adjusts the beam parameters to achieve the desired goals or the outcome. IMRT delivery techniques can be classified as conventional mutileaves collimator IMRT, which can be coplanar and non-coplanar in mode. Fixed gantry based IMRT can be step and shoot IMRT, sliding window or the dynamic MLC, typically 5 to 10 fixed gantry beams and the dense angularly sampled and sparse intensity modulated radiation therapy (DASSIM-RT) with 15 to 30 gantry beams. Others are- VMAT, Tomotherapy (serial and/or Helical), IMRT by applying physical modulator/compensator filters and the robotic linear accelerator IMRT by the Cyber knife.

Both Helical Tomotherapy and VMAT are rotational radiotherapy modalities that use continuous gantry rotation with dynamic MLC. Helical Tomotherapy delivers intensity modulated fan beam using binary MLC in a helical rotational pattern about the patient by translating the patient through the rotating gantry. Whereas VMAT uses a conventional linear accelerator to deliver radiation in cone beam geometry using dynamic MLC, with no couch translation during the treatment. Helical Tomotherapy unit superficially resembles a CT scanner in that the patient is translated through the central aperture of the circular unit as it rotates. Each gantry rotation consists of 51 equally spaced beam projections and 64 binary MLC leaves in ach projection. Projection time is limited by gantry speed (15-60 seconds). The degree of intensity modulation is determined by the modulation factor, which is defined as the maximum leaf open time divided by the average leaf open time.

Similar to Helical CT technology, the degree of fan beam overlapping is determined by the pitch factor which is the ratio of couch translation per rotation to the jaw width. The radiation is delivered using a standard 6MV waveguide, very similar to that in a standard linear accelerator.

VMAT is a major advance over fixed gantry angle IMRT in the efficiency of delivery of the painted dose. There are three major variables in VMAT delivery.

1. Gantry rotation
2. Mutileaves collimator motion
3. Dose rate modulation

Both the MLC aperture and the dose rate can be simultaneously adjusted in an arc of 360 degree or less, whereas gantry speed is modulated as needed. During a VMAT treatment, the target volume dose does not change and the amount of leakage and scatter radiation dose to the rest of the normal tissue is reduced (less) compared to the conventional IMRT.

VMAT uses a progressive sampling algorithm, which starts sampling from 10 gantry angles, and then with each level of optimization, the resolution is gradually improved. In the first level of optimization, the gap between the 10 gantry angles is 32 degrees. In the second level, there are 21 beams with a gap of 16 degrees. In the third level, there are 43 gantry angles with a gap of 8 degrees. In the fourth level there are 87 gantry angles with a gap of 4 degrees and in the fifth and last level there are 177 gantry angles with a gap of 2 degrees.

Both the MLC position and the monitor units are included as optimization parameters, with a cost function based on dose volume constraints of the target and the normal tissues. During optimization, further constraints are imposed on MLC motion, gantry speed and dose rate so that these variables are within the capability of the linac. The optimization processes begins with a small number of points and gradually increase to ensure dose calculation accuracy from single arc to multiple arc as per the requirement.

The planning technique for VMAT has evolved with software upgrades. Initially a plan using a double arc to treat a 2 Gy PTV, the first arc optimization is dosed to 1 Gy. The second arc is then optimized to the existing single arc plan with the smoothing and filling of under dose and overdose regions leading to a more homogenous PTV dose. With the latest software versions the planar defines two arcs with starting and stopping position and then the optimization occurs to the full 2 Gy to the PTV. The VMAT optimization is a two step process. A set of intensity maps is generated first. Additional boost volumes can be added with a second or third arc allowing concomitant boosts or field in field effects.

The current mechanical constraint imposed by the maximum MLC leaf speed is 5mm per degree corresponding to about 2.5 cm per second. The allowable dose rate modulation is 30 MU-600 MU per minute. But when more than 2MU per degree is needed at certain beam angles, the gantry will decelerate to allow delivery of more radiation dose. The full rotation takes approximate 85 seconds. In a double arc treatment the second arc is typically slightly shorter in duration as there is somewhat less modulation. The first arc starts from 178 degree to 182 degree in anticlockwise direction and the second arc in clockwise direction from 182 degree to 178 degree. The combined treatment in a double arc treatment takes 155-170 seconds, with less than 5 seconds needed between arcs for the collimator to rotate 5 degrees to the new start position.

Current VMAT (with 1–3 arcs) oversamples the angular space and does not provide the desired intrabeam modulation in some or all directions. Switching beam energy between the gantry angles is impossible in rotational arc delivery.[3,4]

Two technical advances in RT have been made recently, which are changing the current RT landscape and making a new type of treatment scheme, coined DASSIM-RT possible.[1]

First, in the treatment planning, a compressed sensing based inverse planning strategy, which allows the user to optimally control the level of intensity modulation of the incident beams.[3] Second, in the treatment delivery, a new generation of digital linacs with autofield sequencing that improves the delivery efficiency.[1]

DASSIM-RT explores a large area of uncharted territory in terms of the number of beams (including noncoplanar and/or nonisocentric beams) and level of intensity modulation, and bridges the gap between IMRT and VMAT. Technically, DASSIM-RT is achieved by increasing angular beam sampling while eliminating dispensable segments of the incident fields through the use of emerging compressed-sensing based dose optimization.[3,4]

The removal of dispensable intrabeam modulation and autofield sequencing make DASSIMRT extremely efficient in delivery. A number of variants of DASSIM-RT are possible, such as segment boosted arc therapy in which segmented delivery at some fixed gantry angles and rotational arc delivery are intertwined to achieve a much improved dose distribution without relying on the use of multiple arcs. Of course, the boosting segments at a gantry position can also be distributed over a small angular interval and delivered rotationally by slowing the gantry rotation.[2]

Questioning the worth of acquisition of DASSIM-RT, Mark H. Phillips, argued the clinical application of advantage of speed in limited settings.[2]

While intrafraction motion occurs for some tumor sites, the slow type of drift that is of interest in this comparison may not provide any operational differences between these methods with respect to the need for reimaging.[5]

Faster motions, i.e., respiration induced, create the same problems for all methods and, in fact, fixed beam methods are more amenable to gating. The speed is more of an administrative/clinic issue. As the examples show, the time differences between DASSIM-RT and IMRT plans are only about a minute, and 2–3 minutes longer than a comparable VMAT plan. This seems a small effect on which to base treatment decisions.[2]

Also commenting on clinical benefit to the dosimetric differences, he argued that the differences are not dramatic.[1] Strictly speaking, none of the methods dominates the others, although overall the advantage goes to DASSIM-RT. [6]

The move to VMAT was not instigated by better plan quality, nor is this likely to be the case with DASSIM-RT. What, makes a greater difference are the optimization objectives, including the functional form and parameters.[7,8]

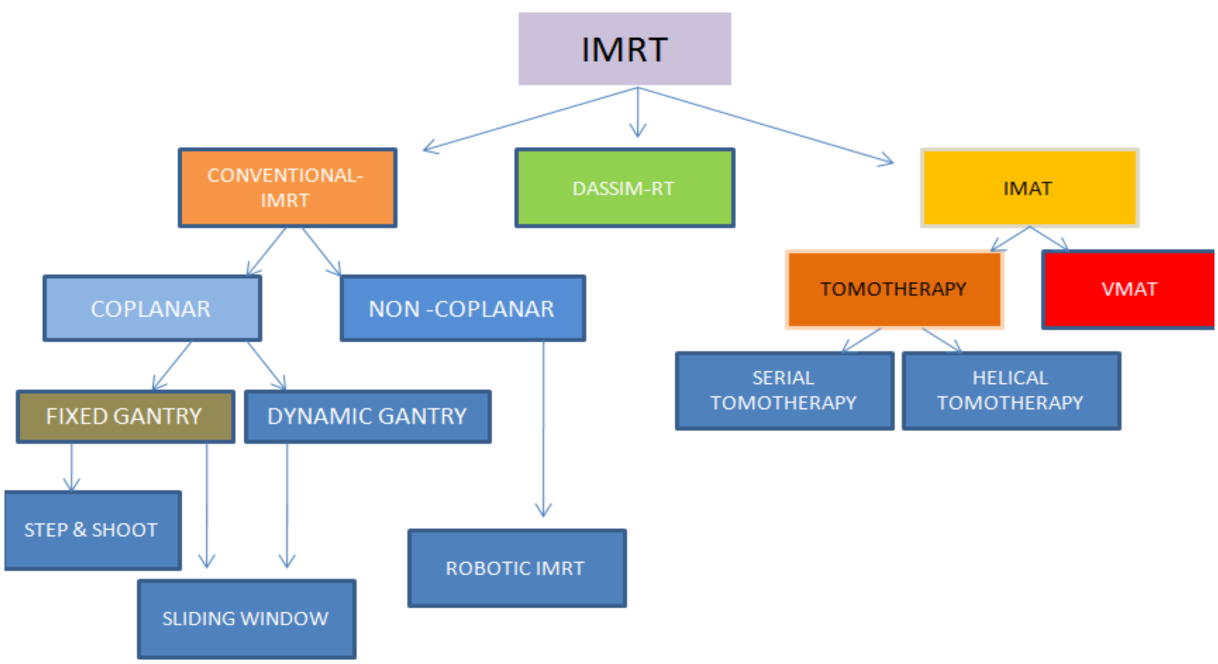
The conformity index (CI) defined by Oozeer et al when compared with the level of intensity modulation for all the three technique having the same number of beams, CI shows increase with increasing level of intensity modulation and given the same level of intensity modulation. Also CI increases with increasing number of beams. But it is important to note that improvement in CI diminishes with increasing levels of intensity modulation and saturates beyond a certain level. This saturating point differs for different number of beams. Conformity Index saturates at lower levels of intensity modulation with more beams and vice versa. The dose delivery time increases with level of intensity modulation and increasing number of beams. But at this juncture, the advantage lies with VMAT which is relatively fast and deliver the whole treatment from 1.5 to 2.5 minutes for one arc and two arcs treatment respectively. But the conformity index makes it less important when compared with the other two i.e. DASSIM-RT and IMRT.

In clinical practice of DASSIM-RT, two recent advancements in radiation therapy support are on the planning side and the other on the delivery side. IMRT inverse planning and dose optimization with first order total variation minimization known as template for first order conic solver (TFOCS) is feasible. And this is capable of dispensing unnecessary segments in intensity modulated beams to produce easily deliverable constant fluence maps. And this also is applicable to treatment with flattening filter free beams.

On the delivery side, it is now possible to concatenate a number of fixed gantry beams so that the delivery can proceed without manual intervention. Another recent development of the "burst mode" (bursts at high dose rate- 2000 MU/min) delivery on linac can also be useful platform for DASSIM-RT planning and delivery scheme. DASSIM-RT can be made possible with mixed energies that is, beams at different gantry angle use different energies and collimator modulation. Last but not the least, this approach is also applicable to non linac machine like cobalt machine with one or more sources.

CONCLUSION

New treatment scheme (DASSIM-RT) seems to outperform conventional IMRT and VMAT in terms of dose conformity to both target and the critical structures, while maintaining high delivery efficiency. But the worth of newer technology needs to be reviewed. We can't outdate previous versions just for a minimal update till we justify the investment made therein. After all best of technology is one that serves the most!!



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