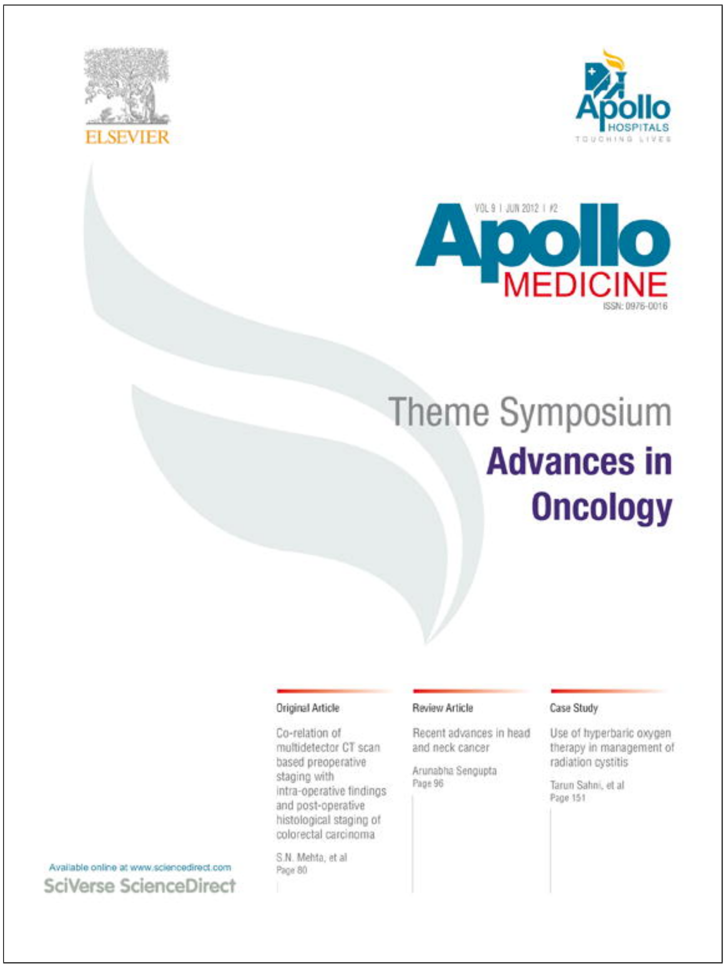
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Review Article

Radiation Oncology in 21st century – Changing the paradigms

Niteen B. More[a,*], Vijay Anand P. Reddy[b]

ABSTRACT

The developments in the field of Radiation Oncology are revolving around understanding of tumor biology, radiation effects, technology for visualization of tumor, and delivery of radiation in a planned manner. In past few decades there has been tremendous development in the field of imaging with addition of magnetic resonance and metabolic imaging. Treatment planning systems are made robust to make the complex planning fast and accurate. Use of multileaf collimators (MLCs) for alteration in beam pathways in three-dimensional conformal radiation therapy (3D-CRT) has become the minimum standard in radiation therapy. Inverse planning with allocating dose constraints to organs at risk (OAR) producing intensity-modulated radiation therapy (IMRT) has shown its benefits in numerous dosimetry and clinical studies. These developments in imaging and computer technology have also been utilized during execution of treatment. Daily variations in patient positioning, organ motion inside body, along with respiratory movements are now managed with the help of image-guided radiation therapy (IGRT). All these developments in the field of Radiation Oncology are aimed at reducing margins around tumor, delivering optimum radiation dose to tumor allowing minimum dose to the organs in close vicinity. Benefits of these developments are proven beyond doubt in some situations like head and neck cancers, prostate cancer, early stage non-small cell lung cancers and many others. Volumetric modulated arc therapy (VMAT) has potential to highly conformal radiation within few minutes. These technologies and their impact on present day practice of Radiation Oncology are discussed.

Keywords: *Radiation Oncology, Intensity-modulated radiation therapy (IMRT), Image-guided radiation therapy (IGRT), Stereotactic body radiation therapy (SBRT), Volumetric modulated arc radiation therapy (VMAT)*

INTRODUCTION

Since its inception radiation therapy has been used as one of the essential treatment options in the management of malignant and some benign tumors. With better understanding of tumor biology many new molecules have been added to the armamentarium of an oncologist. There is continuous improvement in surgical techniques with more emphasis on minimally invasive, organ- and function-preserving techniques. Neoadjuvant chemotherapy with or without addition of radiation therapy has helped surgeon downsizing the tumor and obtaining clearer margins. Multimodality management comprising of surgery, chemotherapy and radiation therapy has thus become the current standard of care in most of the clinical situations. Tumor control and overall survival have increased with the combined modality treatments, however there has been increase in treatment-related toxicities.

Radiation therapy has been evolved over last century from superficial and deep X-ray therapy to megavoltage therapy. Cobalt-60, a radionuclide has been vastly used in last century and is still a viable option in countries with fewer resources. Radiation therapy planning also has evolved over last few decades starting from surface

[a]Consultant Radiation Oncologist, Apollo Health City, [b]Director, Apollo Cancer Hospitals, Jubillee Hills, Hyderabad 500033, India.
[*] Corresponding author. Tel.: +91 9866321254, *email:* niteenmore@yahoo.co.in
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anatomy-based planning to imaging-based planning. Simulator became an essential component of any radiotherapy department. Radiation planning on conventional simulator is useful in more than half of indications of radiation therapy. With the introduction of CT scan and MRI, tumor and adjacent soft tissues were visualized in better way. Computerized treatment planning with dose evaluation in three dimensions became standard for certain clinical situations. At the same time general guidelines in delineating target, addition of margins for microscopic disease, interfraction and intrafraction movements were published in ICRU report and its subsequent updates. PET scan is now integrated with CT scan for radiation planning in selected situations.

Optimum radiation dose to the tumor with minimum possible dose to the adjacent normal structures to achieve best therapeutic index is the ultimate aim of radiation therapy. To achieve this there have been continuous efforts in improvement in techniques of tumor visualization, patient immobilization, and radiation delivery. With the confidence gained with all these mentioned, there have been significant reduction in the planning target volume (PTV) margins beyond the gross tumor volume (GTV) for visible tumor or clinical target volume (CTV) for microscopic disease.

Sparing of critical structures and other normal tissues in body to its maximum and delivering optimum dose to the tumor tissue with dose escalation whenever indicated has now become minimum standard of practicing radiation therapy. Single fraction or hypofractionated stereotactic radiation therapy procedures are being performed with the intention of delivering high biologically equivalent dose to the tumor with minimal dose to vital structures.

Intensity-modulated radiation therapy (IMRT), image-guided radiation therapy (IGRT) including frameless stereotactic radiotherapy (SRS) and stereotactic body radiotherapy (SBRT) and volumetric modulating arc radiotherapy (VMAT) have become the standard of care in present day radiation therapy practice. These forms of radiation therapy techniques have now evolved to the fullest and will be practiced over next several decades.

INTENSITY-MODULATING RADIOTHERAPY (IMRT)

Targeting tumor volume with multiple coplanar and non-coplanar beams was the first step toward advancement in radiation technology. Motor driven multileaf collimators (MLC) have replaced customized cerobend blocks which were used earlier to avoid organs at risk (OAR) from radiation. Three-dimensional conformal radiation therapy (3D-CRT) with use of CT scan based computerized planning thus became standard of care at the end of last century. With the ability to visualize tumor by beam's eye view (BEV) on computer, it was possible for the radiation therapy planner to shield the organs at risk by MLCs and produce a plan with dose conformity around the target volume. It was possible to evaluate the dose distribution with help of dose volume histograms (DVH) on computerized planning systems.

Intensity-modulated radiation therapy is an extension of 3D-CRT planning which modulates the intensity of individual beams by dividing each radiation beam into multiple small beamlets with help of MLCs. A highly conformal radiation plan is produced with inverse planning algorithm in which the dose constraints for organs at risk are given beforehand to the planning computer and dose is calculated. After many permutation and combinations a final plan is generated with high conformity of the target volume and minimal possible doses to the OARs. IMRT planning, because of its dosimetric characteristics became the standard of care in many clinical situations even before confirming its benefits in randomized controlled trials (RCTs). Randomized controlled trials on the other hand are unlikely to be conducted in all the clinical situations as the benefit of IMRT is obvious in most of the dosimetry studies. Most of the benefit of IMRT planning has been obtained in treating tumors which are in close vicinity of critical structures like optic chiasm, brainstem, spinal cord, parotid, rectum, etc. IMRT planning has shown benefits in radiation therapy of malignant gliomas, head and neck cancers, especially nasopharyngeal and sinonasal cancers, lung cancers, intraabdominal and pelvic malignancies.

IMRT in head and neck cancers

Radiation therapy along with surgery and chemotherapy is an essential component of multimodality treatment in almost all the head and neck cancers, especially in locally advanced tumors. Organ preservation in head and neck has been made possible because of optimum delivery of radiation therapy with or without addition of chemotherapy. However, delivery of radiation therapy to head and neck region in conventional technique is often a difficult procedure due to uneven anatomy of face and neck, differential sites of involvement, high lymphatic drainage and close proximity of critical organs. Potentially IMRT is beneficial in sparing of parotid gland, spinal cord, temporal lobe of brain, brainstem, ophthalmic structures, cochlea and oral cavity in the treatment of head and neck cancers (Fig. 1). Escalation of radiation dose has been made possible because of IMRT. Additionally, it has a definite role in

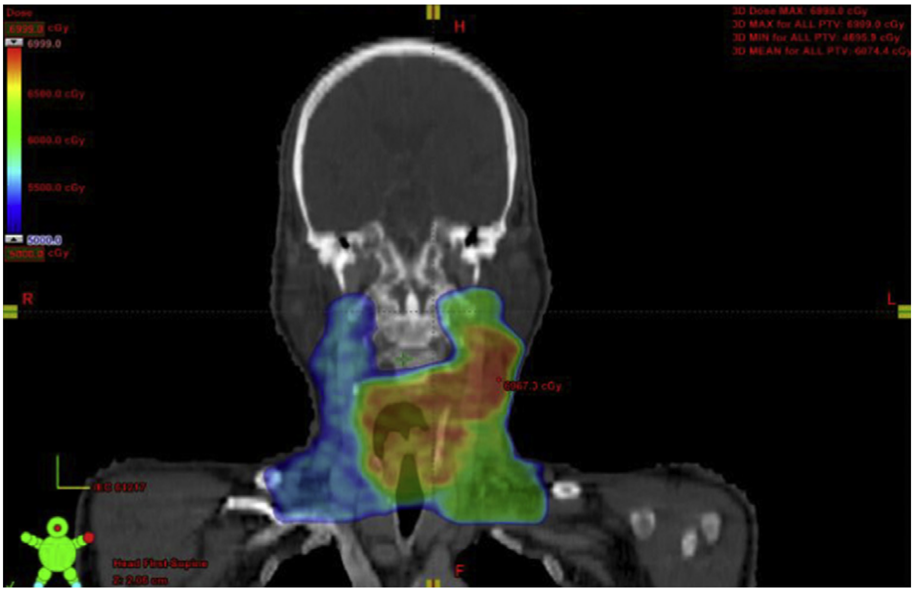

Fig. 1 Lt Hopopharyngeal cancer T3N1, planned for parotid sparing radiation therapy using simultaneous integrated boost technique, 30 fractions. Dose: primary and involved node 2.2 Gy/fr, high-risk nodal area 2 Gy/fr, low-risk nodal area 1.8 Gy/fr.

re-irradiation of recurrent tumors or radiation to the new primary in previously irradiated region.

The benefit of IMRT in head and neck cancers has been proven in many dosimetry and clinical studies. In a phase-III multicenter randomized controlled trial sparing of parotid glands with IMRT has shown to reduce the incidence of xerostomia, recovery of saliva secretion and improvement in associated quality of life.[1] Benefits of IMRT technique compared to conventional radiation therapy (CRT) were shown in a retrospective analysis of 249 patients treated with simultaneous integrated boost.[2] At median follow-up of 42 months 3-year actuarial rates of local control, disease-free survival and overall survival were 95.1% vs. 84.4%, 85.3% vs. 69.3% and 92.1% vs. 75.2% for IMRT and CRT respectively.

IMRT in prostate cancer

Radical radiation therapy of prostate cancer has been made possible with 3D-CRT planning sparing anterior rectal wall and posterior bladder wall. Subsequently, IMRT became the standard of care in prostate cancer radiotherapy with least incidence of radiation proctitis and radiation cystitis (Fig. 2). In a report of 772 patients with clinically localized prostate cancers treated with 81−86.4 Gy using IMRT technique, acute and late rectal toxicities were significantly reduced in comparison with three-dimensional conformal radiotherapy techniques. The 3-year actuarial PSA relapse-free survival rates for favorable, intermediate, and unfavorable risk group patients were 92%, 86%, and 81%, respectively.[3]

Benefit of dose escalation in prostate cancer was proved in randomized controlled trial MRC RT-01 in which 843 men with localized prostate cancer who were randomly assigned to standard-dose CFRT or escalated-dose CFRT, both administered with neoadjuvant androgen suppression. Biological progression-free survival at 5 years was 71% and 60% in the escalated and standard groups, respectively.[4]

IMRT in brain tumors

Benign tumors of brain are common in pediatric population. Because of growing components of central nervous system, endocrine system and optic pathways, it becomes necessary to keep radiation dose for critical structures as low as possible. Impairment of neurocognition has become an important concern for the children with brain tumors who are long-term survivors. In a plan comparative study of benign tumors in pediatric patients, IMRT is shown to be superior to conformal radiotherapy, stereotactic conformal radiotherapy and robotic sterotactic radiotherapy in medium and large sized tumors that are close to OARs.[5]

Craniospinal radiation therapy in the treatment of medulloblastoma using IMRT technique has shown promising results in sparing of neck, thoracic and abdominal organs.

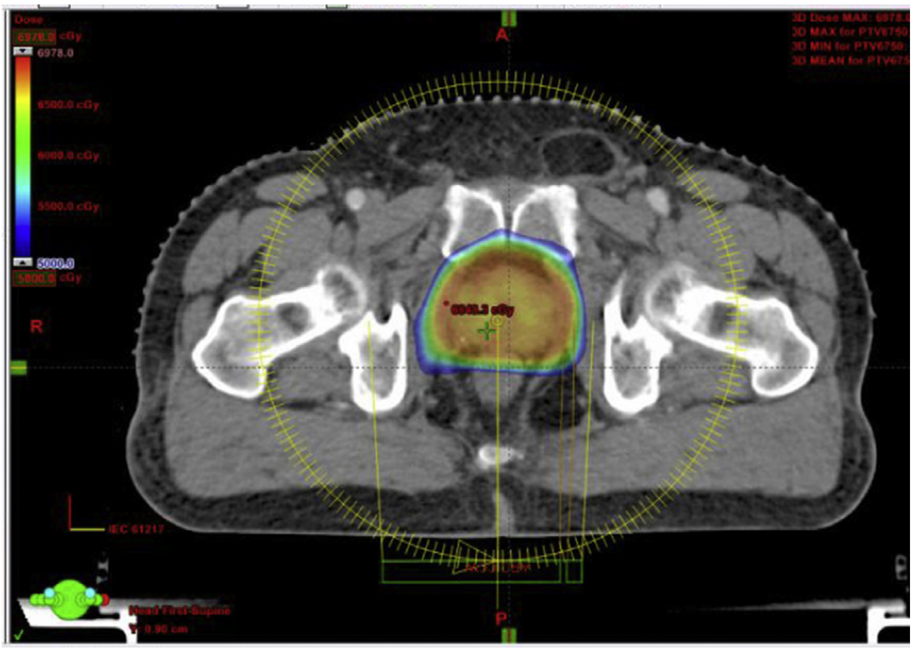

Fig. 2 Carcinoma Prostate planned with hypofractionated radiation therapy with RapidArc technique, PTV (Prostate) received 67.5 Gy in 25 fractions, 1/3 Rectum received 50 Gy.

In a radiation planning study of five patients of medulloblastoma were planned with spinal IMRT with daily intrafractionally modulated junctions.[6] It has shown superior target coverage and junction homogeneity compared with 3D-CRT. A significant dose reduction can be obtained for normal tissues like esophagus, stomach, kidneys, intestine, heart and thyroid in comparison with 3D-CRT. Ototoxicity is a major concern while treating posterior fossa as a boost in patients with medulloblastoma. In a clinical study of 33 patients IMRT to tumor bed has shown no failures in posterior fossa with significant reduction in dose to cochlea and ototoxicity.[7]

Dose escalation in high-grade gliomas is possible with IMRT techniques especially if the tumor is very close to critical structures. Hippocampus sparing IMRT has been made possible with specialized volumetric IMRT technique in patients with multiple brain metastases. In a recent systematic review of dosimetry and clinical studies of 204 patients with glioblastoma in seventeen studies, it is concluded that IMRT is beneficial in carefully selected patients and it can be safely delivered even in association with chemotherapy, with or without hypofractionation using SIB technique.[8]

IMRT in breast

Breast conservation whenever possible followed by whole breast radiation therapy with boost to the tumor bed has been proven to have equal survival as compared to those who undergo mastectomy. In the treatment of whole breast with conventional radiation therapy it is difficult to obtain homogeneous distribution within the breast due to its shape which leads to decrease in depth for the radiation beam at the apex of breast creating hot spots. Base of the breast along chest wall on the other hand gets lower dose. CT scan based planning with incorporation of wedges has improved the dose distribution to some extent. This inhomogeneity in the dose distribution has direct impact on cosmesis of the breast. In a randomized controlled trial of 306 patients, it was observed that patients undergoing radiation therapy with two-dimensional planning were 1.7 times more likely to get changes in the breast appearance compared to IMRT group.[9] In another randomized multicenter trial of 358 patients, Breast IMRT had significantly reduced the occurrence of moist desquamation compared with a standard wedged technique. Moist desquamation during radiation therapy or upto 6 weeks of completion of radiation therapy was observed in 31.2% of patients treated with IMRT compared to 47.8% of patients treated with standard technique.[10] In the treatment of internal mammary nodes, especially in left sided breast cancer, radiation dose to heart can be kept low using IMRT technique.

Simultaneous treatment of tumor cavity with additional dose of radiation along with treatment of whole breast is possible using IMRT technique. This approach is currently being tested in a randomized controlled trial IMRT-MC2.[11] With IMRT the duration of treatment can be reduced by 1−2 weeks compared to conventional fractionation schedule (Fig. 3).

IMRT in ano-rectal cancers

In radiation therapy of cancers of anal canal, the target volume is complex comprising of adjacent part of rectum, pelvic and inguinal nodes making it difficult to plan in conventional way. The treatment often gets interrupted especially if planned along with concurrent chemotherapy. IMRT in such a situation gives beautiful distribution of dose making it possible to treat with curative intent preserving anal sphincters. In a clinical study of 47 patients with cancers of anal canal and anal margins treated with IMRT based chemoradiotherapy significant reductions in normal tissue dose and acute toxicities were observed in comparison with historic controls treated without IMRT, leading to reduced rates of toxicity-related treatment interruptions. Two-year locoregional control and overall survival were 95% and 100% respectively in squamous cell carcinomas.[12] Significant reduction in radiation doses to bowel has been shown in inverse planning IMRT plans compared to 3D-confrmal and forward planning IMRT plans.[13]

IMRT in cervical and uterine cancers

Acute gastrointestinal toxicity is significant in treatment of cervical cancers especially when paraaortic lymphatic chain is irradiated. Concurrent administration of chemotherapy adds to the myelotoxicity that happens due to irradiation of pelvic bones. Radiation cystitis is also an infrequent but nagging problem in long-term survivors. IMRT is proven to be beneficial over conventional RT in overcoming all these problems. In women with cervical or uterine cancers undergoing whole pelvis radiotherapy, gastrointestinal and hematological toxicities were significantly lower in women treated with whole pelvis IMRT compared to conventional radiotherapy.[14,15]

Traditionally whole pelvis is treated for 40−50 Gy by external beam radiation therapy with additional parametrial boost if required. However this dose is insufficient when the pelvic or paraaortic nodes are involved. With IMRT, these gross nodes can be treated with additional few fractions or by hypofractionated doses (Fig. 4). In a prospective study of 60 patients with cervical cancer with paraaortic lymph node metastases were treated with conventional

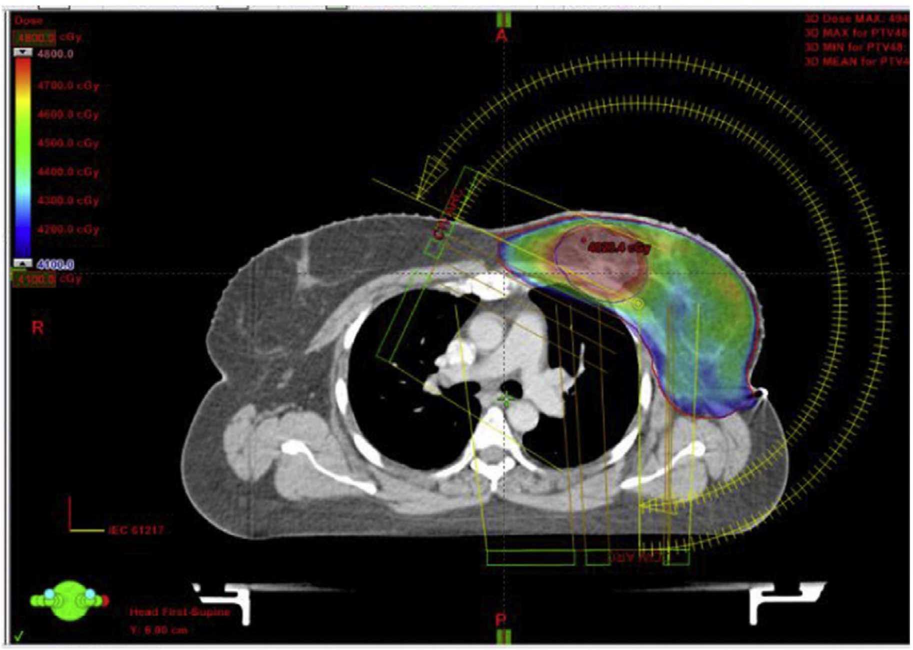

Fig. 3 Lt Breast Carcinoma, T1 N0 after breast conservation surgery planned for Whole Breast Radiotherapy (WBRT) 43.2 Gy with simultaneous integrated boost to tumor cavity 48 Gy in 16 fractions using RapidArc technique.

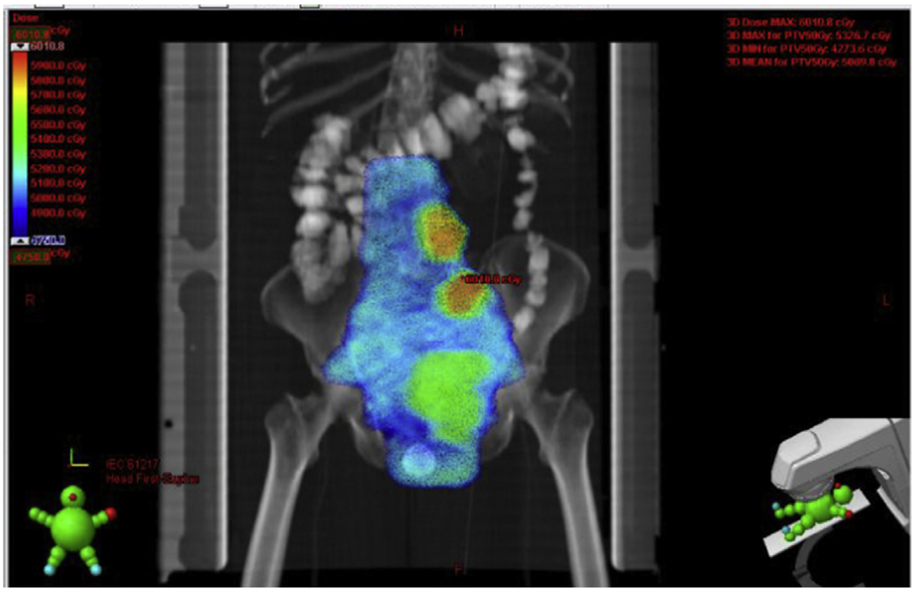

Fig. 4 Carcinoma Cervix (FIGO stage IIIB) with Lt Iliac lymph node involvement, planned for radiation therapy using SIB technique. Doses: Whole pelvis and lower paraaortic lymph nodes 50 Gy (2 Gy/fr), Lt parametrium 56.25 Gy (2.25 Gy/fr), Lt Iliac lymph nodes 60 Gy (2.4 Gy/fr).

paraaortic radiotherapy to 45−50 Gy or IMRT to 58−68 Gy. There was significant reduction in doses to spinal cord and small intestines in IMRT group. The actuarial overall survival, disease-free survival, and locoregional control rates at 2 years were 67%, 77%, and 88%, respectively, in the IMRT group.[16]

IMRT in lung tumors

Locally advanced non-small cell lung cancers when treated with conventional 3D conformal radiation therapy, a large amount of normal lung gets higher doses of radiation. Radiation dose to spinal cord, heart and esophagus is also a concern in delivering radical dose to the lung tumor if it is centrally located. Gross involvement of regional nodes makes the situation worse. IMRT in such tumors improves the target coverage and reduces the volume of normal lung irradiated above low doses.[17−19]

IMAGE-GUIDED RADIATION THERAPY (IGRT)

Traditionally in all radiation therapy procedures, once treatment is planned on conventional simulator or with computerized CT scan planning, the subsequent sessions are carried out with set-up markings on body or immobilization devices. On-board imaging with help of Electron Portal Imaging Device (EPID) is carried out once or twice in a week as per institutional protocol. Images with such a device are often of poor quality.

Interfraction variations are due to differences in daily patient positioning, movement of the organs within or outside target volume on day-to-day basis and anatomical variations because of weight loss or changes in the tumor size over few days.[20] Image guidance therefore has become mandatory in high-precision radiation procedures, dose escalation protocols and where planning target volume is in close proximity to OARs with high dose ingredient. Intrafraction variations occur due to movement of the patient himself during the session of radiation therapy. It also can be due to respiratory movements or mobile organs in the body.

On-board image guidance has become a boon to the radiation therapy with the advent of KV X-ray image verification and cone-beam CT scan integrated to the treating linear accelerator. The correction of variations in daily patient positioning can be corrected by bony anatomy matching with KV or MV X-rays on treatment couch. Variations in organ motion, however require cone-beam CT scan to see the soft tissues. Differential filling of rectum and bladder causing daily change the position of prostate are corrected, soft tissues of pelvis are matched with that of planning CT scan and treatment is executed. Alternatively, radioopaque markers are placed inside prostate gland and CT scan is obtained for radiation planning. Using these radioopaque seeds as surrogate markers for prostate gland position, daily imaging of prostate is performed and the variations are corrected before each treatment session.

Stereotactic radiosurgery for intracranial lesions has now become very simple, out-patient procedure with the help of frameless immobilization devices coupled with image guidance. Moreover, there is no absolute need to have these procedures done on a dedicated radiosurgery machines like Gammaknife as the image guidance devices are installed on the linear accelerators for set-up and treatment delivery. Apart from translational errors, the angular errors in patient positioning are being corrected by 6-dimensional robotic couch on Novalis-Tx linear accelerator producing set-up accuracy equivalent or probably even more compared to frame-based devices (Fig. 5).[21] Radiosurgery is frequently used in many intracranial lesions such as arteriovenous malformation (AVM), vestibular schwannoma, meningioma, recurrent or residual craniopharyngioma, pituitary adenoma and brain metastases. ExacTrac image guidance available with Novalis Tx system eliminates the need of immobilizing patient with metallic frame. Treatment planning and execution have become very convenient and effective as there is no pressure to finish of treatment on the very same day of fixing the frame. Cyberknife is another highly sophisticated IGRT system with mini-linear accelerator placed on a robotic arm. It has ability to take continuous X-rays in patient undergoing treatment and correct the position at the same moment. Treatment gets interrupted frequently if the position of patient or tumor changes during the session. Hypofractionated radiation treatments delivering high dose of radiation in a single or few fractions are possible with such machines.

Stereotactic body radiotherapy (SBRT) refers to the radiation treatment of extracranial tumors including moving tumors especially in lung and liver. It has been made possible with help of respiratory gating and tumor tracking techniques. Four-dimensional CT scan images of chest comprising of many respiratory cycles are registered. Target volumes are drawn by selecting a particular phase of respiratory cycle.[22] In this procedure tumor motion during the respiratory cycles is taken in account and radiation beam is kept on only during desired phase of respiratory cycle.[23] Tumor tracking involves following of tumor by the X-ray beam. High radioablative dose is delivered over few sessions without any toxicity to surrounding lung tissue.

Fig. 5 Novalis-Tx linear accelerator with capabilities of Stereotactic Radiosurgery under ExacTrac image guidance, on-board imaging (OBI) with KV X-ray imaging and Cone-Beam CT added with RapidArc technology for volumetric arc radiation therapy (VMAT) at Apollo Hospital, Hyderabad.

Results of such SBRT treatment in early stage lung cancers have shown encouraging results in medically inoperable and elderly patients with associated comorbidities. In a prospective study of 59 patients with inoperable non-small cell lung cancer treated with stereotactic body radiotherapy, Only one patient had a primary tumor failure; the estimated 3-year primary tumor control rate was 97.6% and overall survival rate 55.8%.[24] In a retrospective analysis of 117 potentially operable early stage non-small cell lung cancer patients treated with stereotactic body radiotherapy median overall survival was 61.5 months, 3-year local control and overall survival rates were 93% and 84.7%, respectively.[25]

Small metastatic hepatic lesions or hepatocellular carcinomas which are medically not resectable can be treated with help of stereotactic body radiotherapy after placement of radioopaque markers in close vicinity of tumor and obtaining 4D-CT scan. In an analysis of 60 patients with hepatocellular carcinoma treated with stereotactic body radiotherapy, at median follow-up time was 27 months, and the median tumor diameter was 3.2 cm. The 2-year local control and overall survival were 90% and 67%, respectively.[26]

Stereotactic radiosurgery of spinal lesions like paraspinal tumors, intraspinal epidural tumors, vertebral metastases and even selected intramedullary tumors in one or few sessions have been made possible with the advent of image guidance.[27]

VOLUMETRIC ARC RADIOTHERAPY (VMAT)

Standard form of intensity-modulated radiotherapy or stereotactic radiotherapy requires placement of beams in different directions in coplanar and non-coplanar fashion. In planning of stereotactic radiosurgery for small and circular targets, arc therapy with static shape of MLC field has helped the planner and therapist to cut down the planning and treatment time to some extent. Dynamic movements of MLCs at fixed gantry angle have produced higher conformity and faster delivery over static beam step-and-shoot techniques. However, these techniques take more time for treatment delivery allowing room for patient's movement during treatment. This is of prime concern in treatment of elderly or morbid patients who may not lie down in same position for longer time. In pediatric patients who are not cooperative, prolonged daily exposure of anesthesia is major issue. Moreover, radiobiologically, it is disadvantageous to deliver particular dose over prolonged time in a session as it allows potential repair and repopulation of cells. Thirdly, higher monitor units (MUs) have to be generated to deliver particular dose during that fraction of treatment exposing patient's body to more amount of radiation scatter increasing the possibility of secondary cancers.

Volumetric modulated arc therapy (VMAT) nullifies all the disadvantages of such static beam IMRT techniques. It is carried out in such a form where the machine gantry rotates around patient's body in 360° angles delivering radiation treatment by multiple small radiation beamlets. With inverse planning, it produces the highest form of conformity around target volume allowing maximum sparing of the critical structures. Arc based therapy can be performed with two kind of machines. Tomotherapy is one of them that allow treatment of target volume slices by slices by rotation of radiation beam around patient as in helical tomotherapy or by simultaneous rotation of gantry along with translational movement of treatment couch as in spiral tomotherapy. The modern form of arc therapy comprises of rotation of machine (gantry) around the patient in differential speed along with continuous changes in the MLC leaves and alteration of dose rate at the same time. This is commercially available as RapidArc by Varian, Elekta VMAT by Elekta and SmartArc by Phillips. Treatment is typically carried out by rotating one or two arcs in 1−3 min. Such a treatment allows utilizing this saved time for image guidance and correction of errors that allows effective utilization of resources allowing more number of treatments without affecting its quality. Although many of the studies published in literature till date are planning studies showing the benefits of VMAT, its clinical benefits are highly inevitable. Keeping all the advantages of this technique in view, it won't be surprising if it becomes the dominated radiation technology in treatment of all tumor types.

VMAT in brain and spine

Whole brain radiation with radiosurgery boost to oligometastases to brain has been proven to be beneficial in randomized trials. This radiosurgery boost can be performed with conventional Gammaknife system or newly introduced frameless radiosurgery systems like Novalis-Tx or Cyberknife using multiple static beams or conformal arcs. Volumetric modulated arc therapy has advantage to perform whole brain radiation therapy with conventional fractionation while performing radiosurgery with hypofractionated boost doses to the gross metastatic lesions (Fig. 6). VMAT in such situation has shown higher conformity index, is more accurate and allows faster radiation delivery.[28] In a treatment planning study, sparing of hippocampus was possible along with simultaneous boost to gross metastatic lesions while treating whole brain.[29]

In the radiosurgery for benign lesions of brain, VMAT has shown to produce high conformity index in comparison with dynamic conformal arcs.[30] In the treatment of spinal metastases using double arc VMAT, spinal cord sparing was superior to IMRT with equivalent PTV coverage.[31]

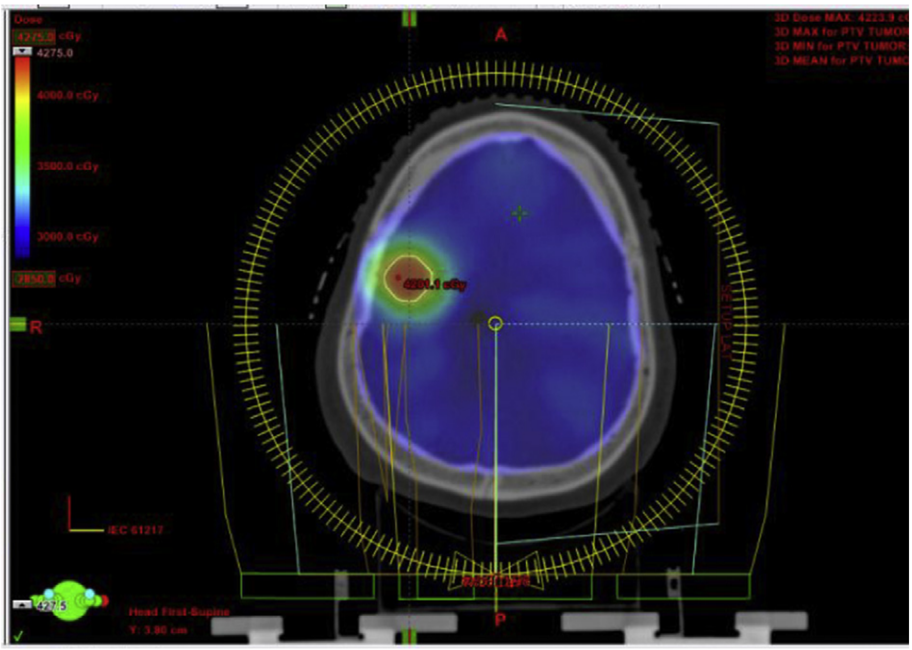

Fig. 6 Rt Parietal Brain Metastasis planned with Whole Brain Radiotherapy (WBRT) 30 Gy with simultaneous integrated boost (SIB) to the metastatic lesion 45 Gy in 10 fractions using RapidArc technique.

VMAT in head and neck cancer

Benefits of IMRT in head and neck cancers have been proven in numerous dosimetry and clinical studies that we have discussed earlier. VMAT in head and neck cancers is an attempt to improve the dose reduction beyond what has been achieved with IMRT. In treatment planning studies VMAT plans were superior to IMRT plans with respect to additional sparing of spinal cord, brainstem and contralateral parotid gland reducing treatment delivery time and monitor units. The sparing is more with double arc VMAT compared to single arc VMAT plans.[32,33]

VMAT in thoracic tumors

We have already discussed the advantages of IMRT planning in whole breast radiation therapy. The scope for volumetric modulated radiotherapy would be limited to few situations where highly conformal radiation therapy is desired. Partial breast irradiation and internal mammary nodes irradiation are the two main areas where VMAT is beneficial in keeping the dose low to ipsilateral rest of the breast tissue, lung and heart.[34,35] VMAT keeps the medium and high dose level volumes of the lungs and heart low in complex and large target volumes such as bilateral breast radiotherapy.[36] The risk of second malignancy in contralateral breast with VMAT is comparable with conventional radiotherapy and it is much lower compared to fixed beam IMRT planning.[37]

In treatment of stage I lung tumors (volume <70 cc) with stereotactic body radiotherapy VMAT plans achieved highest dose conformity and shorter delivery time in comparison with 3D conformal fields and dynamic conformal arc plans.[38]

VMAT in pelvic tumors

Significant intrafraction movement of rectal and bladder was observed during classical IMRT session comprised of 5−9 gantry positions over 15−20 min. This could potentially compromise target volume coverage and reduce tumor local control. In a recent study of 292 patient datasets comparing VMAT and 7-field fixed field IMRT it was shown that VMAT could achieve lower mean doses to the bladder and rectum, particularly in the high dose regions.[39] Once the intrafraction movement is minimized with proper image guidance and fast radiation delivery there is a scope to increase the dose per fraction so as shorten total duration of treatment from eight weeks to less than 5 weeks. Prostate is an ideal site to follow hypofractionated protocols due to its lower estimated α/β ratio. In a phase-III randomized trial of 217 patients with prostate cancer treated with conventional vs. hypofractionated schedules it was observed that biochemical relapse-free survival was higher in hypofractionated arm. Additionally, there was lower risk of genitourinary symptoms at four years.[40]

In treatment planning study of cervical cancer patients, significant dose reductions for rectal, bladder and bowel doses were observed with RapidArc planning compared to IMRT plans.[41] In treatment of anal canal cancer there was improvement in OARs and healthy tissue sparing with RapidArc planning.[42]

SUMMARY

Radiation therapy has evolved over a century and many technological advances have taken place in recent decades. With the development imaging for tumor visualization, sophisticated computerized planning systems to achieve better therapeutic index and on-board image guidance for the delivery of each session of treatment has given a new confidence in achieving better outcomes in of radiation therapy treatment of various sites. Intensity-modulated radiation therapy, especially the volumetric arc radiation therapy has changed the outlook of radiation therapy procedures, making it accurate, reliable and fast. Dose escalation whenever necessary to improve the tumor control and hypofractionation if feasible without compromising tumor control is the new arena to follow. Radiation Oncology community all over the world would continue to learn, practice and upgrade these technologies passing on their benefits to their patients over many decades to come.

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