APPLIED RADIATION ONCOLOGY™
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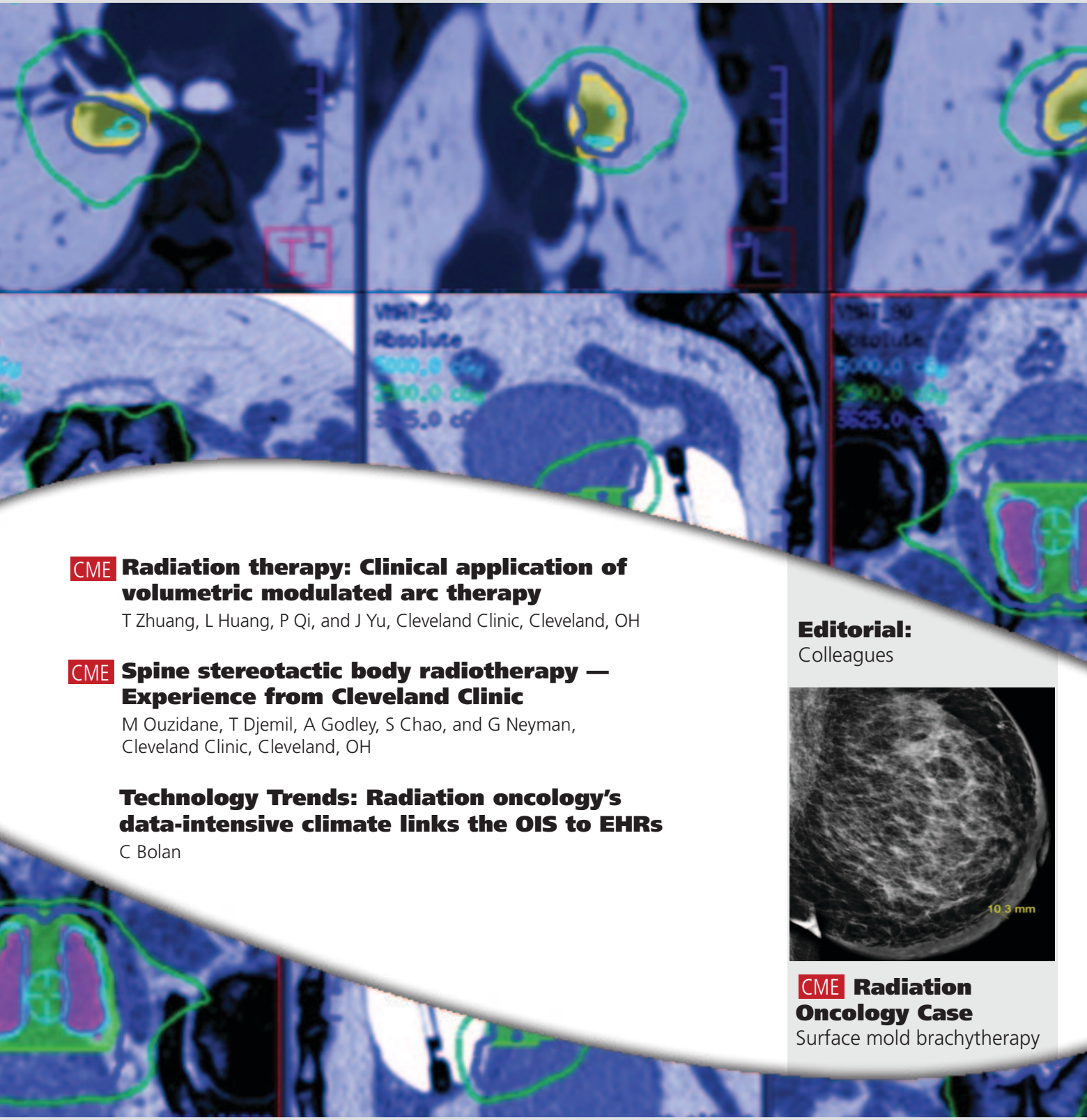

CME **Radiation therapy: Clinical application of volumetric modulated arc therapy**
T Zhuang, L Huang, P Qi, and J Yu, Cleveland Clinic, Cleveland, OH

CME **Spine stereotactic body radiotherapy — Experience from Cleveland Clinic**
M Ouzidane, T Djemil, A Godley, S Chao, and G Neyman, Cleveland Clinic, Cleveland, OH

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Surface mold brachytherapy

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John Suh, MD

Dr. Suh is the Editor-in-Chief of *Applied Radiation Oncology*, and Professor and Chairman, Dept. Radiation Oncology at the Taussig Cancer Institute, Rose Ella Burkhardt Brain Tumor and Neuro-oncology Center, Cleveland Clinic, Cleveland, OH.

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We are pleased to let you know that our community of registered radiation oncologists has grown exponentially over the last few months. We appreciate your support and, as part of our mission to foster an online community where peers share practical solutions in the clinical setting, *Applied Radiation Oncology* is issuing a call for clinical cases and review articles.

We are looking for authors to write and submit clinical cases and review articles on topics that include (but are not limited to): imaging, contouring, target delineation, treatment planning, patient immobilization, organ tracking, safety and quality, and other timely topics essential to the discipline. Important to note is that all articles and cases accepted for publication will be accredited for Continuing Medical Education (CME).

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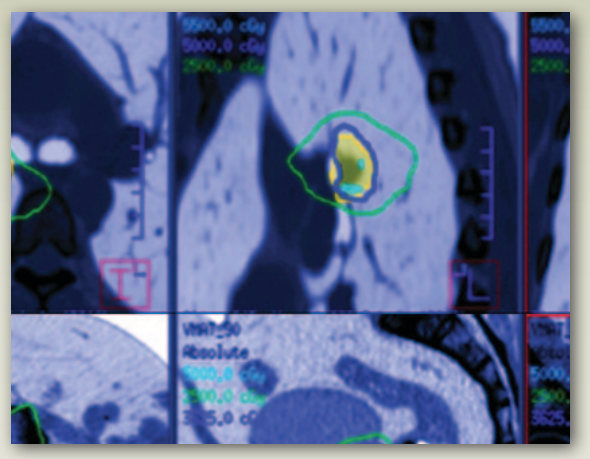

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CME Information

Activity description

In this issue of *Applied Radiation Oncology*, our faculty has assembled a number of articles and cases that provide practical insight to radiation oncology professionals on topics, including volumetric-modulated arc therapy, spine stereotactic body radiotherapy, 3D contouring of supraclavicular lymph nodes for breast cancer patients, and therapeutic skin irradiation in a case of synchronous bilateral breast cancer.

Learning objectives

After reviewing this activity, participants will:

- Understand the difference between VMAT, tomotherapy, and static gantry IMRT
- Know what cancer types have been treated with VMAT.
- Understand the rationale for spine SBRT.
- Understand the imaging, immobilization, planning and radiation treatment options, and requirements for linear accelerator-based spine SBRT.
- Comprehend 3D contouring of supraclavicular lymph nodal clinical target volumes for locally advanced and inflammatory breast cancer.
- Know the risk of radiation pneumonitis, pericarditis, and late-cardiac mortality in planning radiotherapy for breast cancer.

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Principal faculty and their credentials

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Bethany M. Anderson, MD, Department of Human Oncology, University of Wisconsin Carbone Cancer Center, Madison, WI.

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Disclosures

Author Toufik Djemil, PhD, serves as a teacher for Brainlab Inc. Andrew Godley, PhD, is a consultant for Elekta AB. Gennady Neyman, PhD, is a consultant for Elekta AB.

No other authors, or any individuals at IAME or *Applied Radiation Oncology* who had control over the content of this program, have any relationships with commercial supporters.

EDITORIAL

Colleagues

John Suh, MD, Editor in Chief

VMAT can potentially shorten treatment times 50% to 80% compared to IMRT.

Dr. Suh is the Editor-in-Chief of Applied Radiation Oncology, *and Professor and Chairman, Dept. Radiation Oncology at the Taussig Cancer Institute, Rose Ella Burkhardt Brain Tumor and Neuro-oncology Center, Cleveland Clinic, Cleveland, OH.*

Welcome to the second-quarter edition of *Applied Radiation Oncology* 2013! On behalf of the advisory board and publisher, we appreciate your support for this e-journal, which features 2 articles and 2 case reports every quarter.

In this edition, Dr. Zhuang and colleagues review the clinical application of volumetric-modulated arc therapy (VMAT), an emerging and efficient treatment delivery for many different tumors of the central nervous system, head and neck, liver, prostate, lung, and liver. Unlike intensity-modulated radiation therapy (IMRT), which allows for modulation of the intensity of radiation fields to optimize tumor coverage while minimizing dose to normal structures, VMAT delivery alters the dose rate and gantry speed rotation, which allows for greater beam intensity modulation compared to IMRT. As a result, VMAT can potentially shorten treatment times 50% to 80% compared to IMRT, while using fewer monitor units (MU). In some cases, the low-dose regions, such as V5 and V10, may receive higher doses compared to IMRT plans. In addition, 2 or 3 arcs may be required to achieve comparable dosimetric parameters of IMRT plans, which can increase integral dose. Since few studies compare outcomes, particularly with respect to toxicities of VMAT versus those of IMRT, further studies are needed. Given the complex optimization and dose calculation algorithms required for VMAT, greater treatment planning time is currently required for VMAT plans.

Also in this issue, Dr. Ouzidane and colleagues discuss the emerging role of stereotactic body radiation therapy (SBRT) for spinal metastases, a common complication of cancer patients. Given the potential morbidity and neurologic deficits that spinal metastases can cause, proper management should be multidisciplinary to optimize outcomes and ensure personalized care. Advances in immobilization, imaging, computer software, and mutlileaf collimators have allowed for the safe and effective delivery of high doses of radiation to spinal metastases while minimizing dose to the spinal cord or cauda equina. The authors review the active spine-SBRT program at the Cleveland Clinic, including the delivery system, immobilization, imaging, simulation, treatment planning, quality assurance, patient setup, and treatment delivery. Since spine SBRT is resource intensive and expensive compared to conventional radiation therapy, it is important that advocates of spine SBRT support the ongoing phase III RTOG 0631 trial, which randomizes patients with localized spine metastases from the C1 to L5 levels (solitary metastasis; 2 separate spine levels; or up to 3 separate sites) to 8 Gy in one fraction using conventional techniques versus 16 Gy using image-guided radiosurgery or SBRT techniques. The primary endpoint of this trial is whether spine SBRT improves pain control compared to conventional radiation therapy.

Thank you for your interest in *Applied Radiation Oncology*. I invite you to submit an article or case report for publication. Please click here for more information.

Sincerely,
John Suh, MD

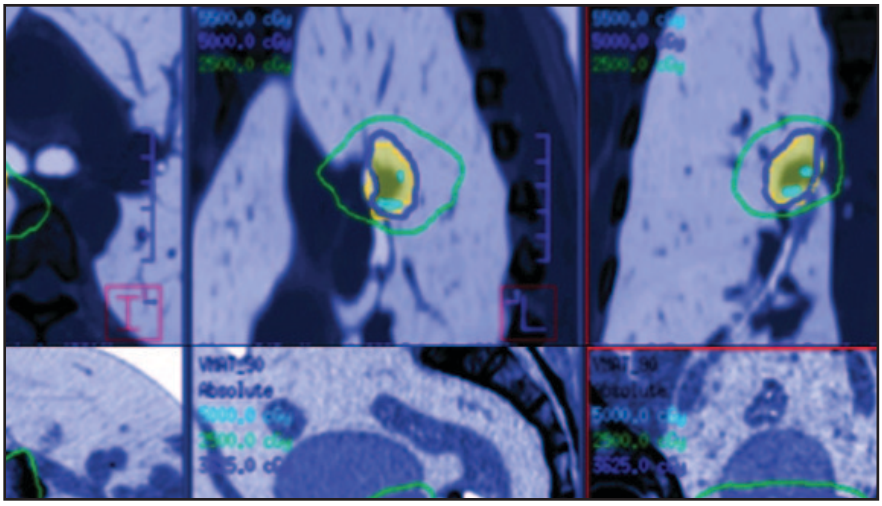
CME SEE PAGE 4 FOR DETAILS

Radiation therapy: Clinical application of volumetric modulated arc therapy

Tingliang Zhuang, PhD, Long Huang, PhD, Peng Qi, PhD, and Jennifer Yu, MD, PhD

The development of intensity-modulated radiotherapy (IMRT) has greatly advanced the field of radiation oncology since its introduction to the clinic in 1990s.[1] Since then, IMRT has been widely used to treat different types of cancers. IMRT is capable of modulating the intensity of the radiation fields such that the tumor is adequately covered while the dose to healthy tissue is minimized.

Two techniques are used to deliver IMRT. One is static gantry IMRT, which is composed of 5 to 11 radiation beams. For each beam, a multi-leaf collimator (MLC) is used to modulate the beam intensity in a dynamic sweeping manner (sliding window or SW) or in a step-and-shoot (SS) manner. The other technique delivers IMRT while the gantry is rotating. In 1993, Mackie et al developed a rotating fan-beam technique using a dedicated helical tomotherapy system.[2] In 1995, Yu proposed the linac-based rotating cone-beam technique, and coined this technique intensity-modulated arc therapy (IMAT) as an alternative to tomotherapy.[3] In the original design of IMAT, several arcs were required to achieve intensity modulation.



One key feature of IMRT is inverse planning, where computational optimization algorithms are utilized to design the motion trajectories or segment shapes of the MLC to achieve intensity modulation. Depending on the planning technique, the MLC patterns can be directly outputted by the optimization algorithm, or be converted from the optimized fluence map with a leaf-sequencing algorithm. Different planning systems and optimization algorithms have been developed for static gantry IMRT. At that time, an efficient planning method for IMAT was not available, yet much research has since been devoted to developing optimization algorithms for IMAT.[4] In 2008, Otto designed an optimization algorithm to deliver IMAT in a single-arc manner,

Dr. Zhuang, Dr. Huang, Dr. Qi, *and* ***Dr. Yu*** *are in the Department of Radiation Oncology at the Taussig Cancer Institute, Cleveland Clinic, Cleveland, OH.*

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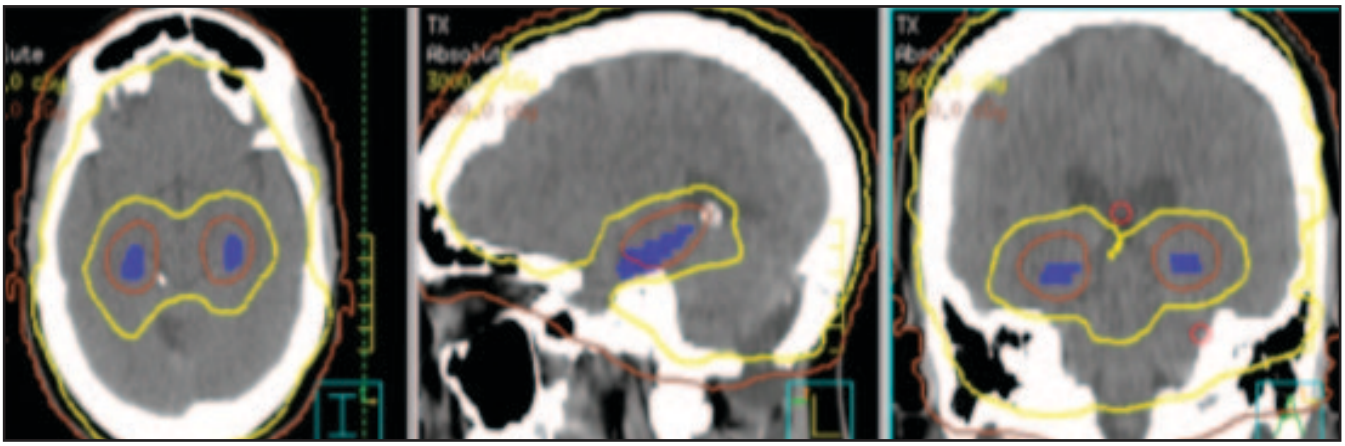

FIGURE 1. *Dose distributions of VMAT plan for whole-brain treatment with hippocampal avoidance. Yellow lines are prescription isodose lines of 30 Gy. The shaded blue regions represent the hippocampal volume.*

which he called volumetric-modulated arc therapy (VMAT).[5] In VMAT delivery, both dose rate and gantry rotation speed can vary. These additional degrees-of-freedom increased the capability of beam intensity modulation.

Based upon Otto's VMAT algorithm, Varian (Palo Alto, CA) implemented the single-arc form of IMAT and named the system RapidArc™. Elekta (Stockholm, Sweden) and Philips (Amsterdam, The Netherlands) also released their rotational IMRT solutions, VMAT™ and SmartArc™ respectively. Since the clinical implementation of these different single-arc forms of IMAT by different vendors, the feasibility of applying this novel delivery technique to different cancer sites has been explored. Comparisons between VMAT, 3-dimensional (3D) conformal therapy, conventional static gantry IMRT, and helical tomotherapy have been extensively studied to better understand the differences among different techniques.

Theoretical investigations[6,7] and treatment planning studies compared different intensity-modulation techniques. This article reviews clinical applications of VMAT technology in treating tumors of the central nervous system, head and neck, lung, liver, prostate, and other sites, and discusses advantages and limitations of VMAT.

Clinical applications of VMAT

Brain cancers

VMAT has been used to treat primary brain tumors and metastases. Davidson et al[8] compared VMAT and standard IMRT to treat gliomas, specifically with respect to the dosimetric impact of adding one partial arc to one full arc for VMAT planning. The researchers observed improved spinal cord sparing and reduced integral dose with the use of an additional coplanar partial arc and concluded that VMAT offers faster treatment than IMRT, with similar dosimetric qualities.

Clark et al[9] reported the feasibility of using VMAT stereotactic radiosurgery (SRS) to treat multiple brain metastases. For each patient, 3 VMAT plans were designed—single-arc/single isocenter, triple-arc/single isocenter, and triple-arc/triple-isocenter—to deliver 20 Gy prescription dose to all lesions. They found that the single isocenter VMAT plan has similar conformity as multiple isocenter plans with < ½ beam-on time. Multiple isocenter plan was recommended for closely spaced targets.

Hsu et al[10] investigated the feasibility of using VMAT to treat whole brain with hippocampal avoidance and a simultaneous integrated boost for 1 to 3 brain metastases. They showed that VMAT achieved adequate whole-brain coverage with conformal hippocampal avoidance and radiosurgical quality dose distribution for 1 to 3 brain metastases. The mean delivery time was 3.6 min. Awad et al[11] shared their experience of whole-brain radiotherapy with hippocampal avoidance and a simultaneous integrated boost to achieve stereotactic radiotherapy (SRS) for melanoma brain metastases. The treatment was well tolerated, with only one patient among 26 having grade 4 late toxicity. They concluded that VMAT provided safe treatment with survival times similar to conventional SRS.

In our clinic, VMAT was also utilized to treat whole brain with hippocampal avoidance. Figure 1 shows the dose distribution of a representative VMAT plan.

Spinal tumors

VMAT has been used to treat both primary paraspinal tumors and spinal metastases. The geometric relationship between the target volume and the spinal cord brings challenges to treatment

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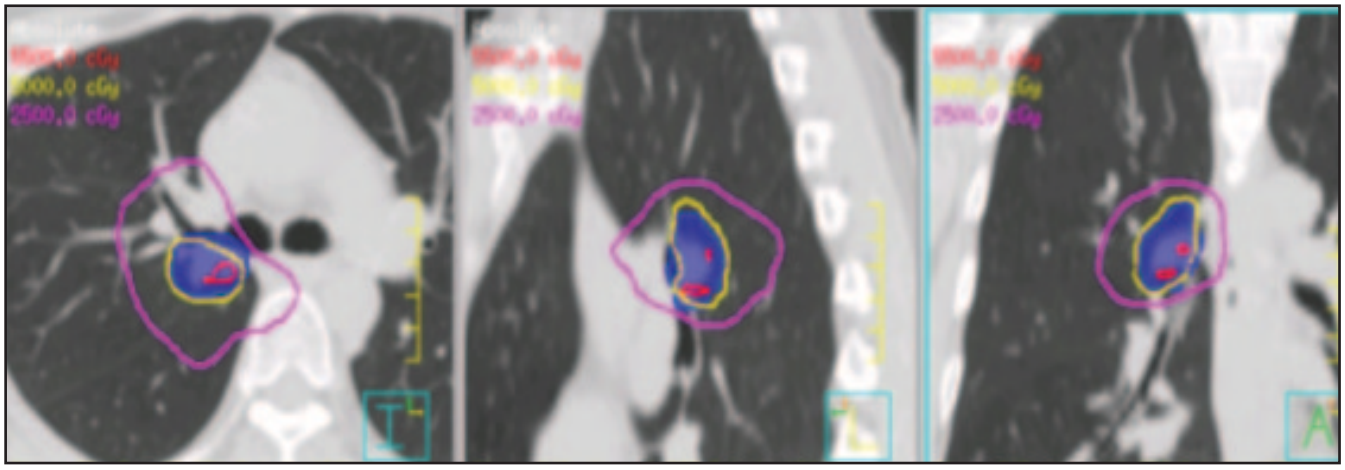

FIGURE 2. *Dose distributions of a VMAT plan for SBRT of lung cancer with an active-breathing-coordination device. The yellow lines are prescription isodose lines of 50 Gy. The shaded blue region is the planning target volume.*

planning. Bedford et al[12] reported a case study where VMAT was used to treat a paraspinal tumor. A highly conformal dose distribution while sparing spinal cord was achieved using VMAT and the delivery time was 2 min 15 sec. Lee et al[13] compared a single arc VMAT with 7-field IMRT to deliver a concomitant hypofractionated treatment to spine metastases with simultaneous integrated boost. They found that target coverage was similar for IMRT and VMAT plans; however, a higher dose to the regions around the spinal cord was observed in VMAT plans of unclear clinical significance. The mean delivery time of VMAT plans was one third that of IMRT plans. Wu et al[14] evaluated the feasibility of using VMAT for spine stereotactic body radiotherapy (SBRT) to achieve highly conformal dose distributions while sparing the spinal cord. They found that single-arc VMAT could not achieve spinal cord sparing comparable to IMRT, whereas two-arc VMAT could. The monitor units (MUs) and treatment time were significantly reduced (> 50%) in the two-arc VMAT plan compared to the IMRT plan. No significant difference in integral dose was observed.

Navarria et al[15] assessed the clinical outcomes (acute toxicity, local control, and survival) for re-irradiating patients with spinal metastases with VMAT. Thirty-one patients were included in their study; 93% obtained clinical pain remission, and 73% showed neurological improvement. No acute or late toxicities were observed and no recurrence occurred. Median survival was 10 months (range 6-24 months).

Head and neck cancer

IMRT is the standard technique used to treat head and neck cancers to spare several organs at risk (OAR) surrounding the tumor volume. Bertelsen et al[16] replanned 25 oropharyngeal or hypopharyngeal carcinoma cases treated with IMRT using one single-arc VMAT. Similar or better target coverage and OAR sparing were observed with the VMAT plans compared to clinically used step-shoot IMRT plans. The MUs and treatment time were reduced by 8.5% and 35%, respectively, in VMAT delivery compared to IMRT. Johnson et al[17] compared VMAT and IMRT plans using a simultaneous integrated boost for head and neck cancer. Similar plan quality in terms of target coverage and OAR sparing were achieved by VMAT; however, the MUs of VMAT plans were reduced to one-third that of IMRT plans. Comparisons between VMAT and serial tomotherapy for head and neck cancer were also conducted by several authors.[18,19] In general, tomotherapy provides equivalent dose distribution or better conformity index, but longer delivery time, than VMAT. Neubauer et al[20] assessed the shoulder position variation and its impact on dose in VMAT and IMRT plans for head and neck cancer. The shoulder motion averaged 2 mm to 5 mm in each direction and caused D99 (minimal dose to 99% of the volume) of the clinical target volume (CTV) to decrease by 1.01 Gy and dose to the brachial plexus to increase by 0.72 Gy. IMRT plans were more sensitive to posterior shifts than VMAT plans. Oliver et al[21] evaluated the tradeoffs in planning and treating locally advanced head and neck cancer with IMRT and VMAT techniques. Based on 15 patients in their study, the main tradeoffs between IMRT and VMAT were shorter treatment times, but longer planning times, for VMAT.

Lung cancer

Conventional fractionated radiotherapy and SBRT for lung cancer can both be delivered using VMAT techniques. Bedford et al[22] reported using VMAT to deliver 50 Gy in 25 fractions for lung cancer. An in-house planning system

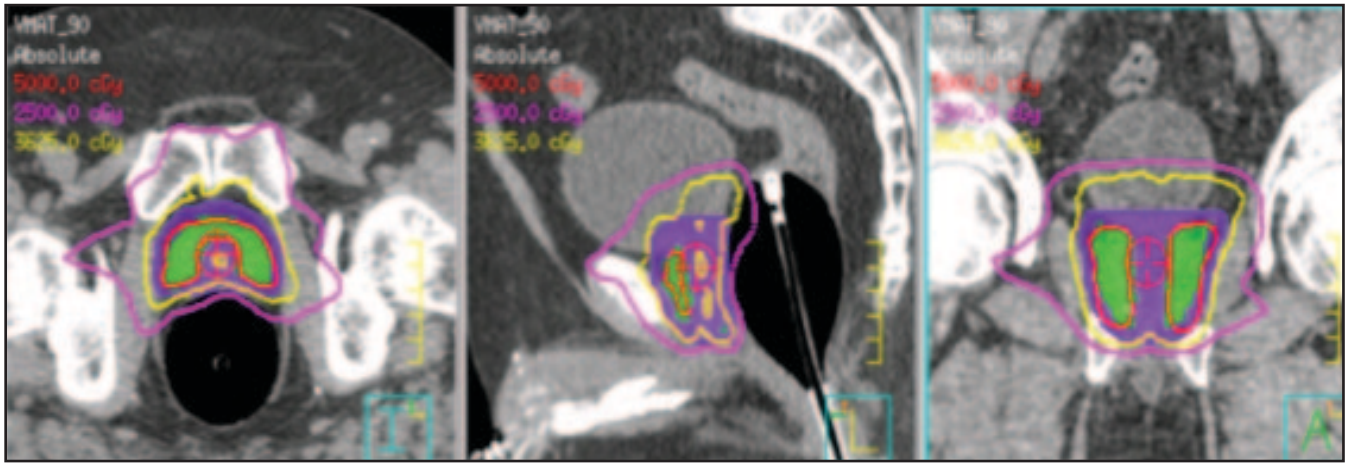

FIGURE 3. *Dose distributions of a VMAT plan for SBRT of localized prostate cancer. The yellow lines are prescription isodose lines of 36.25 Gy. The shaded purple region is the planning target volume, and the shaded green region is the high dose volume receiving 50 Gy.*

was used to generate VMAT plans that were compared to conventional 3-field 3D conformal plans. The authors found that VMAT improved the efficiency of delivery. VMAT has also been used to treat early-stage nonsmall cell lung cancer (NSCLC).[23,24] In a study by Brock et al, comparisons between VMAT plans with the best 3D conformal plans with coplanar and noncoplanar 3-, 5-, 7-, and 9-beams showed that VMAT had equivalent V20 of lungs and target coverage, but much faster delivery time. However, in another study by McGrath et al[24] that compared VMAT to 3D conformal plans, an improved V5, V10, V12.5, and V20 of lungs in the VMAT plan were observed. This difference was due to the partial arcs used in McGrath study to avoid the contralateral lung.

Recently, SBRT has emerged as an efficacious treatment for medically inoperable NSCLC with excellent control rates and acceptable toxicity.[25-27] VMAT has also been used to deliver SBRT treatment of lung cancer. Holt et al compared VMAT plans with coplanar and noncoplanar IMRT plans for lung SBRT prescribed to 54 Gy in 3 fractions.[28] Plan quality was evaluated using the RTOG 0236 criteria. They concluded that VMAT achieved similar plan quality as noncoplanar IMRT and better quality than coplanar IMRT. In addition, the delivery time could be reduced by 70% with VMAT.

Tumor motion in lung-cancer treatment is a concern with VMAT and IMRT techniques due to the interplay between tumor motion during the respiratory cycle and the movement of the MLC leaves.[29] Active breathing coordination (Elekta, Stockholm, Sweden) may be used to manage tumor motion by temporarily suspending patient breath. In our clinic, VMAT combined with active breathing control were used to deliver SBRT treatment for NSCLC. Figure 2 shows the dose distributions for a representative case with a prescription of 50 Gy in 5 fractions.

Abdominal cancer

Scorsetti et al conducted a feasibility study using VMAT for SBRT for abdominal targets, including primary or metastatic liver tumor, pancreatic cancer, and nodal metastasis in the retroperitoneum.[30] They found that the planning objective on targets and OARs were met in most cases. Delivery time ranged from 2.8 to 9.2 minutes on average. Good early clinical results in terms of local control and toxicity were observed at 6 months after treatment. Local control at 6 months was achieved in 19 patients with a crude rate of 79.2% (assessed in 24 of 37 patients).

Gong et al[31] reported their experience in treating hepatocellular carcinoma with VMAT combined with the use of an active-breathing-coordination device. Compared to conventional IMRT, the VMAT plan achieved more conformal and homogeneous dose in the PTV while the V5 and V10 of the liver was higher. The average treatment time of using the VMAT plan was 2 min 10 sec, which was comparable to the 3D conformal radiotherapy and significantly reduced compared to IMRT plans (average of 10 min 26 sec).

Prostate cancer

Treatment for prostate cancer offers an ideal geometry for application of VMAT technique. Palma et al[32] compared VMAT with IMRT and 3D-conformal plans for treatment of localized prostate cancer in terms of dose to OARs, equivalent uniform dose, dose homogeneity and conformity, and MUs. They concluded that both IMRT and VMAT resulted in lower dose to normal structures than 3D conformal therapy. Variable-dose rate VMAT provided best sparing of OAR. VMAT plans required less MUs (~40%) than

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IMRT plans. Yoo et al[33] compared VMAT to IMRT for prostate cancer involving seminal vesicles and lymph nodes. They found that IMRT better spared OARs for lymph nodes-positive cancer. VMAT plans with two arcs achieved similar dose distributions to IMRT plans if only prostate and seminal vesicles were involved. Wolff et al[34] compared VMAT, tomotherapy, step-shoot IMRT, and 3D-conformal therapy for treating prostate cancer. VMAT, tomotherapy, and IMRT offered better plan quality compared to 3D-conformal treatments. Tomotherapy provided the best OAR sparing and VMAT was the most efficient treatment option. Pardo-Montero et al[35] performed a methodological comparison between tomotherapy-like and VMAT-like techniques for prostate cancer. They found that the quality of tomotherapy-like plans depended on the fan-beam width and pitch used to deliver treatment. With 1 cm fan-beam width, tomotherapy-like plans achieved slightly better quality than VMAT-like plans. However, with 2.5 cm fan-beam width, the dosimetric advantage was lost.

Myrehaug et al[36] investigated the acute toxicity of VMAT and IMRT for hypofractionated high-risk prostate cancer radiotherapy. They found that VMAT planning with 2 or 3 arcs were necessary to achieve adequate dosimetric quality. They found a higher integral dose without consistent dosimetric benefits for VMAT plans. Consistent with other studies, the treatment times were reduced.

Using VMAT to treat localized prostate with SBRT in 5 fractions to a total dose of 36.25 Gy was also implemented in our clinic. A rectal balloon was inserted to minimize the intra-fraction prostate motion. Figure 3 shows the dose distribution for one representative case.

Other tumors

VMAT technique has also been implemented for other cancers and treatments, such as total-marrow irradiation (TMI),[37-40] pancreatic malignancies,[41] and breast cancer.[42-44] Improved delivery efficiency (fewer MU and shorter treatment times) with VMAT was a common finding from these studies. This advantage is particularly important for pediatric patients for whom the risk of secondary cancer in long-term survivors is a concern. Shaffer et al conducted a planning study to compare VMAT, IMRT, 3D conformal therapy, and parallel opposed (POP) beams in the treatment of pediatric retroperitoneal tumors.[45] They found that VMAT was dosimetrically similar to IMRT and offers a reduction of treatment time by 50%. POP beams resulted in the fastest delivery and the worst dosimetry quality.

Conclusion

VMAT can generate treatment plans with similar planning target volume coverage as conventional IMRT, 3D conformal therapy, and tomotherapy. However, the plan quality differences regarding OAR sparing, integral dose, and low dose to normal tissue between VMAT and other conventional techniques were controversial among the different studies reviewed. This difference is partially due to the number of arcs used in VMAT plan and the number of beams used for IMRT/3D conformal therapy. For instance, the use of partial arcs in VMAT plans resulted in lower integral dose for brain tumors[8] and reduced low-dose to normal lung for lung tumors.[24] In general, VMAT plans with two arcs can achieve better dosimetric quality than single-arc VMAT.

All the studies reviewed have shown that VMAT improves efficiency of delivery with reduced MU and delivery time compared to conventional IMRT. The lower MU in VMAT delivery may potentially reduce the risk of radiation-induced cancers, which needs to be validated by long-term studies. Few studies have reported on the toxicity and clinical outcomes of VMAT compared to IMRT. In general, VMAT is a safe and efficient treatment modality for various cancer types. However, longer treatment planning time for VMAT is needed due to the complicated optimization process and dose calculation.

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CME SEE PAGE 4 FOR DETAILS

Spine stereotactic body radiotherapy – Experience from Cleveland Clinic

Malika Ouzidane, PhD, Andrew Godley, PhD, Sam Chao, MD, Gennady Neyman, PhD, and Toufik Djemil, PhD,

After achievements in the treatments of intracranial tumors with stereotactic radiosurgery (SRS) on a specialized modality, such as Gamma Knife (GK) (Leksell Gamma Knife, Elekta, Stockholm, Sweden), the investigation of alternative technologies emerged. As a result, medical linear accelerators (linacs) in radiosurgery became viable treatment options. These versatile machines can be used for different radiosurgery and radiotherapy treatments.

Initially, technological developments in hardware and software, such as the X-Knife SRS System (Integra Radionics, Inc.) in the 1980s, and the BrainLab Beam Shaping SRS System (Brainlab AG, Feldkirchen, Germany) in the 1990s, permitted conventional linacs to adapt into radiosurgery. They provided stereotactic systems of head frames and rings with posts and pins, and magnetic resonance (MR), computed tomography (CT), and angiography fiducial localization boxes for imaging, similar to those of the GK machine. Eventually, almost a decade later, a new generation of radiation therapy machines dedicated to radiosurgery was born.

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The recent technological innovations integrate high-precision radiation dose delivery and precise tumor localization. These systems may be used with rigid frames and special applicators, such as cones, or with multileaf (MLC) or micro-multileaf collimators (mMLC). They can also deliver noninvasive, or minimally-invasive, frameless treatments that overcome the restrictions of frame-based radiosurgery and increase flexibility for imaging, planning, and treatment. These linacs, equipped with image-guided radiotherapy (IGRT); constitute an excellent platform for SRS and SBRT treatments. Custom-fitted devices, such as aquaplast head-to-shoulder masks, vacuum bags, and body wraps of radiotranslucent material, provide immobilization with or without implanted fiducial markers for image guidance. Treatments can be multifractionated and applied to intracranial and extracranial targets. The technique is based on the use of multiple noncoplanar arcs of circular or dynamically shaped beams or step-and-shoot techniques converging to the machine isocenter, which is stereotactically placed at the center of the imaged target volume. The dose distribution is shaped by selectively blocking parts of the circular field, dynamical shaping with MLC, changing arc angles and weights, using more than one isocenter, combining arcs and stationary fields, and using intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT). These dedicated linacs deliver high-precision conformal doses to irregularly shaped tumors while sparing adjacent organs at risk, making them suitable for dose escalation protocols and potentially resulting in higher tumor control rates and fewer side effects.

Linac-based stereotactic radiosurgery is used to treat cancers of the brain, lung, liver, pancreas, kidney, prostate, and spine. Here we present a review of SBRT treatment, focusing in particular on spine radiosurgery..

Spine SBRT

A significant percentage of cancer patients (50%–85%)[1] develop skeletal metastases, about two-thirds of which are located in the spine.[2] Bone, particularly in the spinal column, is the third-most common site of metastasis after the lungs and liver.[3] Tumors which

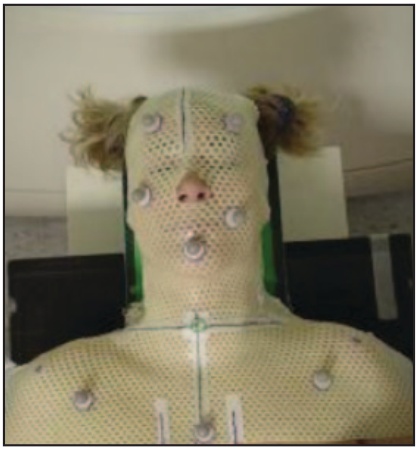

FIGURE 1. *C1 to T5 immobilization using a five-point Efficast thermoplastic mask system is illustrated.*

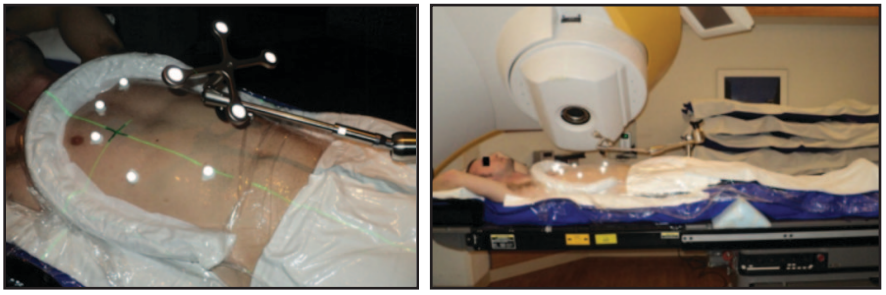

FIGURE 2. *The image shows T6 to sacrum immobilization using the BodyFix dual-vacuum system.*

have spread to the bones (osseous metastases) constitute a serious health problem, considering the increase of cancer incidence worldwide and the longer life expectancy of patients with cancer.[4] The spine represents an important and sensitive target due to the frequency of its involvement and the serious potential disabilities that result from the progression of disease and intrusion on the spinal cord and sensitive nervous tissue. Spinal metastases can cause significant morbidity, pain, and neurological deficits and affect quality of life.[4] In up to 20% of cases, patients develop symptomatic cord or nerve root compression.[5] Osteolytic vertebral compression fractures are becoming a problem due to increased patient survival with ongoing bone loss. Usually, the main symptom of spinal metastasis is pain (83%-95% of cases),[6,7] but a patient may experience limb heaviness and weakness, motor dysfunctions, such as paralysis, anal and urethral sphincter dysfunction, and sexual dysfunction.[6,7] Proper treatment and management of spinal metastases is a medical challenge requiring interdisciplinary collaboration. Treatment must be individually tailored to the needs of each patient, considering their overall prognosis for survival, and based on their disease situation including bony stability, compression of neural structures, tumor radiosensitivity, pain, and the extent of metastasis.[2]

Various palliative surgical and radiotherapeutic options (fractionated external-beam radiation therapy, EBRT) have been recommended and widely used for the management of spinal metastases. Pain medications, corticosteroids, and chemotherapy have also been used.[5] EBRT in conjunction with reconstructive open surgical procedures (decompression, stabilization with internal fixation hardware, and bone grafting) has also been practiced to prevent potential structural instability and progressive vertebral collapse. But all these treatments are usually not very effective over the long run.[5] A number of programs started investigating high-precision radiosurgery for spinal metastasis after the success achieved by SRS in brain tumors..[5] With the advances in imaging, computer technology, and radiation delivery systems, radiosurgery is becoming the standard of care in the treatment of spinal metastases. Also, with the recent surge in interest in minimally invasive therapeutic approaches, physicians are exploring high-precision spine radiosurgery combined with minimally-invasive restorative surgical procedures, such as kyphoplasty or vertebroplasty.

The spine SBRT program at the Cleveland Clinic opened in 2006. We have treated 562 patients and performed 619 procedures. A summary of our spinal metastasis radiosurgery, including the equipment used, the treatment protocol and doses prescribed, localization, immobilization, image-guided radiation therapy (IGRT) methods, and quality-assurance (QA) procedure is presented.

Radiation delivery equipment

The linear accelerator (linac) used at Cleveland Clinic is the Novalis (Brainlab, Feldkirchen, Germany), a recent technological innovation in radiation therapy. The system integrates high-precision dose delivery and precise tumor localization, making it suitable for dose escalation to achieve higher control rates with fewer side effects. It uses the intensity-modulated radiosurgery (IMRS) mode to deliver high-precision conformal doses to irregularly-shaped tumors while sparing adjacent organs at risk. This is achieved by dynamically modulating the intensity of the beams with a computer-controlled accelerator equipped with a fine mMLC. Image-guided targeting is ensured by high-resolution x-ray imaging (ExacTrac Positioning System, Brainlab). Internal structures or implanted markers are imaged right before treatment using 2 x-ray tubes housed in the linac floor and two amorphous silicon flat panel detectors mounted in the ceiling. By comparing the x-rays to digitally reconstructed radiographs (DRR) from a reference CT used in planning, the tumor is pinpointed with a high precision (< 2 mm).

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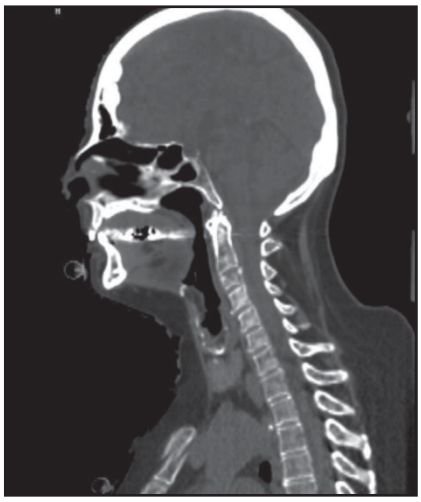

FIGURE 3. *Image shows lesions at C6 and T2 levels.*

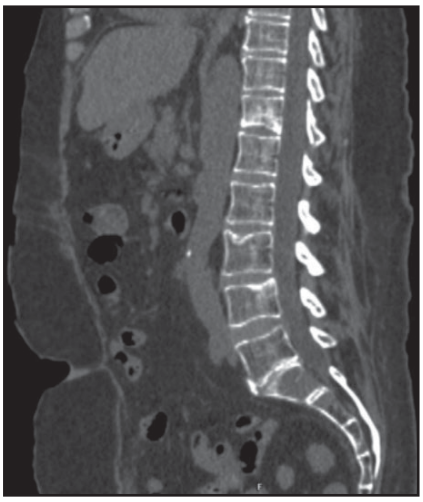

FIGURE 4. *A lesion at T12 level is shown.*

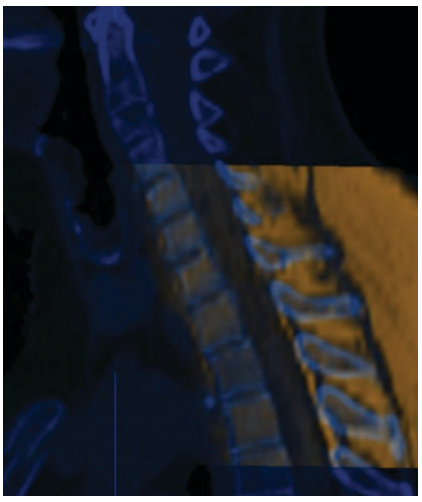

FIGURE 5. *Image demonstrates CT and MRI fusion around T2.*

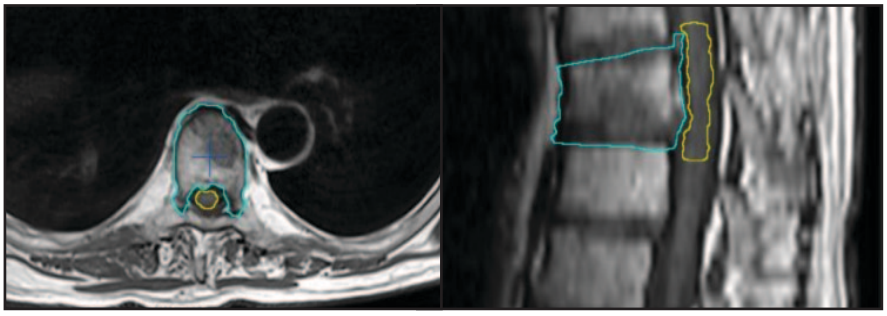

FIGURE 6. *The CTV and cord are delineated with high-definition MRI.*

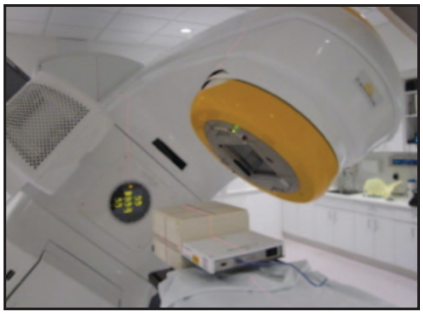

FIGURE 7. *The MatriXX QA system is featured.*

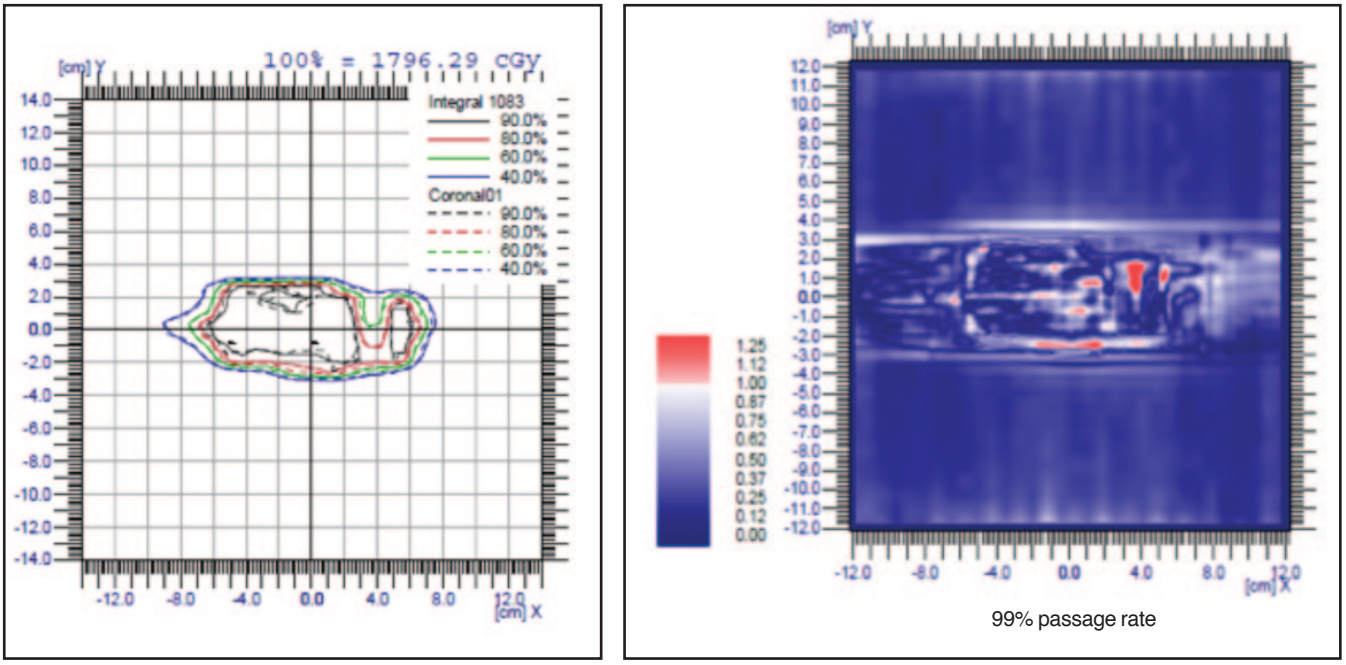

FIGURE 8. *Isodose lines and gamma analysis are featured.*

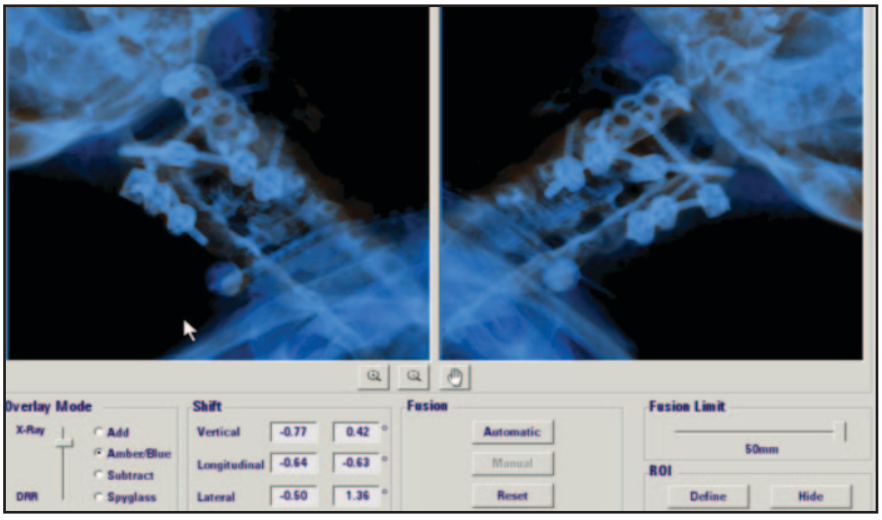

FIGURE 9. ExacTrac fusion of stereotactic x-rays to DRRs is featured.

Immobilization

Accurate target immobilization and localization and precise delivery of radiation are of utmost importance. Because high doses are given, often in a single fraction, errors may result in irreparable damage. To deliver high dose to the spine lesion while sparing the cord, the intra-fraction motion due to respiratory, skeletal/muscular, cardiac, and gastrointestinal effects has to be greatly minimized, if not eliminated. For spine lesions, the intra-fraction motion is due mostly to discomfort or pain for lying on a rigid surface for a long period of time. Consequently, a robust immobilization device is a must. Historically, before the advent of IGRT, an invasive solution was proposed to immobilize the spine by skeletal fixation above and below the region of interest.[8] The spinal column is highly mobile and rigid fixation is not practical.[5] Other noninvasive body frames (BF) were also proposed.[9] The patients are kept in the BF during the whole procedure, from simulation to treatment, which takes several hours. With the introduction of IGRT, such as CT on rail, kilovoltage, and megavoltage cone-beam CT (kV and MV CBCT), or a pair of stereotactic kV x-rays, performing the whole procedure in one day became unnecessary.[10] The patient is immobilized and simulated one day and brought back for treatment a few days later.

At Cleveland Clinic, 2 types of custom-fitted immobilization devices are used, depending on the location of the lesion. For an average height patient, with a lesion between C1 and T5, we use the 5-point Efficast system (Orfit Industries, Antwerp, Belgium), a thermoplastic head to shoulder mask illustrated in Figure 1.

For lesions located beween T6 and the sacrum, we use the BlueBAG BodyFix Vacuum Cushions (Elekta Inc., Medical Intelligence, Schwabmuenchen, Germany Co.). It is a dual-vacuum technology device with a full-body- length vacuum bag/pillow under the patient and a body wrap of radiotranslucent material that provides a vacuum seal over the top of the patient. The device is represented in Figure 2. The cutoff vertebra body (T5) can be moved superior or inferior depending on the height of the patient. For example, we could use the five-point Efficast system up T4 for a tall person, and we may extend it to T6 for a short patient.

Imaging and simulation

Plain x-ray may be used to identify metastatic lesions and evaluate spinal stability, [7,11] but x-rays are insensitive in early stages of diagnosis.[6,7,11] MRI is the gold-standard for diagnosis of spinal metastasis. It allows the visualization of infiltration and/or compression of paravertebral, osseous, and neural tissue.[6,7,11] T1- and T2-weighted imaging, contrast-enhanced and fat-suppressed studies are usually used.[7] CT imaging is an excellent modality in assessing the osseous spine and has a high degree of accuracy in identifying metastatic lesions, vertebral destruction, and spinal stability.[6] At the Cleveland Clinic, we use both a CT and an MRI fused together.

CT Scan

After the immobilization is constructed, all spine patients are scanned using 1.5-mm thick contiguous slices. To make counting the vertebral levels easier when the lesion is superior to T10, we scan from C1 to 2 vertebral bodies inferior to the lesion (Figure 3). When the lesion is inferior to T10, we scan from 2 vertebral bodies superior to the lesion down to the sacrum (Figure 4).

MR imaging

All spine patients undergo high-definition, 3-mm MRI scans around the lesion, T1 and STIR sequences, usually the same day as the CT simulation. The scans are performed on a flat couch without immobilization. The imaging technologists strive to position the patient as close as possible to the treatment position. In some cases, due to the presence of implanted hardware that makes MRI not very useful, the patient is sent for CT angiogram (CTA) for better visualization of the spinal cord.

Fusion of imaging data sets

The MRI or CTA images are imported into the treatment planning system, iPlan RT 4.1 (Brainlab, Feldkirchen, Germany) and fused to the simulation CT. The fusion is perfected around the region of interest. Occasionally, some rotation may occur outside the region of interest, but it may be ignored (Figure 5).

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Contouring

Neurosurgeons at the Cleveland Clinic delineate the gross tumor volume (GTV) and the clinical target volume (CTV). The CTV typically includes the whole vertebra body and sometimes the pedicles, depending on the GTV location. In our practice, we do not add any margins to the CTV to generate the planning target volume (PTV=CTV). The cord or the cauda equina is delineated based on the high-definition MRI. The cord/cauda contours are extended 5 mm (3 slices) superior and inferior to the CTV (Figure 6).

Planning

In treating spinal metastasis with SBRT, our fractionation scheme is to deliver 16 Gy to the lesion in one fraction. We use IMRT techniques and 7 to 9 beams to generate the treatment plan. In general, we try to avoid anterior beams. Usually, we use 7 posterior coplanar beams. The gantry angles would be: 265, 230, 205,180, 155, 130, and 105 degrees. The beam arrangement might be different, depending on the shape of the tumor. Sometimes we obtain a better plan using mostly posterior coplanar beams with gantry angles: 300, 260, 220, 180, 140,100, and 60; or 9 equidistant, coplanar beams with gantry angles: 0, 40, 80, 120, 160, 200, 240, 280, 320. Also, the beam arrangement may vary to accommodate a particular condition of the case. For example, when a patient has had a partial nephrectomy, we arrange the beams so that we avoid irradiating the opposite kidney.

On iPlan RT, we use between 15 and 20 segments per beam. We select 2 mm as a nominal grid size for dose calculation, with the adaptive grid feature for smaller structures turned on. If the treatment planning system is not equipped with the adaptive grid feature, we use the smallest grid size that the memory of the system allows.

The criteria for an acceptable plan are mainly ample coverage of the PTV (at least 90% of the volume receives the prescription dose), while sparing the cord or organ at risk (OAR). The cord is limited to no more than 10% of the volume as defined earlier, receiving 10 Gy or more and a maximum point dose limited to 14 Gy. The contraints on the cauda equina are no more than 10% of volume receives 12 Gy or more and the maximum point dose is 16 Gy. RTOG 0631 protocol is a good resource for other organ limits.[12] Hot spots are desirable in the middle of the CTV (prescription to 70%-90% isodose line, IDL), but to be avoided within 3 mm to 4 mm of the cord.

Patient-specific IMRT QA

Once the plan has been approved by the physician, it is delivered on the MatriXX QA system ((IBA Dosimetry GmbH, Schwarzenbruck, Germany) illustrated in Figure 7. It consists of an ionization chamber array, a gantry angle sensor, a MultiCube phantom, and OmniPro RT software. Other systems may also be used. The measured data and the prediction from mapping the plan onto the MatriXX phantom are compared using the Gamma 3%/3 mm criteria. A typical report of the results is given in Figure 8.

Patient setup and treatment delivery

Most patients are set up using the ExacTrac IGRT system. The patient is prepositionned using the superficial infrared markers. Once the tumor is approximately at the isocenter, the final position is found by taking 2 stereotactic x-rays and fusing them, using bony anatomy, to 2 digitally reconstructed radiographs (DRRs) in the same planar orientation (see Figure 9). The 2 DRRs are generated from the simulation CT. The patient is then shifted to the final position and an anterior and lateral ports are taken to confirm the vertebra body to be treated. Once the ports are approved, the treatment begins. Usually, we take a verification x-ray with ExacTrac midtreatment to make sure the patient did not move. The treatment is usually takes about 30 minutes.

Conclusion

When done correctly, SBRT treatments of the spine are very safe and feasible, and results show good local control with minimal adverse effects. With these newer approaches, we see a paradigm shift in the way we think about spinal metastases. Although bone metastases represent advanced disease, some patients can be expected to have a survival measured in years warranting the investigation of novel, high-tech approaches.

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Radiation oncology's data-intensive climate links the OIS to EHRs

Cristen Bolan, MS

"If you can't measure it, you can't manage it" is a popular mantra in health care, where measuring and managing data has become part and parcel of a doctor's daily routine. Couple that with pressures on reimbursement and procedure times, and only the most powerful health record systems are able manage all of that data in the most efficient way.

This data-intensive climate in the clinical setting makes selecting the right electronic health records (EHRs) for an existing oncology information system (OIS) more important than ever.

On Jan.1, 2013, the Centers for Medicare and Medicaid Services (CMS) implemented changes in payment policies and rates, resulting in an overall 15% payment reduction for radiation oncology services. This includes a 7% change in treatment times for intensity modulated radiation therapy (IMRT) and stereotactic body radiation therapy (SBRT) procedure codes.

Some of the code changes include reducing procedure times from 60 minutes to 30 minutes for IMRT, and from 90 minutes to 60 minutes for SBRT. This could negatively impact patient safety. Ultimately, IMRT delivery reimbursement has decreased by 40% this year, and SBRT delivery reimbursement has decreased by 28%.[1]

The cuts in procedure times pose a significant challenge to maintaining the same levels of patient throughput with the same quality of care.

Efficiency in a multidisciplinary environment

One of the most fundamental changes providers can make to adapt to CMS requirements is to maximize workflow efficiency.

To streamline department workflow, however, procedural inefficiencies need to be identified. Some key questions to ask include: Is there access to a single patient record in a central repository or are data being siloed in disparate systems? How fluid is communication and collaboration among specialists?

Many cancer programs take a multidisciplinary approach to care, and the trend will continue as studies have shown patients receiving treatment in such a multidisciplinary setting had an improved 2-year survival.[2-4] This collaborative environment requires coordination among many different specialties,[2] and integrating disparate systems across radiology, pathology, oncology, and other departments offers several benefits to radiation oncology workflow. To coordinate a complex network of care, many cancer care centers are integrating the OIS with the enterprise EHR.

EHR-enabled OIS

Today, most radiation oncology facilities use an EHR system,[5] according to results from a pilot study published in 2012. The study was designed to determine the level of adoption and barriers to implementation of meaningful use (MU) for the EHR Incentive Program. Of the 40 academic institutions and private practices surveyed, all respondents said they use an electronic record-and-verify (R&V) system, and a large percentage (81%) said they used at least one EHR system.[5] That is not to say that adopting an EHR doesn't come with many obstacles. The study found that the most common challenges to successful EHR system implementation were:

1. Unexpected difficulties in implementation (71%),
2. Inadequate support services (52%)
3. High cost (47%)
4. Lack of physician support (18%)

Starting with an OIS that is interoperable with any EHR can lessen the burden. A powerful OIS has been instrumental in bringing one small clinic in Arizona to the next level. Cancer Treatment Services Arizona (CTSA) is a full-service outpatient cancer treatment center in Casa Grande, AZ, providing oncology and hematology services, and administering chemotherapy, biologic therapy, and supportive care for regimens of all

TECHNOLOGY TRENDS

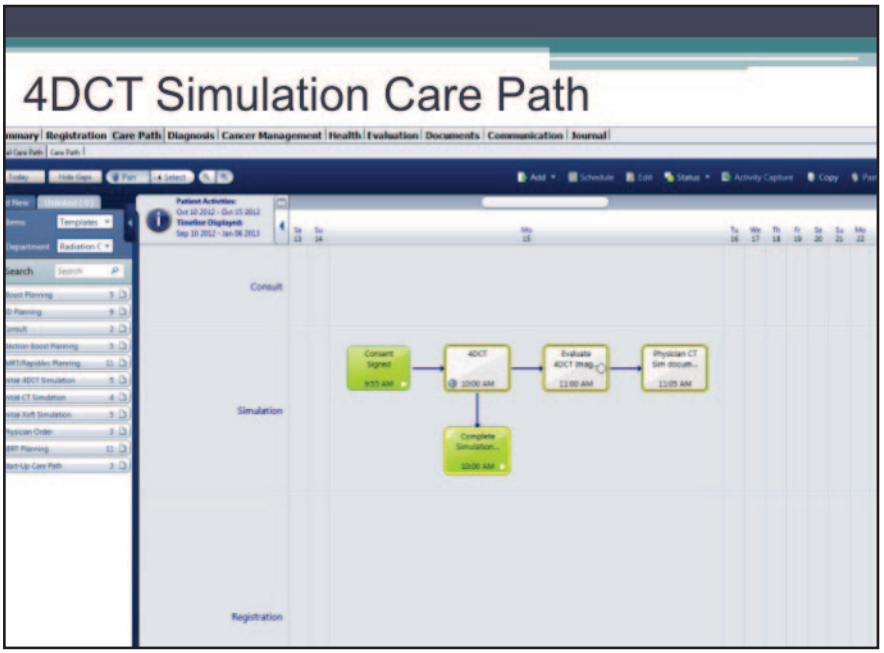

FIGURE 1. *Varian's ARIA OIS provides Visual Care Paths, flow charts providing a graphical view. Featured is a 4DCT simulation view. Activities are linked, which means that the 4DCT appointment must be completed prior to the Evaluate 4DCT activity showing up on the task pad. Courtesy of Ajay Bhatnagar, MD, MBA, Cancer Treatment Services Arizona.*

levels of complexity. Patients are treated using clinical pathways, or evidence-based treatment "roadmaps," that are disease and stage specific.

The clinic's services include 3-dimensional (3D) conformal radiation therapy, IMRT, image-guided radiation therapy (IGRT), and stereotactic radiosurgery (SRS) using the Trilogy Stereotactic System from Varian Medical Systems (Palo Alto, CA). To boost efficiencies, the center added RapidArc to the Trilogy system, decreasing radiation treatment times by up to 60% while maintaining the same level of precision and therapeutic efficacy. Nonetheless, with new protocols dramatically cutting procedure times, the clinic needed to maximize efficiencies even further.

The clinic's first step to better managing data was to implement ARIA, Varian's oncology-specific EHR solution. Using standard HL7 interfaces, ARIA enables multiple departments to interface with other healthcare departments, to connect radiation oncology with pathology, radiology, pharmacy, lab, and billing.

"I can access the patient's plan and radiation dose. We're also connected to ARIA medical oncology, so we can get chemotherapy, we have access to their diagnosis, stage, specific cancer therapy, the type of radiation, what dose they are at right now, as well as the chemotherapy," explained Ajay Bhatnagar, MD, MBA, a Radiation Oncologist at Cancer Treatment Services Arizona Adjunct, and an Assistant Professor of Radiation Oncology, University of Pittsburgh School of Medicine.

ARIA links the key components across the continuum of care, providing access to the patient chart, the physician modules, the treatment planning modules, the R&V system, and the EHR.

"You can go from the patient manager or the clinical modules, to the treatment planning modules all within the same system," said Dr. Bhatnagar. "It enhances the workflow because everyone now has access to the charts, and everyone can do their own particular task for that patient on their own computer, thus making it efficient rather than having to wait to get the physical chart. This allows for increased throughput because it allows the patients to be seen quicker."

CTSA uses ARIA v11, which provides Visual Care Paths, a tool that helps doctors at CTSA communicate, assign tasks, and provide status checks (Figure 1). "Sometimes the oncologist is not available to talk to the therapist and dosimetrist, but this lets the oncologist communicate with me without having to talk to me. This significantly helps our treatment planning process because that process requires a team of people," noted Dr. Bhatnagar.

The system has expedited the entire care process at CTSA. As Dr. Bhatnagar explains, doctors can perform a clinical assessment, complete documentation with follow-up notes, have the report faxed to the referring physician, and bill for the visit by the time the doctor leaves the exam room. "We can also do e-prescribing and directly fax to the pharmacy—that significantly enhances efficiency and throughput," he said.

Another leading OIS is the MOSAIQ Oncology Information System from Elekta (Stockholm, Sweden). The system centralizes radiation oncology, particle therapy, and medical oncology patient data into a single user interface, accessible by multidisciplinary teams across multiple locations. It provides image, data and workflow management, interfacing with a wide range of treatment planning systems and radiotherapy treatment delivery devices.

MOSAIQ Evaluate allows clinicians to review the entire treatment plan on any MOSAIQ workstation. This allows the dosimetrist to compare multiple plans from various treatment

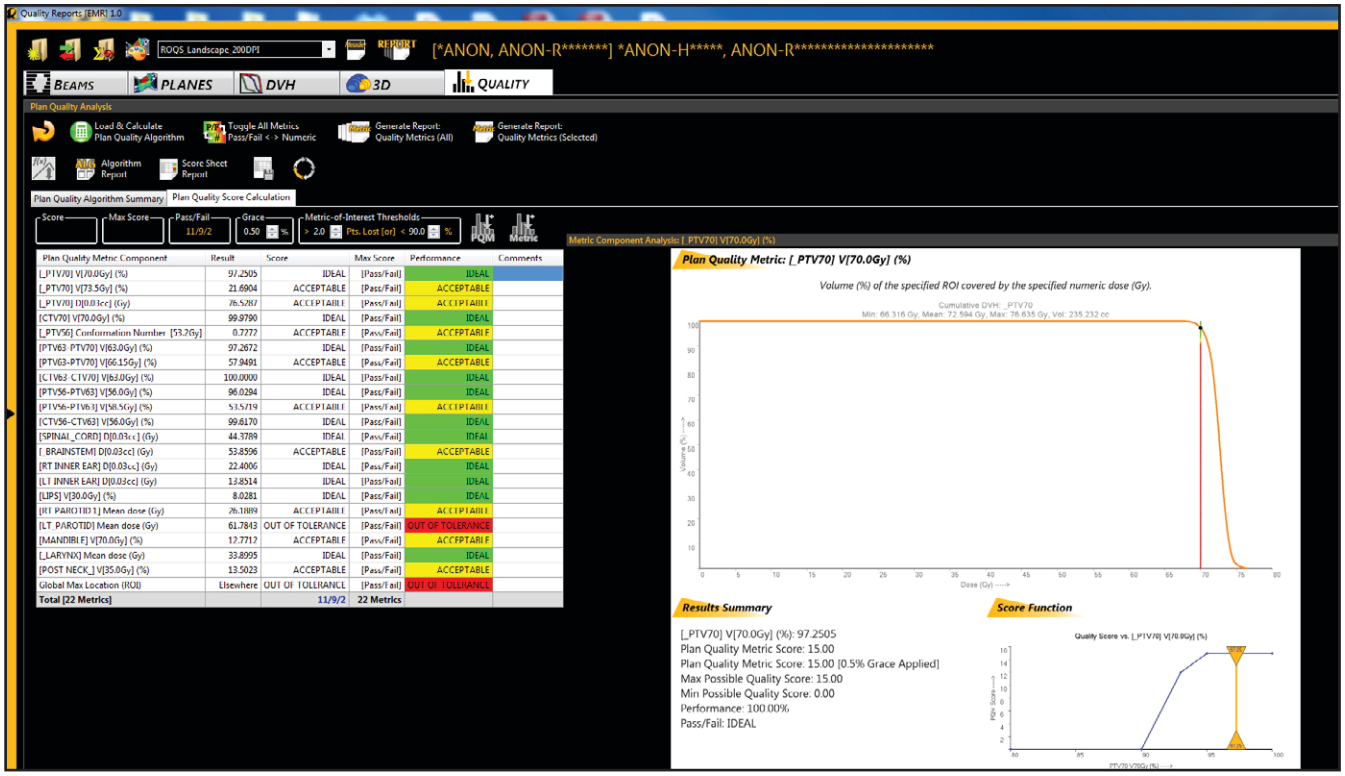

FIGURE 2. *Quality Reports EMR assigns a score to different dose constraints and then calculates the score for each treatment plan.*

planning systems and modalities and to access the complete clinical treatment data. Users can send treatment plans and reference images concurrently to MOSAIQ and view an interactive display of the actual plan and DRRs. MOSAIQ also provides safety and quality assurance tools. Supporting financial management of the cancer program, MOSAIQ handles treatment authorization, code capture, medical billing, and accounts receivable.

Meanwhile, Accuray's standards-based interface from the TomoTherapy and CyberKnife Systems is interoperable with other vendors' OIS. The company's OIS Connect also features treatment safety and quality assurance tools, including clinician worksheets, quality checklists, and care plans, biometric patient identification, and patient positioning and verification tools to summarize and support patient safety centers in scheduling appointments in the main departmental calendar held and managed in the OIS. Users can capture treatment procedures in the OIS, which facilitates charge capture and billing for treatments.

Measuring quality care

"The thrust of medicine of the future is measuring quality in a meaningful way," said James A. Wheeler, MD, PhD, Medical Director of Radiation Oncology at IU Health Goshen Center for Cancer Care, Goshen, IN.

This is already true today with the EHR Incentive Program. In Stage 1 of the program, clinical quality measures (CQMs), or tools that help measure and track the quality of healthcare services, are required as a core meaningful use objective.[6] In Stage 2, participants are required to submit CQMs to remain in the program.[5] The challenge will lie in standardizing the quality of care.

This is where EHR-enabled software can play a critical role. In fact, in the previously referenced pilot study, among the 17 facilities that use EHR systems, 71% reported that they believe EHR systems did improve safety or quality.[5]

Doctors at IU Health Goshen Center for Cancer Care have found the same to be true. The medical, surgical and radiation oncology staff, along with other specialists, work closely to develop comprehensive treatment plans for each patient. To standardize and automate their treatment plan analysis, they adopted Quality Reports EMR software from Radiation Oncology Resources, Inc. (Goshen, IN). Compatible with Varian, Elekta, and other companies' EHRs, the solution generates automated, customizable reports for radiation therapy that are compatible with treatment planning and R&V systems. Quality Reports EMR is designed to minimize the risk of omission by systematically analyzing and

Table 1. What can current users do to prepare for meaningful use?[8]

1. Make sure that CPOE are entered in the EHR
2. Enter the correct data for:
    a. Allergies – allergy information must be entered on every patient through allergies and alerts
    b. Medication list – all patients must have their medications entered in the EHR medication list
3. Set up a lab interface
4. Purchase and implement ePrescribing
5. Enter the patient's vital signs: At minimum this means entering height, weight, blood pressure, temperature, and pulse

displaying every dose constraint. Then the Plan Quality module score sheets provide rapid analysis of dose constraints or clinical goals (Figure 2).

"I can specify in Quality Reports EMR my criteria for doses I don't want the normal tissue to exceed, and the minimum coverage for the cancer tissues that I need to treat. We color code the results in the program. If everything shows up green, then I know that the plan met all of my constraints. If something shows up red, then I know there's a problem, and I have to look it that," said Dr. Wheeler.

The system has improved the facility's workflow and quality. "Previously, the dosimetrist would have to try several different approaches, but now the software will tell us if a particular constraint is achievable or not," he said.

With a performance distribution module, users can save data for statistical analysis and correlation with patient outcomes. Each of the different dose constraints is assigned a score, and the Quality Reports EMR software calculates the score for each treatment plan. "This tells us if we are above or below the standard score for this tumor," said Dr. Wheeler. "It encourages development of uniform dose constraints for each particular body site and tumor type. This, in turn, promotes better uniformity of the treatment plans within the institution, which may have several dosimetrists and several physicians."

Numerical quality scores of treatment plans over time are then used to set benchmarks for acceptability. This allows the department to establish clear guidelines for minimum quality standards for each treatment plan and enables supervisors to trend the quality of treatment plans.

"When you are using indicators that actually correlate to survival or local control, and you can put clinical endpoints to those quality scores—that's measuring quality care," indicated Dr. Wheeler. As the same time, the doctors at Goshen can enter these measurements into the EHR to work toward compliance with EHR Incentive Program.

The right EHR for MU compliance

One of the biggest game changers in the health care industry is the EHR Incentive Program. The program was designed to improve efficiencies, minimize errors, increase productivity, and streamline administrative processes. However, there are several challenges to overcome before providers can reap those benefits.

The American Recovery and Reinvestment Act (ARRA) established EHR incentive programs to promote the use of EHRs by health care professionals and hospitals.[7] The HITECH Act provides incentives for showing the "meaningful use" of certified EHRs. Eligible physicians (EPs) and hospitals that entered the program in 2011 will receive incentives totaling $44,000 over the course of 5 years, and those who begin in 2013 will get $39,000. For those who don't meet the criteria, penalties will kick in. Starting in 2015, there will be a 1% reduction in Medicare fees per year and up to 3% by 2017.

Qualifying for those funds makes choosing the right EHR partner critical.

Compared to many other specialties, radiation oncology has better integration [rates] with electronic information systems.[5] The pilot study found the majority of large academic practices (84%) were aware of MU criteria, and of these, 67% had expected to implement MU-compliant systems by the year 1 reporting deadline of Oct. 1, 2011.[5] The most frequently cited barriers to implementation were high cost, difficulty integrating with hospital systems, and a lack of national guidelines for implementation.[5]

While many EHRs are certified for the program, MU generally applies to primary care physicians; radiation oncologists interpret MU differently. Therefore, it is important that vendors provide support customized to the needs of each specialty.

CTSA, which is participating in the MU program for medical oncology and radiation oncology, attested to Stage 1 in February using ARIA's EHR and clinical practice management system certified for ambulatory environments. The doctors at CTSA value ARIA's dashboard, which monitors compliance with MU criteria.

"It requires a lot of work to implement MU and understand the system in terms of utilizing the EHR and the specific MU modules. You have to create patient-care visits, end-of-care summaries after they leave, and quality indicators. All of these requirements are

typically outside of the doctors' workflow, but it is inside the ARIA EMR," Dr. Bhatagar said.

"Complying with the MU program can be worth the investment, especially if there are multiple providers in the practice," he added.

Elekta's MOSAIQ solution is also a certified EHR, supporting EPs in demonstrating Stage 1 of MU. In addition, the company offers STRATEGIQ consultative services to help clients prepare to demonstrate meaningful use (Table 1). STRATEGIQ experts conduct an audit of a center's operations, and provide advice and action plans to reach program objectives. MOSAIQ v2.3, v2.4/2.41, and v2.5 are certified as complete EHRs.

Additional software components that are interoperable with EHRs can help in demonstrating compliance with meaningful use. With Quality Reports EMR, the enterprise EHR is populated directly with clinical data. "Meaningful use means you have to prove that your EHR has the relevant components for decision making and for treatment, and Quality Reports EMR has everything I need to review a plan," said Dr. Wheeler.

Quality Reports EMR also standardizes and automates the EHR documentation and performs billing tasks, including justification of 3-dimensional (3D) or IMRT utilization. "In order for insurance companies to approve IMRT, you often need to show that you truly had to do IMRT and couldn't get by with a 3D plan. Most of the modern planning systems can do a plan comparison, but with the Quality Reports EMR you can show that you couldn't satisfy a critical dose constraint with the 3D technique and needed to do IMRT. That lets a nonclinical person understand why IMRT was necessary," said Dr. Wheeler.

He noted, "Quality Reports alone doesn't make your EHR satisfy the meaningful use requirement by itself, but it helps you prove you're using EHRs in a 'meaningful' way."

Can MU wait?

Most oncology care centers may have begun the process of meeting MU criteria, yet a sizeable number have yet to attest to Stage 1 MU.

Despite the CMS' guidelines, which specify 15 common core objectives, researchers suggest that developing guidelines and measures that specifically target safety and quality in radiation oncology practices would improve outcomes to a greater extent than the current general objectives. They suggest including documentation of prior radiation treatment, uniform documentation of quality assurance checks, and ability to share planning and treatment delivery information electronically.

While the barriers to compliance—cost, IT integration, and a lack of guidelines specific to radiation oncology standards—still exist, many physicians believe there is no reason to postpone the inevitable.

"MU will have to be part of our work system because downward payment adjustments begin in 2015 for eligible professionals who aren't successful in demonstrating MU," said Dr. Bhatagar. "We should do it while it is a bonus, so we might as well start participating now."

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CME SEE PAGE 4 FOR DETAILS

Are the current RTOG Contouring Atlas definitions for supraclavicular lymph nodes adequate for all breast cancer patients?

John A. Vargo, MD, and Sushil Beriwal, MD

CASE SUMMARY

A 49-year-old gravida 3, para 2 premenopausal white female presented with subacute right mastalgia, erythema, and edema, plus palpable right axillary lymphadenopathy. Initial treatment with antibiotics provided no resolution. Further work-up, including bilateral diagnostic mammography and ultrasound, delineated diffuse skin thickening of the right breast and a 4-cm right axillary lymph node (new since screening mammogram 2 months prior). Ultrasound-guided core biopsy evinced infiltrating ductal carcinoma nuclear-grade 2 (ER +, PR -, HER-2/Neu -) within the lymphovascular spaces. Breast magnetic resonance imaging (MRI) and positron emission tomography/computed tomography (PET/CT) scanning confirmed neither evidence of contralateral disease nor distant metastases, but showed hypermetabolic, enlarged supraclavicular lymphadenopathy (cT4dN3cM0, Stage IIIC). The patient completed 4 cycles of neoadjuvant adriamycin/cytoxan, followed by Taxotere and right modified-radical mastectomy, with complete pathologic response in the breast and 10 axillary lymph nodes. She completed adjuvant chest wall and supraclavicular radiotherapy to a dose of 50.4 Gy in 25 fractions, followed by a 10 Gy scar boost and a 5.4 Gy boost to the involved supraclavicular lymph node. The supraclavicular field was modified to incorporate the involved posterior-lateral supraclavicular lymph node (Figure 1). At last follow-up, there was no-evidence-of-disease at 8-months post-radiotherapy on adjuvant Tamoxifen without late complications.

*Prepared by **Dr. Vargo** and **Dr. Beriwal** while at the Magee Women's Hospital of University of Pittsburgh Medical Center, Pittsburgh, PA.*

IMAGING FINDINGS

Prechemotherapy PET/CT scans showed a 1.6-cm right posterior-lateral supraclavicular lymph node with a maximum SUV of 5.9, with complete metabolic response on postneoadjuvant chemotherapy PET/CT (Figure 2).

DIAGNOSIS

Clinical Stage IIIC (T4dN3cM0) inflammatory right breast cancer with complete metabolic and pathologic response to 4 cycles of neoadjuvant chemotherapy status following a right-modified radical mastectomy.

DISCUSSION

Numerous landmark randomized trials have established the importance of adjuvant locoregional radiotherapy in breast cancer, with a 1 in 4 reduction in breast cancer-specific survival for each locoregional recurrence prevented.[1] Supraclavicular lymph-nodal irradiation is commonly incorporated into adjuvant radiotherapy, as supraclavicular failure accounts for 30% to 40% of locoregional recurrences following mastectomy and doxorubicin

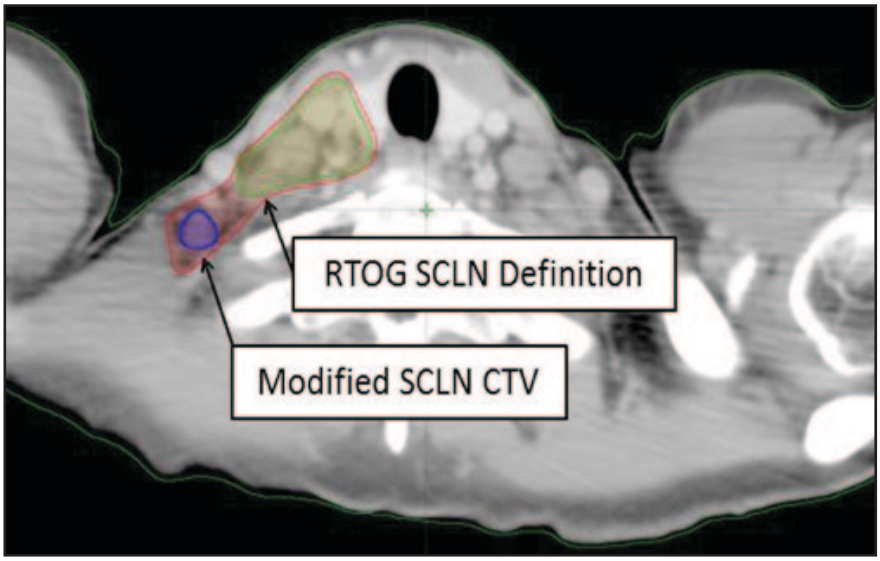

FIGURE 1. *Treatment-planning CT scan for inflammatory breast cancer patient evincing inadequate CTV coverage of posterior-lateral SCLN (blue), contoured by The RTOG Contouring Atlas definition (green), with suggested modifications (red).*

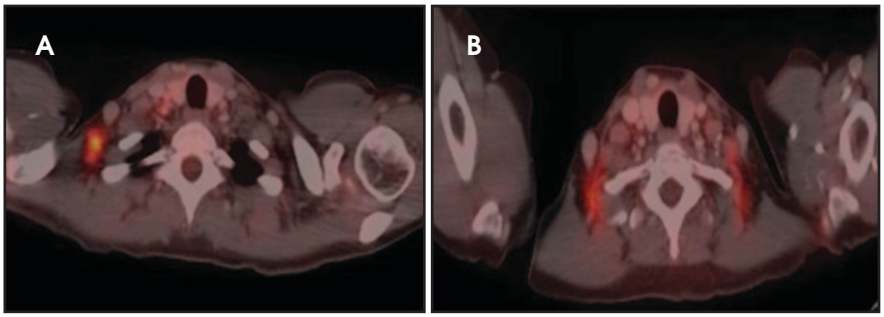

FIGURE 2. *FDG-PET/CT (A) showing 1.6-cm hypermetabolic posterior-lateral supraclavicular lymph node with complete metabolic response (B) on postneoadjuvant chemotherapy FDG-PET/CT (incidentally noted symmetric posterior FDG avidity from brown fat).*

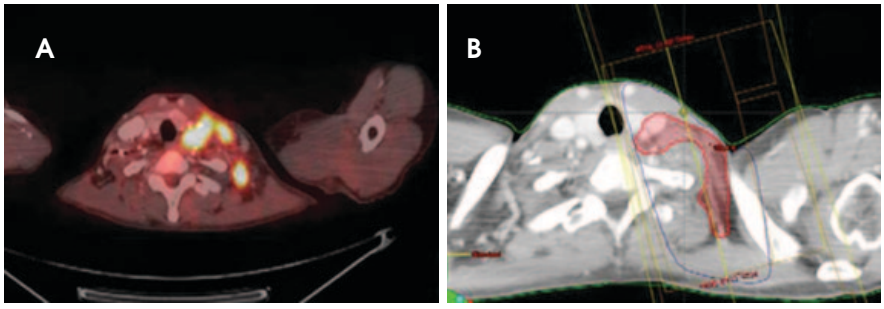

FIGURE 3. *(A) FDG-PET/CT for early-stage breast cancer with isolated medial and posterior-lateral SCLN recurrence following breast conservation surgery, with (B) treatment-planning CT highlighting suggested SCLN field extension.*

chemotherapy without radiotherapy.[2] The emergence of CT-based planning and intensity-modulated radiation therapy (IMRT) has placed increased emphasis on accurate contouring of the clinical target volume (CTV) in lymph-node regions at risk for micrometastases in adjuvant breast radiotherapy. Current guidelines, such as The RTOG Contouring Atlas, serve as invaluable tools for the radiation oncology community; however, continued reassessment of appropriate target definitions and individualized patient application is essential.

Supraclavicular lymph node (SCLN) fields in breast cancer were formerly defined in 2-dimensional (2D) planning by the clavicular head, cricoid cartilage, cervical spine pedicle, and humeral head, which included the undissected level-III axillary region and low neck (level IV and adjacent level V) nodal regions (though coverage varied by depth). However, the definition for the SCLN CTV in 3-dimensional (3D) planning remains equivocal, but is of increasing importance. The current volumes recommended in The RTOG Contouring Atlas define the SCLN CTV to include the undissected axillary and level IV cervical lymph nodes. However, they omit the adjacent level V region, instead defining the SCLN borders as consisting of:

- Cranial: the cricoid cartilage;
- Caudal: the junction of the brachiocephalic and axillary veins clavicular head;
- Anterior: the sternocleidomastoid;
- Posterior: the anterior scalene muscle;
- Lateral: the sternocleidomastoid/clavicle-first rib junction; and,
- Medial: the thyroid and trachea.[3]

CME

Similarly, clinical trials, including the EORTC-22922 and MA-20 trials, have also focused on the medial SCLN.[4,5] Studies quantifying SCLN recurrence have not separated medial from lateral SCLN.[6]

With the emergence of PET/CT, both in locally advanced and inflammatory breast cancer, we increasingly have noted disease in posterior/lateral SCLN fossa (low neck level V). The presented IBC patient highlights one exemplary case (of at least 5 during a 3-year period) at our institution with SCLN extension into the lower neck nodes, which would not be included in the currently recommended RTOG contouring definitions (Figure 1). Others have reported similar concerns, where 15% of N3c patients had SCLN posterior to the transverse vertebral process, with level V representing 21% of the total SCLNs identified by PET/CT.[7] Indiscriminate application of contouring guidelines without consideration for specific patient disease, anatomy, and risk could result in a geographic miss of posterior lateral SLCN, as seen Figure 3, where an infiltrating ductal carcinoma patient experienced isolated SCLN recurrence with posterior-lateral involvement.

CONCLUSION

The current definitions recommended in The RTOG Contouring Atlas may inadequately represent the lower, adjacent level V neck nodes, especially in patients with gross medial SCLN involvement and inflammatory or locally-advanced breast cancer at high-risk for subclinical disease. Caution is advised when applying this definition of the SCLN CTV in such patients without patient-specific consideration of disease, anatomy, and risk. Particular attention is warranted when using IMRT, where sharp dose gradients in the target area may increasingly omit at-risk nodal regions relative to 3D techniques. If available, pretreatment PET/CT should be focused carefully on identifying grossly involved posterior-lateral SCLN. Further research is warranted in defining patients who may benefit from including adjoining level V nodes. We recommend case-by-case consideration for individualized specification of medial-versus-lateral SCLN risk in applying current RTOG contouring guidelines to avoid geographic miss.

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SEE PAGE 4 FOR DETAILS CME

Surface mold brachytherapy: A means to achieve therapeutic skin irradiation in a case of synchronous bilateral breast cancer with extensive cutaneous involvement

Pranshu Mohindra, MD, Rupak K. Das, PhD, and Bethany M. Anderson, MD

CASE SUMMARY

A 38-year-old female, gravida 2 para 2, presented with a 8 to 10-month history of progressive firmness and nipple retraction of her right breast with multiple areas of dimpling and skin redness bilaterally that started as she was breastfeeding. Upon examination, patchy skin erythema with multiple nodular lesions scattered over both the breasts were noted. On palpation, the right breast was nearly completely firm and immobile. No appreciable masses were palpated in the left breast. Bilateral palpable axillary and supraclavicular lymphadenopathy was noted.

IMAGING FINDINGS

Diagnostic mammogram findings are as shown in Figure 1. An ultrasound-guided biopsy of the breast mass as well as bilateral axillary lymph nodes confirmed malignancy. Systemic staging work-up with laboratory evaluations, bone-scan and a computed tomography (CT) scan showed no evidence of distant metastatic disease. The final diagnosis was stage IIIC (cT4b cN3a cM0), bilateral breast invasive ductal carcinoma, grade-2, estrogen/progesterone receptor positive, HER-2/neu amplified.

*Prepared by **Dr. Mohindra, Dr. Das,** and **Dr. Anderson** while at the University of Wisconsin Carbone Cancer Center, Madison, WI.*

DIFFERENTIAL DIAGNOSIS

Malignancy, chronic mastitis, abscess, eczema, hidradenitis suppurativa, idiopathic granulomatous mastitis

DISCUSSION

In order to facilitate bilateral mastectomy, neoadjuvant chemotherapy with dose-dense adriamycin-cyclophosphamide followed by paclitaxel-herceptin was completed. A partial response, especially over the cutaneous lesions, still precluded bilateral mastectomy. Hence, radiotherapy (RT) targeting bilateral breasts (including the skin) and the axillary, internal mammary, and supraclavicular nodes was planned. To minimize irradiation of the underlying lungs and heart, intensity-modulated radiotherapy (IMRT) technique was employed for the initial phase treatment (Figure 2). Bolus was used, and thermoluminescent dosimeter measurements were obtained to confirm appropriate skin dose (1.8 to 2 Gy per fraction). Limited by radiation tolerance doses for the lungs and heart, the final boost to the skin was planned using surface mold-based, Iridum-192 high-dose-rate (HDR) brachytherapy (Figures 3 and 4). This was treated alongside 3-dimensional (3D) conformal fields for bilateral supraclavicular nodes. Brisk acute grade-2 radiation dermatitis with nonconfluent moist desquamation was seen at one-week post-RT with good resolution by one-month. Successful bilateral mastectomy was subsequently performed with the pathological assessment revealing only minute foci (< 1%) of residual carcinoma in bilateral breasts, and one of 3 right axillary lymph nodes and zero of 7 left axillary lymph nodes were positive for residual carcinoma. Significant treatment effects with areas of mucin and fibrous changes were noted in the

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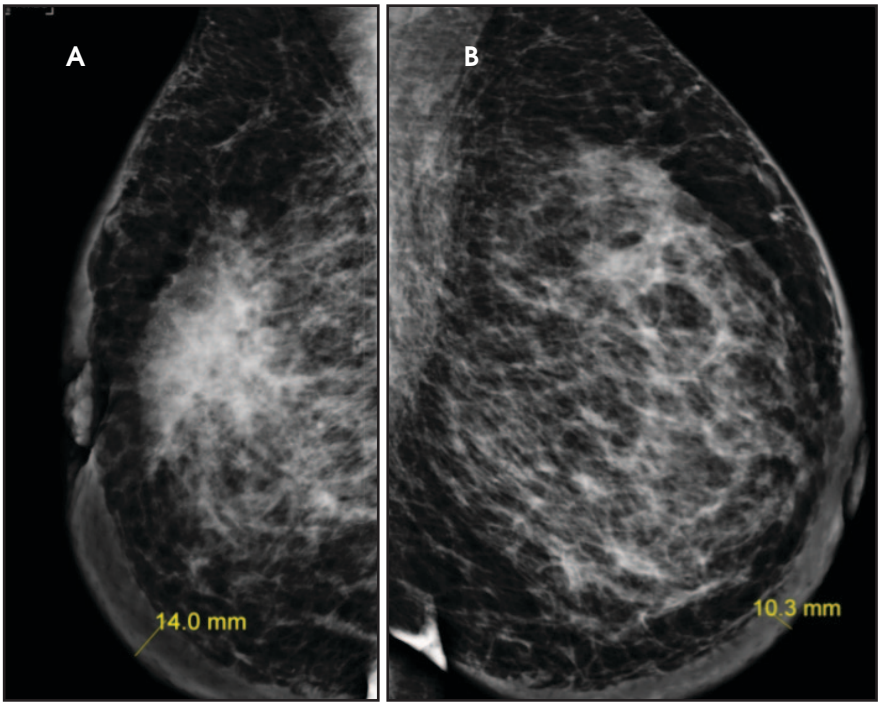

FIGURE 1. *Right and left (A and B) mediolateral oblique views of a diagnostic mammogram showing a large mass in the upper aspect of the right breast at the 12 o'clock position with fine pleomorphic calcifications involving all 4 quadrants. No discrete mass was noted on the left side. There was associated diffuse skin thickening and skin changes bilaterally.*

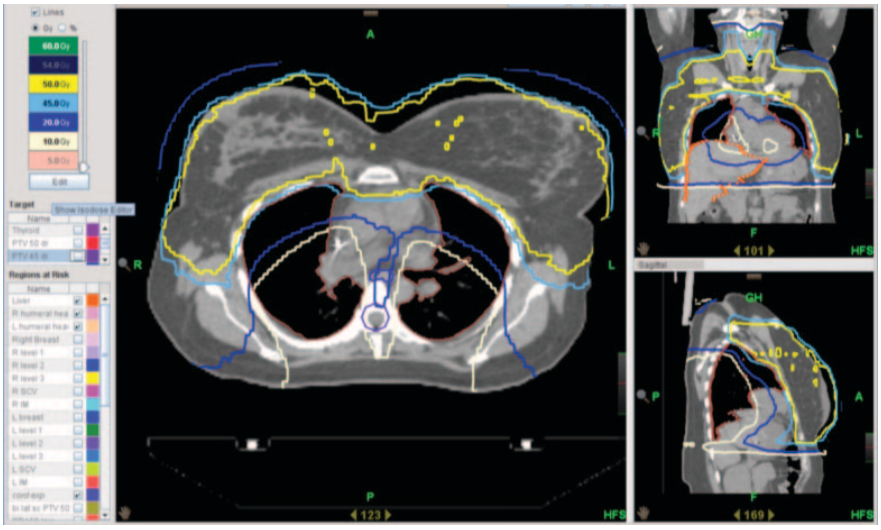

FIGURE 2. *The initial phase of radiotherapy was delivered using Tomotherapy-based intensity-modulated radiotherapy (IMRT) to deliver 50 Gy at 2 Gy/fraction to the bilateral breasts, level I-III axillary, supraclavicular, and internal mammary lymph nodes and 45 Gy at 1.8 Gy/fraction to the bilateral lower cervical lymph nodes. Bilateral clinically suspicious supraclavicular lymph nodes were then boosted using 3D conformal fields, with a planned cumulative dose of 60 Gy, although treatment of the left supraclavicular nodes was discontinued after 52 Gy due to confluent moist desquamation in that area.*

breast and nodal tissue. Ten months post-RT and surgery, the patient has developed lymphedema of the right upper extremity, but no symptomatic radiation pneumonitis or other late radiation toxicities.

Radiotherapy plays a critical role in management of breast cancer. CT scan-based 3D-conformal radiotherapy (3D-CRT) planning techniques are utilized to limit dose to normal underlying lung and heart (in left-sided malignancies).[1] The challenge of RT planning is increased even further in the setting of bilateral breast cancer (BBC), especially if regional lymphatics need to be irradiated.[2] In an old series reported from Massachusetts General Hospital in 1981, 3 out of 15 long-term survivors with synchronous or metachronous BBC developed medial subcutaneous fibrosis/necrosis after having received comprehensive bilateral breast and lymphatic irradiation planned in the conventional 2-dimensional (2D)-era.[3] The authors described various techniques for match-line management in that era. Investigators from the University of Pennsylvania reported their initial experience in 55 patients with BBC who received whole-breast RT (WBRT) after breast conserving surgery (BCS) using conventionally planned tangential portals.[4] One-quarter of the patients had a midline field overlap of up to 4 cm. No patient developed match-line fibrosis with 4% patients developing pneumonitis. Yamauchi et al described 17 patients with synchronous or metachronous BBC who were treated with BCS followed by WBRT (50 Gy in 25 fractions) using tangential portals with midline matched fields designed using CT-based planning.[5] Treatments were well tolerated, with only one patient developing moderate midline subcutaneous fibrosis. No cases of significant pneumonitis were reported. Sharma et al described electron

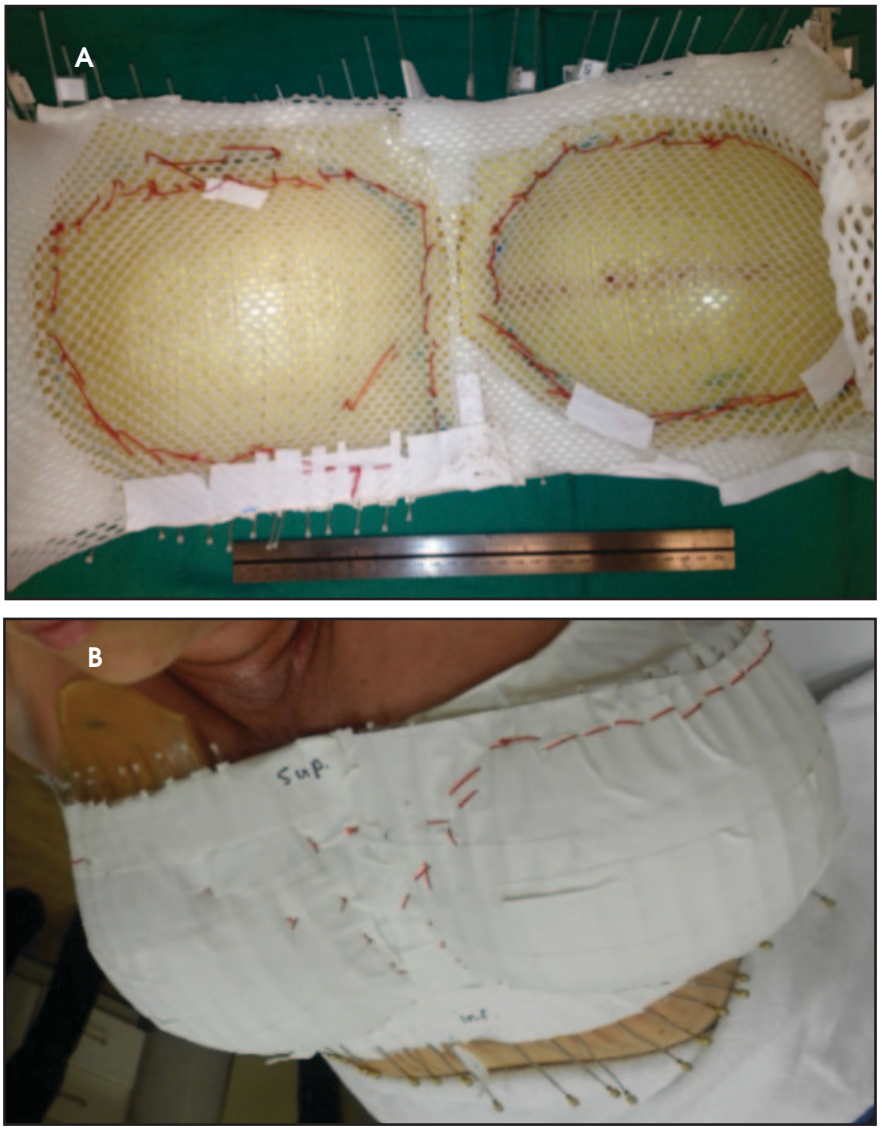

FIGURE 3. *A customized surface mold corresponding to the contour of the patient's breasts was created using a thermoplastic mold with interstitial high-dose-rate (HDR) catheters (17 on each side) placed in an adhesive material. To minimize surface hot spots, catheters were fixed at 1-cm intervals. 5-mm tissue equivalent bolus material was placed over a small area of residual skin nodularity extending outside the range of the brachytherapy mold, which was boosted simultaneously with supraclavicular nodal boost fields.*

arc therapy to treat bilateral chest walls in the postmastectomy setting.[6] This technique provides adequate skin doses, reduces the risk of field overlap in the midline from conventional tangential fields, and also effectively reduces dose to underlying lung and heart. However, treating regional lymphatics can still require matched photon fields. In addition, the authors noted that meticulous treatment planning with strict quality assurance is required for electron dosimetry.

More recently, IMRT-based radiation planning and delivery techniques are used to additionally reduce normal tissue irradiation.[7] In the setting of BBC, IMRT offers the advantage of treating a complex target of bilateral breasts/chest walls and locoregional lymphatics, while eliminating the challenges associated with field matching and minimizing the dose to the organs at risk. Nicolini et al described a dosimetric comparison between fixed-field IMRT and volumetric-modulated arc therapy (VMAT) for treating bilateral breasts and showed several dosimetric improvements with the VMAT technique.[8] Lee et al attempted to enhance IMRT planning even further by comparing dose-volume based IMRT planning versus generalized equivalent uniform dose-based optimization planning and demonstrated superiority in dosimetric outcomes by pursuing the latter approach.[2]

In our case, for the initial phase of RT (50 Gy in 25 fractions) we utilized Tomotherapy-based IMRT technique. Nonetheless, considering the large volume of tissue requiring irradiation, the volume of bilateral lungs receiving 30 Gy (V30 Gy) was 18%, while V20 Gy and V5 Gy was 28% and 65% respectively, and the mean bilateral lung dose was 14.7 Gy. The heart V25 Gy, V20 Gy, V10 Gy and mean doses were 23%, 35%, 75%, and 18.5 Gy, respectively. To maintain a risk for symptomatic pneumonitis of ≤ 20%, Quantitative Analysis of Normal Tissue Effects in the Clinic (QUANTEC) guidelines currently recommend limiting the bilateral lung dose to V20 Gy ≤ 30%, with mean dose ≤ 20 Gy.[9] Cardiac dose is limited to mean < 26 Gy and V30 Gy < 46% to reduce the risk for pericarditis, while V25 Gy should be < 10% to keep the risk for long-term cardiac mortality < 1%.

An IMRT boost plan to adequately treat bilateral breast skin resulted in intolerably high pulmonary and cardiac doses. Instead, a customized surface brachytherapy (BRT) mold was generated to allow delivery of an additional 10 Gy in 5 fractions, prescribed to a depth of 7 mm beneath the skin surface of the breasts. Achieving irradiation of skin to therapeutic doses was especially critical since lack of dermal response

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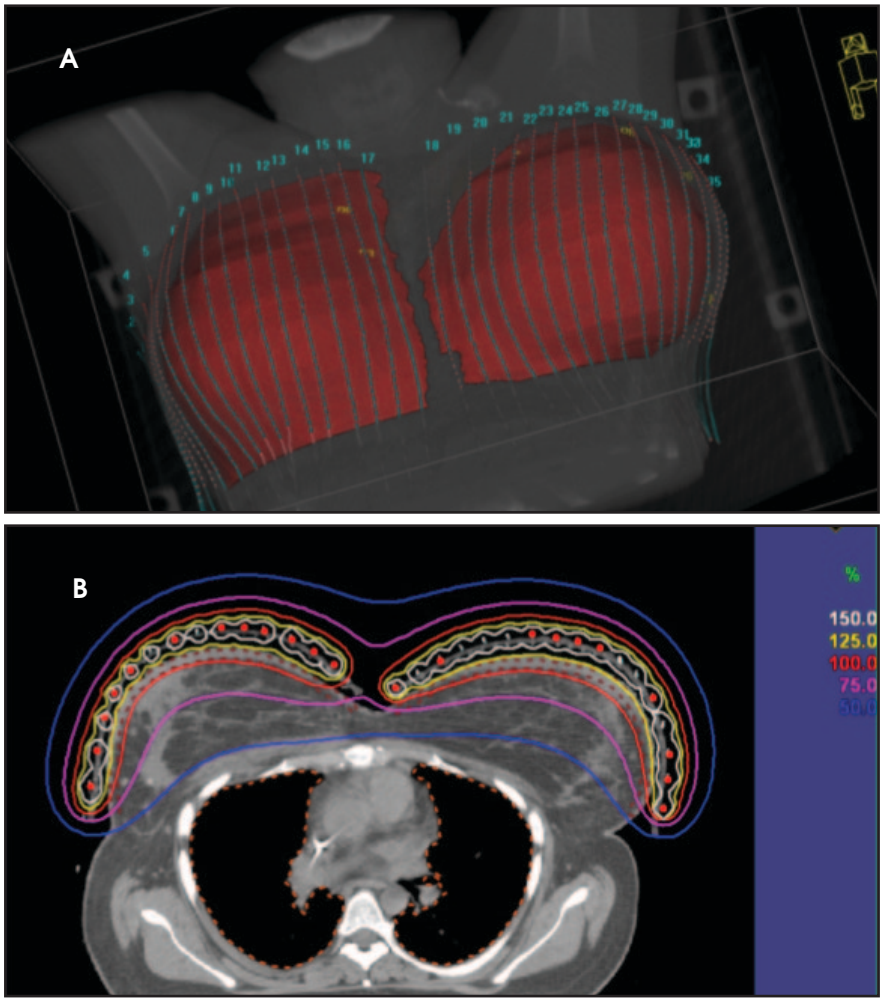

FIGURE 4. *(A) A digital representation of the target volume (red surface) with positioning of the brachytherapy catheters represented with light blue color numbered lines against a background of the patient's skeletal and surface anatomy. (B) The isodose distribution of the brachytherapy plan is shown. The brachytherapy treatment was prescribed to prescription points placed 7 mm underneath the skin surface, to a dose of 10 Gy in 5 fractions. Lung dose was very low, with only 0.8 Gy per fraction delivered to the maximally irradiated 2 cc's (D2cc) of lung tissue.*

was the primary reason for unresectability. Surface brachytherapy is not used very commonly in management of breast cancer. Older experiences have been described from the University of Heidelberg using reusable pulsed-dose-rate (PDR) skin mold brachytherapy in patients with cutaneous involvement from primary or recurrent breast cancer.[10,11] Stewart et al described the utility of high-dose-rate (HDR) surface applicator-based BRT to deliver scar boost radiation in 2 patients who underwent immediate breast reconstruction postmastectomy, a scenario that is increasingly seen in the current era.[12] When comparing with electron-fields, superior homogeneity, and coverage of the scar was noted.

CONCLUSION

Radiotherapy planning for bilateral breast cancer with cutaneous involvement can be a practical challenge. In our patient, initial comprehensive IMRT followed by skin boost delivered using surface-mold BRT safely provided therapeutic radiation doses to the skin, while minimizing the dose heterogeneity and other challenges associated with matching multiple radiation fields. This can be considered as an option for the management of this rare and complex clinical scenario.

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