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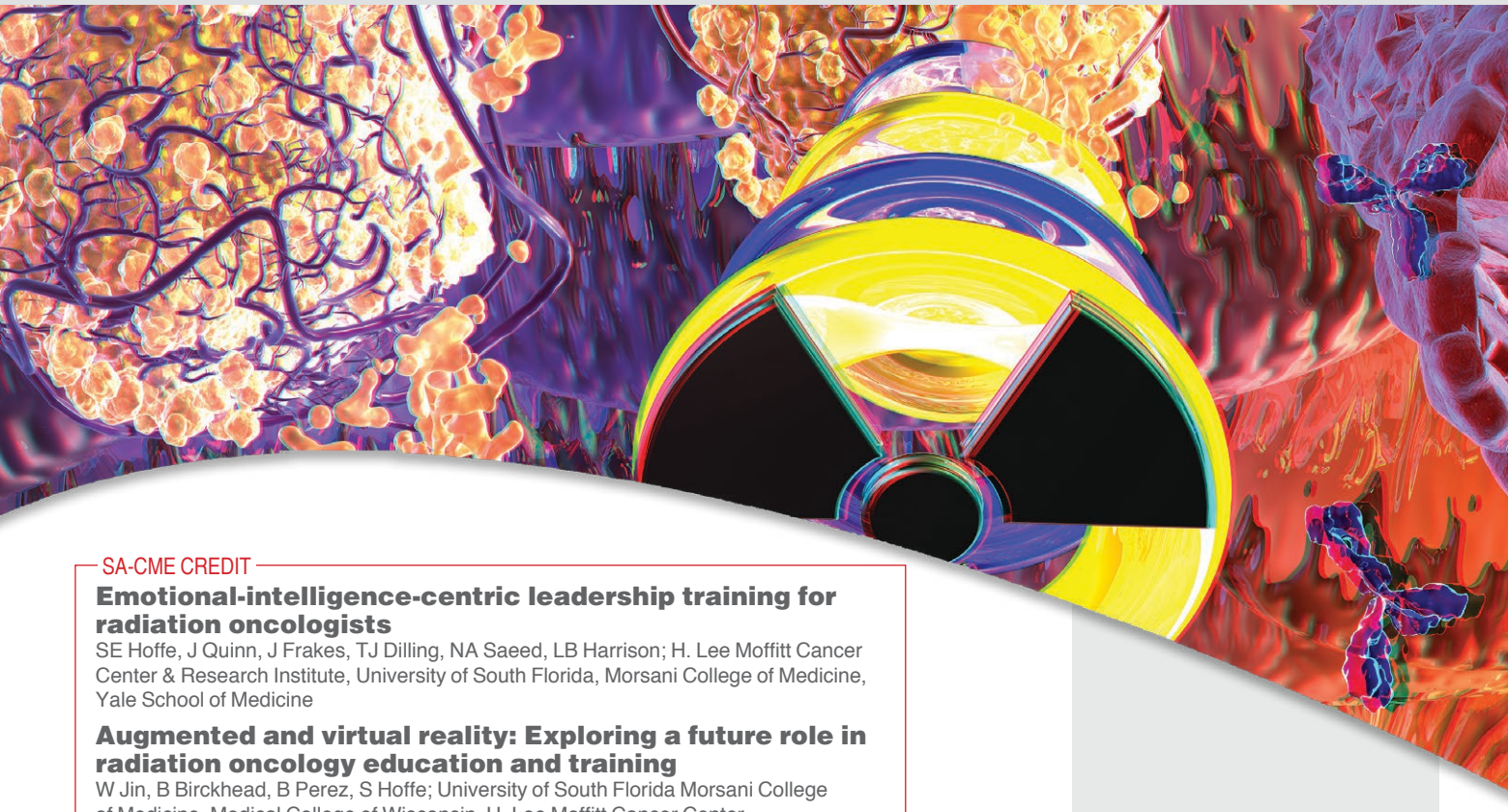

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Emotional-intelligence-centric leadership training for radiation oncologists

SE Hoffe, J Quinn, J Frakes, TJ Dilling, NA Saeed, LB Harrison; H. Lee Moffitt Cancer Center & Research Institute, University of South Florida, Morsani College of Medicine, Yale School of Medicine

Augmented and virtual reality: Exploring a future role in radiation oncology education and training

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CB-CHOP: A simple acronym for evaluating a radiation treatment plan

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Incidental nodal irradiation in locally advanced nonsmall cell lung cancer treated with involved-field IMRT

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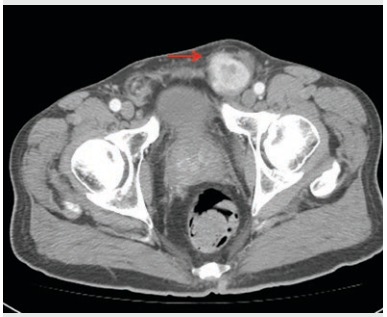

Radiation Oncology Case

A case of spermatic cord leiomyosarcoma: Clinical presentation, treatment and literature review

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The value of emotional intelligence (EI) as an essential leadership competency in healthcare has been growing, but the data are still mixed. For medical students, EI has been associated with building leadership and empathy skills, and interest is growing in developing a leadership curriculum in undergraduate medical education. This article addresses whether an EI-based leadership curriculum has a potential role in the postgraduate medical training of U.S. radiation oncology residents.

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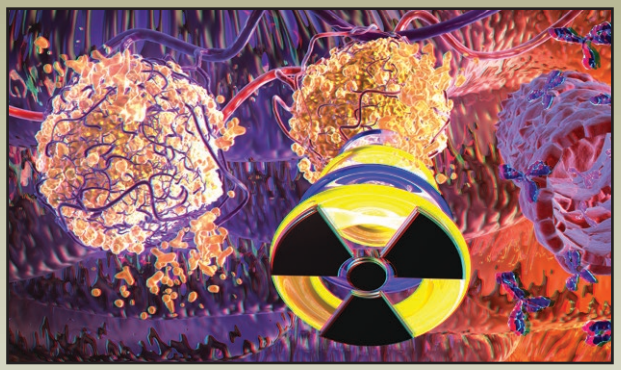

About the cover: *Oncological Battleground, the 3D work of art on this month's cover, is by Jeff Hazleton of Lucid Global. To be featured at the Moffitt Cancer Center, Tampa, FL, the art can be viewed with 3D glasses for full visual effect.*

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EDITORIAL

Pillars of progress through leadership, education and collaboration

John Suh, MD, FASTRO
Editor-in-Chief

Welcome to the December 2017 issue of *Applied Radiation Oncology*! This month we are excited to announce a new collaboration with the Association of Residents in Radiation Oncology (ARRO), a national leadership society that fosters career development and professional growth for the next generation of radiation oncologists. In addition, this issue focuses on leadership and education, which are paramount to advancing radiation oncology.

Joining our advisory board as the ARRO liaison is ARRO Chair Kaleigh Doke, MD, PGY-4 resident at the University of Kansas, who will spearhead efforts to recruit resident-penned editorials, case reports and review article submissions. She also will work with us to spotlight the achievements and experiences of ARRO's Global Health Scholars, leading us on invaluable and eye-opening journeys through the trials, triumphs and practices of radiation oncology facilities around the world. Such information-sharing serves as a foundation for building bridges to improve radiation therapy internationally, especially in countries with severely limited resources. Since serving as a Global Health Scholar is a tremendous opportunity with far-reaching potential, we are delighted to showcase this program in future issues. For more about ARRO initiatives and resident leadership roles, please see Dr. Doke's ARRO Resident Voice editorial in the issue.

We are also pleased to announce the appointment of Nadia Saeed, MD candidate at Yale School of Medicine, to the new role of medical student representative for the ARO advisory board. Among her stewardship roles, she will write and help recruit peers to submit review articles and editorials, with a focus on education and other issues facing medical students in radiation oncology. The first article is *Augmented and virtual reality (AR/VR): Exploring a future role in radiation oncology education and training* by William Jin, a 4th-year medical student at the University of South Florida (USF). In this well-composed review article, Jin and colleagues examine the novel subject of how AR/VR technologies can cost-effectively enhance training in our highly complex medical specialty.

The companion article, *Emotional-intelligence-centric leadership training for radiation oncologists*, by Sarah E. Hoffe, MD, of USF and Moffitt Cancer Center, and her colleagues, offers a timely and interesting review detailing how and why an EI-based leadership curriculum plays an important role in the postgraduate medical training of U.S. radiation oncology residents. She describes how radiation oncology residents may be in a unique position to lead the way in crafting EI-centric leadership competencies. We hope you enjoy these leadership/education reviews, as well as the issue's additional articles and case reports.

On behalf of *Applied Radiation Oncology* and our expanding advisory board, I wish you and your families a wonderful holiday season and 2018!

***Dr. Suh** is the editor-in-chief of* Applied Radiation Oncology, *and professor and chairman, Department of Radiation Oncology at the Taussig Cancer Institute, Rose Ella Burkhardt Brain Tumor and Neuro-oncology Center, Cleveland Clinic, Cleveland, OH.*

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ARRO RESIDENT VOICE

Lead time: Resident roles in shaping the future

Kaleigh Doke, MD

Cancer care is constantly evolving, and we as future leaders in radiation oncology must take ownership and responsibility for the direction in which to guide our field. In residency training, while we should primarily focus on becoming excellent clinicians, we should also challenge ourselves to think about the future of our specialty. As the next generation of radiation oncologists, we must learn from those ahead of us to continue an unbroken chain of leadership. We have to make a collective effort to develop innovative ways to use radiation therapy, integrate our treatment with new immunotherapies and targeted agents, collaborate with others in multidisciplinary care, and become more involved in health policy, all with the end goal of advancing patient care. Leadership organizations such as the national Association of Residents in Radiation Oncology (ARRO) benefit radiation oncology and support this ongoing chain of leadership. The professional society provides resources for career development, and exposes residents early on to critical discussions about the future of our field. It also acts as an avenue for those in national leadership positions to mentor the next wave of radiation oncologists.

ARRO is made up of three committees. The Education Committee creates monthly cases and image challenges, and is launching new educational resources, including the Landmark Trials project and Meet Me in Treatment Planning videos. The Global Health Committee partners with physicians and cancer centers around the world, connecting residents with international rotations. They support three residents each year to complete radiation oncology projects through the Global Health Scholars program. The Communications Committee connects residents and disseminates educational material including late-breaking journal articles through various platforms, including ARRO.org, Facebook and Twitter (@ARRO_org). Additionally, ARRO plans a seminar as well as other programs and events at the annual ASTRO meeting. Executive members of the board also give residents a voice by serving on ASTRO committees and representing trainees in other national organizations. Members act as advisors to several journals, and advocate for our patients and physicians at Advocacy Day in Washington, DC, every year.

With the future of our discipline at a crossroads, we are excited to work through organizations such as ARRO to continue to elevate the field and public perception of our specialty. As the next generation of aspiring radiation oncologists, we aim to stay involved in cancer care as a primary member of the decision-making team to advocate for the best care of our patients.

Dr. Doke *is chair of the Association of Residents in Radiation Oncology (ARRO) and a PGY-4 resident at the University of Kansas Cancer Center, Kansas City, KS.*

ARRO board members are excited to become more involved with Applied Radiation Oncology. Look for more editorials, cases and review articles from residents, including spotlights on projects from the Global Health Scholars.

SA–CME Information

EI-CENTRIC LEADERSHIP TRAINING (PAGE 8)

Description: Current residency training in radiation oncology does not incorporate leadership competency skills. Additionally, increasing administrative burdens in healthcare correlate with growing physician burnout and stress, but residency training has no systematic strategy to increase resiliency. Although simulation-based medical education (SBME) can incorporate teamwork, communication, and collaboration exercises at the undergraduate medical level, it has not been studied/incorporated at the national graduate level in radiation oncology. This article addresses the role of an emotional-intelligence (EI)-based leadership curriculum during such training.

Learning Objectives:

After completing this activity, participants will be able to:

1. Describe 3 categories of competency skills for a global radiation oncology leader curriculum identified by an international Delphi consensus study.
2. Identify the 4 quadrants of the EI Model and the underlying 12 competencies.
3. Explain how EI training could impact the professional development of residents.

Authors: **Sarah E. Hoffe, MD,** is section head, Gastrointestinal Radiation Oncology at H. Lee Moffitt Cancer Center and Research Institute and the year 1 & 2 leadership module co-director for the University of South Florida (USF) Morsani School of Medicine SELECT program. **Jessica Frakes, MD,** is a GI radiation oncologist and a USF Morsani School of Medicine professional development coach, **Thomas J. Dilling, MD,** is a thoracic radiation oncologist and the residency program director, and **Louis B. Harrison** is deputy physician in chief and chair, Department of Radiation Oncology, H. Lee Moffitt Cancer Center & Research Institute, Tampa, FL. **Joann Quinn, PhD, MBA,** is the director of SELECT Competency Assessment, USF Morsani College of Medicine, Tampa, FL. **Nadia A. Saeed, BA,** is a first-year medical student, Yale School of Medicine, New Haven, CT.

AR/VR IN EDUCATION, TRAINING (PAGE 13)

Description: The range of differences on the augmented/virtual reality AR/VR spectrum are mainly attributed to its depth of immersion. AR/VR technology is being used, through all spectrums of their devices, in surgery, imaging, medical student/resident/fellow education. The utility of AR/VR lies in its advantage to be massively scalable, reproducible, and realistic in simulating clinical environments. This article discusses how AR/VR technologies can cost-effectively enhance radiation oncology training.

Learning Objectives:

After completing this activity, participants will be able to:

1. Understand what constitutes the AR/VR spectrum.
2. Describe its uses and practical applicability in medicine.
3. Identify AR/VR utility in medical student education.

Authors: William Jin is a 4th-year medical student, University of South Florida (USF) Morsani College of Medicine, Tampa, FL. **Brandon Birckhead, MD,** is a radiation oncologist at Medical College of Wisconsin, Department of Radiation Oncology, Milwaukee, WI. **Bradford Perez, MD,** is a radiation oncologist, Moffitt Cancer Center, Tampa, FL. **Sarah E. Hoffe, MD,** is section head, GI Radiation Oncology, and the leadership module co-director for USF Morsani School of Medicine year 1&2 SELECT program.

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SA-CME (see page 7)

Emotional-intelligence-centric leadership training for radiation oncologists

Sarah E. Hoffe, MD; Joann F. Quinn, PhD, MBA; Jessica Frakes, MD; Thomas J. Dilling, MD; Nadia A. Saeed, BA; Louis B. Harrison, MD

Strong direction from a competent leader especially skilled at leading individuals and teams is a well-established expectation in business.[1] Moreover, the core set of principles embedded in the emotional intelligence (EI) model are valued for business leaders, with data showing that organizations with successful leaders score high on EI.[2,3] Translating these strengths from the business world to medicine, however, is no easy task—especially when a changing medical landscape, with new models of delivery and payment, demand high levels of inter-professional collaboration.[4]

Traditionally, healthcare leaders have been chosen for strength in their discipline rather than in leadership skills and competencies.[5] This is compounded by the fact that few undergraduate/graduate training programs exist in medicine with a longitudinal leadership curriculum, and even fewer with an EI foundation. In the multidisciplinary field of radiation oncology (RO), team-based skills are particularly important; yet current U.S. training programs do not specifically incorporate these elements. Educators have indicated the need for discussion about a leadership curriculum for residents at the national level.[6] This is a significant opportunity for the field of RO to set the bar for leadership training in graduate medical education.

Recently, Turner et al reported on a global radiation oncology leader curriculum with 20 leader competency skills defined after an international Delphi consensus study.[7] These competencies were housed in 3 broadly defined categories: contributing to the improvement of cancer care delivery in teams and wider health systems, engaging in stewardship of cancer care resources, and demonstrating elements of leadership in practice. In the last category, the development of self-awareness was incorporated by attention to strengths, weaknesses, values, drivers, behaviors, and impact on others. This study demonstrated that developing a global leadership curriculum for radiation oncology

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Table 1. Twelve Core Competencies Forming the Emotional and Social Competence Inventory (ESCI)

SELF	OTHER
Self-awareness: Emotional self-awareness	**Social awareness:** Empathy, organizational awareness
Self-management: achievement orientation, adaptability, emotional self-control, and positive outlook	**Relationship management:** Coach and mentor, inspirational leadership, influence, conflict management, and teamwork

is feasible, and is actively being initiated in Canada, Australia and New Zealand. Next year at the annual European Society for Radiotherapy and Oncology (ESTRO) meeting there will even be a new course teaching the principles of leadership for radiation oncologists at the ESTRO educational school.

A resident curriculum in RO for enhancing interpersonal and communication skills as well as professionalism is not well-defined, despite data showing that better doctor-patient communication has been associated with fewer patient complaints[8] and medical errors.[9] Moreover, while nearly 10 years have passed since The Joint Commission issued its Sentinel Event Alert cautioning that disruptive behaviors of healthcare personnel can compromise patient safety,[10,11] many radiation oncology residency programs still struggle with how to incorporate curricula to improve these skills in an already tight agenda.

The value of EI as an essential leadership competency in healthcare has been growing, but data are still mixed.[12] For medical students, EI has been associated with building leadership and empathy skills,[13,14] and interest is growing in developing a leadership curriculum in undergraduate medical education. While some evidence suggests that leadership training that includes EI can benefit family medicine residents,[15,16] others have not shown a benefit to incorporating EI.[10] Thus, the question we address in this article is whether an EI-based leadership curriculum has a potential role in the postgraduate medical training of U.S. radiation oncology residents.

Potential EI Model Benefits for RO

Several models describe and assess EI, with perhaps the best known deriving from the work of Goleman and Boyatzis. In this model, EI consists of 4 quadrants: self-awareness, self-management, social awareness, and relationship management. Although many tools assess EI, one used in business and graduate business education for over 20 years has been the 360-degree survey, the Emotional and Social Competence Inventory (ESCI). The ESCI is comprised of 12 core competencies that form the basis of EI. (**See Table 1**.) In the self-awareness quadrant is emotional self-awareness. Within self-management are the competencies of achievement orientation, adaptability, emotional self-control and positive outlook. Social awareness is comprised of empathy and organizational awareness. Finally, 5 competencies form relationship management: conflict management, coach and mentor, influence, inspirational leadership and teamwork.

Goleman has proposed that EI can be learned, as the potential exists for practice-based learning beyond an individual's intrinsic genetic capabilities.[17] This potential resides in the brain's limbic system, which governs feelings, impulses, and drives that can be "rewired" with practice. This model, thus, has the potential to be "taught" to radiation oncology residents with practice-based learning.

Effectively teaching EI to RO residents could yield multiple downstream benefits. Data at the medical student level have shown poorer specific and overall communication skills as rated by standardized patients in students whose reflections indicate higher emotional withdrawal[18] and poor decision-making.[19] Since emotion is closely intertwined with the journey of oncology patients and their families, the multiple opportunities for radiation oncology residents to develop empathy during 4 years of training could offer extensive immersion in practice-based learning. At the faculty level, data reported by Pollak et al have shown that when oncologists respond to patients

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with statements classified as "continuers" that allow them to express emotion, patients report less anxiety and depression as well as greater satisfaction and adherence to therapy, yet oncologists responded in this manner only 22% of the time.[20] Continuer statements allowed the physician to state the patient emotion, empathize with the emotion, praise the strength of the patient, show support, and explore with the patient more of the emotion being expressed. If RO residency training incorporates the first EI quadrant, trainees could not only benefit themselves but also their patients.

In parallel with EI training in self-awareness, developing self-management competencies could yield significant benefits. With accelerating changes in healthcare, increasing feelings of burnout among faculty and resident radiation oncologists have been reported, often attributed to concerns regarding documentation, reimbursement, and patients' health insurance coverage.[21] A study evaluating academic chairs of radiation oncology programs[22] noted that major stressors were budget deficits and human resource issues. Additionally, a recent study of academic radiation oncology chairs found that higher EI correlated with low rates of self-reported burnout,[23] reinforcing the idea that resident training on self-management, time management, and stress response within the consistent framework of the EI model could help programs nationally decrease burnout within training and prepare residents for resilient postgraduate careers.

As residents gain confidence in recognizing and managing their emotions, the broader context of social awareness may not only lead to the development of empathy with patients, but also with others in the healthcare team. Moreover, the organizational structure of oncology, both in the clinical and research domain, is bathed in a dynamic interplay of multiple disciplines interacting daily. Clinically, residents interact with faculty and staff in the related oncology, surgical and medical subspecialties as well as with colleagues in pathology, radiology, internal medicine, and infectious disease in a variety of settings ranging from tumor boards to inpatient units. During residency, however, trainees are often not exposed to formal training in relationship management.

On the research front, such social awareness and management are no less important, especially given the high-achieving residents who pursue active research projects during training. Recent data show that over 90% of radiation oncology residents perform retrospective research while 20% lead prospective clinical trials, and 50% participate in translational projects.[24] These projects immerse residents in teams comprised of other physicians both internal and external to radiation oncology, as well as biostatisticians, basic scientists, computer engineers, mathematical oncologists, and epidemiologists. During such collaborative work, conflicts may arise due to factors such as differences in power dynamics as well as difficulties in team members learning to collaborate, negotiate conflicts, resolve differences, and work effectively in the team environment. However, training in these essential skills is lacking within the traditional radiation oncology resident curriculum.

In the current cancer continuum, the pace of translating discoveries from bench to bedside is exponentially increasing as disruptive technologies continue to evolve with contributions increasingly coming from those in nonbiomedical fields such as computer science and engineering.[25] Nationally, there is parallel interest in fostering cross-disciplinary collaboration among health scientists to promote the types of scientific teamwork that can improve population health.[26] Recent data support the trend of increasing collaboration in science, with more grant submissions and publications from cross-discipline collaborators vs. within-discipline collaborators.[27] In oncology, pairings of basic scientists with clinicians are seen as important foundations to an integrated academic culture to accelerate discovery and innovation.[28]

With the future inviting more opportunities for collaboration, radiation oncology residents may be in a unique position to serve at the forefront of developing EI-centric leadership competencies. Long term, this has the potential to expand the representation of radiation oncologists in prominent leadership roles at the organizational/institutional level, rather than just the RO departmental level, thus widening the range of the voice of RO as a specialty. Given the smaller class size of residency programs, trainees across all 4 years are in the same lectures, journal clubs, and case conferences. Built into training is the capacity for role modeling of the first-year residents observing the performance of older residents. There is also the "safety" net of a same-discipline cocoon in which trainees can develop skills through engaging role play.

The challenge is how U.S. programs could incorporate such curricula within the confines of an already packed schedule. The structure of the 4-quadrant EI model may potentially provide the best fit in this setting. Such structure could be reinforced with practice-based learning environments in the context of the clinical content taught that day. At the medical student level, simulation labs with standardized patients have fostered clinical skills, and are being used for specifically developing and assessing students' EI competencies as well. This simulation-based medical education (SBME) has been shown to improve patient safety and, with appropriately

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structured learning objectives, can focus on individual or team-based activities with attention to communication, collaboration and teamwork, and decision-making.[29]

With some format modifications, the SBME program could potentially apply to RO residency training in the existing content modules. For example, a tumor board scenario could be designed that would integrate case workup and review as well as journal articles. The faculty lead could assign each resident an appropriate journal article and position to defend. The senior residents could play the roles of medical and surgical oncologists and engage the first year in a conflict scenario. First-year residents would later write a reflection on how they felt when their position was questioned and how they managed their internal response. Senior residents would write a reflection on how their role affected how they spoke to the colleague and what strategies they used to influence the tumor board group to their position. As such, the senior residents would be practicing not only conflict management skills, but also their ability to influence the team. Integrating an EI-centric approach may thus enhance the engagement of the residents and potentially enrich their understanding of the material since they would have to actively assimilate the scientific journal content to best articulate their position to the group. The simulated tumor board group environment could be maximized in the context of case conferences and journal clubs.

The 4-quadrant EI model also has the foundation for integrating it as a coaching tool. Residency programs featuring a coaching approach have traditionally done so with a faculty/resident pairing, with qualitative data suggesting that such coaching dyads during postgraduate training can breed physician leaders who can improve the clinical practices in which they work.[30] At the faculty level, peer coaching has been reported to positively impact those who coach as well as those who receive the coaching by contributing to professional development by encouraging reflection time and learning.[31] The specifics of the type of dyad model to consider in RO training would need further testing, but given the small numbers of trainees, both the faculty/resident and senior/junior resident may have a role.

An EI-centric approach to leadership training for RO residents may provide a systematic approach to accomplish many of the competencies espoused in the global Delphi consensus study. With respect to improving cancer care delivery in teams and wider health systems, training programs may decide to engage coaching pairs in quality improvement (QI) projects for the department. By working in pairs, the residents would need to seek engagement for the appropriate stakeholders, which would allow them to practice communication skills with staff both inside and outside the department. They would have the opportunity to manage a project, meet deadlines, run meetings, and lead themselves to successful completion. At the end of each year, the projects could be presented orally to the faculty, which would also allow them to practice professionalism skills. To engage residents in cost and resource stewardship, basic training in finance could be taught so projects could have appropriate budgetary metrics to meet. Finally, these yearly projects may provide the opportunity to demonstrate competency in elements of leadership. To complete the project, the resident pairs would need to add other advisors to their team and learn how to influence different stakeholders to accomplish their goal.

Conclusion

The changing healthcare landscape offers increasing opportunities for specialists in radiation oncology to become effective physician leaders in larger organizational settings, spanning both the clinical and research environments. The 4-quadrant EI model has been associated with superior achievement in the business community but has not been validated in RO residency training. A global Delphi consensus study has now defined a leader role curriculum for RO. Further evaluation of an immersive EI-centric leadership training curriculum would be feasible for U.S. residents in radiation oncology.

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Augmented and virtual reality: Exploring a future role in radiation oncology education and training

William Jin, MA; Brandon Birckhead, MD; Bradford Perez, MD; Sarah Hoffe, MD

Abstract

Background: Recent advancements in computer-generated graphics have enabled new technologies such as augmented and virtual reality (AR/VR) to simulate and recreate realistic clinical environments. Their utility has been validated in integrated learning curriculums and surgical procedures. Radiation oncology has opportunities for AR/VR simulation in both training and clinical practice.

Methods: Systematic review was performed to query the literature based on a combination of the search terms "virtual," "augmented," "reality," "medical student," and "education" to find articles that examined AR/VR on learning anatomy and surgery-naïve participants' first-time training of procedural tasks. Studies were excluded if nonstereoscopic VR was used, if they were not randomized controlled trials, or if resident-level participants were included.

Results: For learning anatomy and procedural tasks, the studies we found suggested that AR/VR was noninferior to current standards of practice.

Conclusions: These studies suggest that AR/VR programs are noninferior to standards of practice with regard to learning anatomy and training in procedural tasks. Radiation oncology, as a highly complex medical specialty, would benefit from the integration of AR/VR technologies, as they can be cost-effective methods of enhancing training in a field with a narrow therapeutic ratio.

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Healthcare providers strive for cost-effective, easily accessible methods to train and practice medicine in this changing landscape. Virtual reality/Augmented reality (VR/AR) systems are readily available programs that can realistically simulate clinical environments. These immersive technologies are on a continuum of reality-virtuality.[1] A real environment is the reality we live in and is filled with real objects. A virtual environment fills a display device with virtual objects.[1] Everything between these two environments can be called mixed reality or extended reality (XR). One platform within XR is AR, in which a display device will overlay a digital image into the field of view of a real environment. Google Glass is considered a "nonimmersive" version of AR as it projects a computer monitor display into the upper right corner of a field of view. There are several factors to consider when assessing XR technology and several devices included within it that will not be discussed further in this paper. These platforms are typically used with either a head-mounted display (HMD) or a monitor-based display device.

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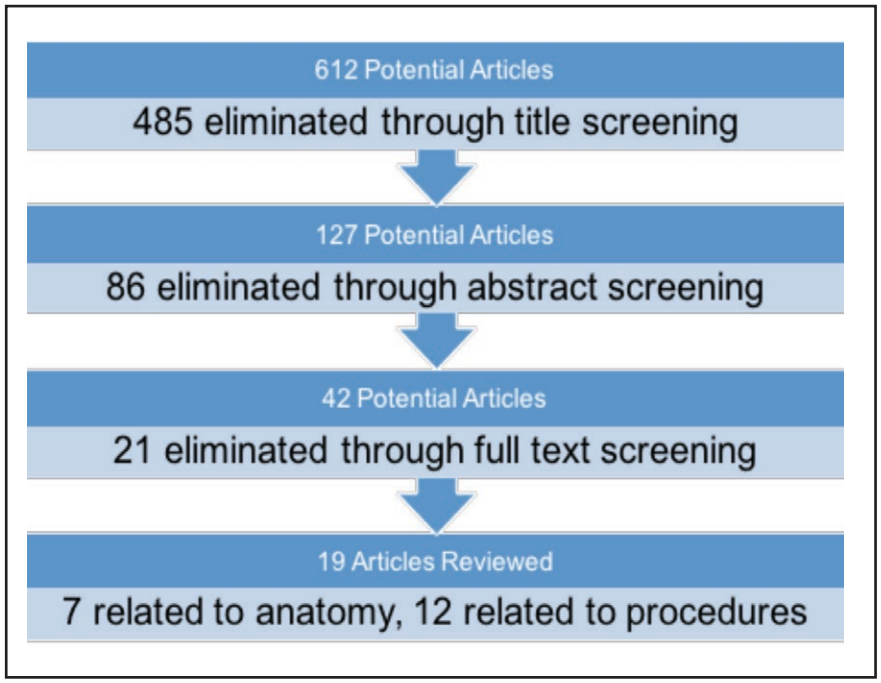

FIGURE 1. *Selection process for systematic review*

The most basic VR programs remain "nonimmersive," displaying traditional content, such as watching a movie on a computer screen. However, the most advanced VR programs try to emulate 3 sense-based modalities to provide a truly immersive environment: sight, sound and touch. The HMD-based devices use stereoscopic animations and surround sound, re-creating sight with depth perception and sound with distance localization.[2] Haptic feedback, or touch sensation, is on the horizon as well.[3-5]

AR-based devices work with some form of optic modulation through a medium such as glasses, a smartphone, and possibly contact lenses in the future. Some of the simplest nonmedical AR uses include smartphone applications that use a smartphone's gyroscope, internet connection and global positioning system (GPS) to triangulate and display astronomical constellations on the phone when pointing its camera lens to the night sky. Regardless of their level of immersion, one aim of these technologies is to help us see things that are difficult to visualize.

Previous iterations of immersive console experiences were unsophisticated with clunky, pixelated graphics; however, the latest graphic cards can produce photorealistic virtual environments.[6,7] In medicine, this advantage can translate to simulating procedures requiring precision dexterity that can possibly harm a patient. The experience required to obtain deft procedural ability would previously have been at the expense of real patients. Our surgical colleagues have already noticed the utility of simulated environments using the daVinci Surgical Simulator (dVSS) (Intuitive Surgical Inc.; Sunnyvale, California),[8,9] which is of particular interest to radiation oncology residency programs that train young physicians not only in external-beam techniques,[10] but also in internal brachytherapy delivery.[11] In radiation oncology practice, ensuring the safe delivery of implanted dose is of the highest significance due to the proximity of adjacent normal tissues and the potential of long-term radiation-induced late complications. Indeed, quality assurance programs in radiation oncology aim not only to ensure that the graduating physician possesses the technical ability to perform external-beam and brachytherapy delivery, but also that such competent skill is safely maintained over the lifetime of the practitioner.

The entire practice of radiation oncology is predicated on the individual practitioner's successful deployment of specific technologies. From contouring anatomical structures, to creating dose angles for treatment, to the technical insertion of permanent radioactive seeds or temporary catheters for high dose rate (HDR) brachytherapy, opportunities for AR/VR technology integration are numerous.[10,12-14] Clinical application of this new technology will be a challenge, as randomized controlled trials are needed to prevent unnecessary patient harm. A safer method of examining the utility of this technology in preliminary studies is by comparing noninferiority with traditional means of training.

The aim of this review is to determine whether AR/VR is a suitable surrogate for training clinically naïve radiation oncology healthcare practitioners. It is hypothesized that the main advantage of AR/VR's immersive environment is that it helps healthcare professionals understand 3-dimensional (3D) visuospatial representations better, or at least equal to, traditional textbook learning. Therefore, this study sought to find articles in which visuospatial learning would be most utilized, in anatomy and simple procedures requiring the understanding of anatomy.

Methods and Materials

Search Strategy and Study Eligibility

An initial search in the literature for articles written in English on the use of AR/VR for educational use at the medical student level as a surrogate for the entry level radiation oncology resident was performed, dating from 1997 to 2017. Specifically, articles that dealt strictly with anatomy education and

Table 1. AR/VR Articles Related to Medical Student Level Anatomy Education

Study & Pub Date	VR Program Software	Population & Control	Intervention & Comparison	Outcomes	Results	Notes
Codd et al (2011)	**VR:** Blender	**Population:** Medical students **Control:** Students w/o prior knowledge of anatomy (n = 13).	**Traditional:** 7 hrs DD, 5 hrs CD, 2 hrs GS (n = 14). **VR:** 50m w/ VR model (n = 12).	10q PA	**Stats:** ANOVA. VR group scored 7.3 ($p < 0.001$) and traditional group scored 6.8 ($p < 0.001$), both performed significantly better than control (1.5). VR not significantly better than traditional.	No correlation between past experience with 3D video games on scores.
de Faria et al (2016)	**VR:** Quicktime	**Population:** Medical students **Control:** 2D images in 60 m DD (n = 28).	**3D:** 60m interactive nonstereoscopic learning methods (n = 28). **VR:** 60m interactive stereoscopic lectures (n = 28).	10q MC	**Stats:** ANOVA. 3D scored 5.97 ± 1.3 ($p < 0.05$) and VR scored 6.03 ± 1.2 ($p < 0.05$), both performed significantly better than control (4.72 ± 1.2). VR not significantly better than 3D.	Some complaints of nausea and dizziness limited VR utility.
Moro et al (2017)	**VR:** Oculus Rift **AR:** Vuforia v5 on Samsung Galaxy Tab S2	**Population:** Anatomy and medical students **Control:** interactive 3D model of a skull via tablet application & 10m audio DD (n = 22).	**VR:** VR app for anatomy (n = 20). **AR:** AR app for anatomy (n = 17).	20q MC	**Stats:** ANOVA. No significant difference was observed among the 3 groups. VR scored 64.5% AR scored 62.5% 3D scored 66.5%	Blurred vision, difficulty focusing, double vision, nausea, and discomfort higher in VR group.
Kockro et al (2015)	**VR:** DextroBeam	**Population:** MS2s **Control:** Audio and Powerpoint DD (n = 80).	**VR:** audio DD with 3D animated tour (n = 89).	10q MC	**Stats:** ANOVA. VR (5.19 ± 2.12) did not score significantly higher than control group (5.45 ± 2.16, $p = 0.215$).	Students subjectively rated VR group higher due to spatial understanding, application in future anatomy classes, effectiveness, and enjoyability ($p < 0.01$)
Kucuk et al (2016)	**AR:** Aurasma and Magicbook	**Population:** MS2s with smartphones **Control:** 5h DD (n = 36).	**AR:** 5h DD supplemented with 6 3-5m AR videos with 3D anatomy model available (n = 34).	30q MC	**Stats:** ANOVA. AR (78.14 ± 16.19) scored significantly higher than control (68.34 ± 12.83, $p < 0.05$).	VR group had lower cognitive load ($p < 0.05$)
Nicholson et al (2006)	**VR:** Robotic surgical simulator (RoSS) for da Vinci Surgical System	**Population:** Medical students and surgery-naïve residents. **Control:** 2D DD (n = 5).	**VR:** 2D DD with RoSS system (n = 5).	150s timed test PA	**Stats:** Wilcoxon. VR (118s) completed the test faster than control (143s, $p = 0.048$). VR (4.2) scored more correct identifications than control (2.9, $p = 0.009$). VR group (0.4) committed fewer errors than control (1.7, $p = 0.015$)	Low n for both groups.
Peterson et al (2016)	**AR:** VH Dissector for Medical Education	**Population:** Graduate health science students **Control:** CD & DD (n = 28).	**AR:** control + 12h AR (n = 28).	4 PAs & 4 x 27q MC	**Stats:** Chi-square. AR performed better than control group ($p < 0.0001$).	Participants with higher GPA performed better than those with lower GPA ($p < 0.0005$).

Key: ANOVA: Analysis of Variance; CD: cadaveric dissection; DD: didactic lectures; GPA: grade point average; GS: group study or group learning; m: minutes; MC: multiple choice; MS2: second-year medical students; PA: practical assessment, consisting of identification of anatomical structures in prosected dissection; q: question; VR: virtual reality

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Table 2. AR/VR Articles Related to Medical Student Level Procedures

Study & Pub Date	VR Program & Software	Patient Population	Intervention & Comparison	Primary Outcomes	Results	Notes & Secondary Outcomes
Nickel et al (2014)	**VR:** Symbionix LAP Mentor II	**Population:** Lap-naïve MS **Control:** 10h BT & 2h of e-learning for 3D video games lap chole (n = 42)	**VR:** 12h of LAP Mentor II (n = 42) by 3 blinded, trained raters on lap chole explanted on liver LPM	**Evaluation:** 16q MC & OP evaluated on MC (13.3 vs. 11.0, p < 0.001). NSD in OP. Shorter OT for VR (75.8m vs. 77.6m, = 0.03). **Outcome:** OT	**Stats:**N/A. Control scored higher p = 0.03)	Males > females in OT (75m vs 78.4m)
Banaszek et al (2017)	**VR:** ARTHRO VR Simulator **BT:** Sawbones	**Population:** MS1-MS2s **Control:** Neither VR nor benchtop training (n = 8)	**Both:** 1h DD, 15m video & baseline practice on VR & BT **VR Crossover:** Students trained in VR and BT for 10m, then trained on VR for 6-8h for 5w (n = 16) **BT Crossover:** Students trained in VR and BT for 10m, then trained on BT for 6-8h for 5w (n = 16)	**Outcome:** GRS & 14-point arthroscopic checklist to evaluate pre- and post-training	**Stats:** ANOVA VR > BT in GRS (p < 0.001). VR & BT performed significantly better better on checklist, but not from each other.	BT > VR in efficiency (economy of motion, secondary outcome, p = 0.038).
Kanamuri et al (2008)	**VR:** MIST-VR simulator **3D:** ProMIS Simulator	**Population:** Lap-naïve MS3s **Control:** ProMIS (n = 8)	**VR:** 8h of VR (n = 8)	**Outcomes:** Pre- and post-test of live porcine model performance scores, TTRP	**Stats:** Mann-Whitney U. NSD in proficiency scores. VR > Control in TTRP (43 s. 75m, p < 0.05)	VR more effiicient (# iterations, 17 vs. 38, p < 0.05)
Vargas et al (2017)	**VR:** dVSS	**Population:** Surgery-naïve MS **Control:** online training module and in person orientation (n = 19)	**VR:** Control + dVSS tasks including camera clutching, suture sponging, and tubes (n = 16)	**Task:** Cystostomy closure on LPM via GEARS.**Outcomes:** Mean task times	**Stats:** Mann-Whitney U. NSD in performance scores or mean task times.	Participants set their own hours for training.
Henn et al (2013)	**VR:** Procedicus arthroscopy simulator	**Population:** Arthroscopy-naïve MS1s **Control:** MS received baseline proctored arthroscopy training (n = 8)	**VR:** Control + arthroscopic VR sim in six sessions over 3M (n = 9)	**Outcomes:** TTC	**Stats:** Paired t-test. VR faster than control (233s vs. 325s, p = 0.04).	
Feifer et al (2010)	**VR:** dVSS & LapSim VR simulator	**Population:** Surgery-naïve MS **Control:** No training in LAPSim ProMIS or daVinci (n = 5)	**Both:** 1.5M LapSim ProMIS & 1.5M dVSS (n = 5) **LapSim:** 3M LapSim ProMIS (n = 5) **dVSS:** 3M dVSS (n = 5)	**Evaluation:** MISTELS **Outcomes:** Pre- and post-training composite score of peg transfer, cutting, intracorporeal knot, & cannulation skills	**Stats:** Mann -Whitney U. Training in both LapSim and dVSS performed better than any other group (p = 0.009)	All experimental arms improved from baseline, but only training in both improved skills in 4+ more domains

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surgery-naïve procedural skills were sought. A combination of the terms "virtual reality," "augmented reality," "VR," "AR," "medical student," and "education" were queried.

A diagrammatic flow chart of the search algorithm used is depicted in **Figure 1**. The initial search of the literature yielded 612 articles. After this initial screening of article titles, 127 were selected for abstract review. Among criteria for exclusion were the inclusion of resident-level anatomy topics or participants; use of nonstereoscopic 3D models; and trials that were not randomized and controlled, not adequately powered, or did not have the article available in text. Additionally, studies were excluded if they did not explicitly test for a procedural task in a randomized controlled trial. Finally, studies were excluded if they did not utilize a true stereoscopic virtual reality simulator or augmented reality if the final test was not a 2-dimensional (2D) laparoscopic procedure or if the articles were unavailable in text.

After eliminating 86 studies, 42 articles were reviewed in full text. Finally, 19 articles were left that met inclusion criteria and form the basis for this review.

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Table 2. ***continued from previous page***

Study & Pub Date	VR Program & Software	Patient Population	Intervention & Comparison	Primary Outcomes	Results	Notes & Secondary Outcomes
Madan et al (2006)	**VR:** MIST-VR simulator	**Population:** MS1 & MS2s **Control:** Students received no prior training (n = 16)	**VR:** 200m of MIST-VR (n = 17) **BT:** 200m of LTS (n=14) **Both:**100m of LTS and 100m of MIST-VR (n = 18)	**Evaluation:** LPM tasks. **Outcomes:** Pre- and post-TTC in 4 lap tasks	**Stats:** Chi-Square. Both VR and BT significantly improved TTC in 3/4 tasks (p <0 .01). VR & BT NSD from each other.	Training in only VR actually increased TTC in 3/4 tasks.
McDougal et al (2009)	**VR:** Simbionix LAP Mentor	**Population:** Lap-naïve MSs. **Control:** 30m DD, then 2h LapEd BT (n = 10)	VR: 30m DD, then 2h VR (n = 10)	**Evaluation:** Cystostomy & Cystorrhaphy in LPM **Outcomes:** OSATS, TTC	**Stats:** ANOVA. NSD in TTC or OSATS.	Students subjectively believed that the time allotted to train was insufficient.
Nomura et al (2015)	**VR:** LapSim **AR:** ProMIS	**Population:** MSs **Control:** 12 x 30m in 6w of AR (n = 12)	**VR:** 12 x 30m in 6w of VR (n = 19)	**Outcomes:** Pre- and post-ProMIS evaluation, TTC, instrument path lengths, EoM	Stats: ANOVA. VR > AR in TTC (p < 0.001), instrument path lengths (p = 0.001), & EoM (p < 0.001). NSD in ProMIS evaluation.	
Chien et al (2012)	**VR:** SensAble VR simulator on WorldViz	**Population:** Surgery-naïve MS **Control:** 40m of PT and BC practice in 3D game (n = 7)	**VR:** 10x PT & BC practice (n = 7)	**Outcomes:** TTC in BC & PT	**Stats:** Independent test. VR > control in BC (p < 0.001) & PT (p = 0.002)	Only VR improved between pre- and post-training times/ distance travelled.
Tanoue et al (2007)	**3D:** Procedicus MIST	**Population:** MS **Control:** 30m DD (n = 15)	**VR:** 2 x 2h VR training (n = 20) **BT:** 2 x 2h BT training (n = 20)	**Evaluation:** Suturing and knot tying on BT **Outcomes:** TTC, # errors, EoM	**Stats:** Mann Whitney-U. NSD.	Evaluated on BT for both trainings.
Brinkmann	**VR:** unlisted	**Population:** Surgery-naïve MS3s **Control:** DD + 4 x 18 BT training sessions (n = 18)	**VR:** DD + 4 x 18 VR training sessions (n = 18)	**Evaluation:** Lap chole in LPM **Outcomes:** GOALS	**Stats:** Mann Whitney-U. NSD.	

Key: BC: bimanual carry; BT: box trainer; chole: cholecystectomy; DD: didactic lectures; dVSS: daVinci Surgical Simulator; EoM: economy of movement, how efficient a proceduralist's movements are performed; GEARS: Global Evaluative Assessment of Robotic Skills; GOALS: Global Operative Assessment of Laparoscopic Skills, objective rating system evaluating for depth perception, bimanual dexterity, efficiency, tissue handling, and autonomy; GRS: Global Rating Scale, objective rating system to assess procedural efficiency and efficacy; h: hours; Lap: laparoscopic; LPM: live porcine model; LTS: laparoscopic training simulator; m: minutes; M: months; MIST: Minimally Invasive Surgical Trainer; MISTELS: McGill Inanimate System for Training and Evaluation of Laparoscopic Skills, a hybrid AR training program available on the ProMIS system; MS: medical student; MS1: first-year medical student; MS3: third-year medical student; NSD: No(t) significant difference; OP: operative performance; OSATS: Objective Structured Assessment of Technical Skills, includes pre-procedure checklist and GRS; OT: operative time; PT: peg transfer; s: seconds; TTC: time to task completion; TTRP: time to reach proficiency; w: weeks

Meta-analysis was not performed due to heterogeneity in outcomes measured; controls; and randomized, controlled trial arms.

Results

Medical Student Anatomy Education

We identified 7 articles that used VR/AR to supplement anatomy courses at the pre-clerkship medical student level (**Table 1**).[15-21] Most of the studies found that AR/VR did not significantly differ in standardized testing scores when compared with traditional anatomy lectures that included cadaveric dissection. A variety of VR programs were used, with no single study using the same program for anatomy teaching. Participants included first- and second-year medical students, with one study including graduate-level students taking a medical anatomy course.[19] Controls across the studies varied, but all were randomized controlled trials. Outcomes measured were similarly heterogeneous, ranging from 10- to 30-question multiple choice exams and practical exams requiring cadaveric identification of structures.

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Medical Student or Surgery-naïve Procedural Learning

Twelve studies[22-33] were identified that sought to evaluate AR/VR training vs. box training in improving procedural tasks in surgery-naïve medical students (**Table 2**). Box trainers are the current standard of laparoscopic training. They consist of an enclosed box with a minimum of 2 laparoscopic port sites for instrument entry, a camera that displays the inside of the box, and a variety of objects inside to train in procedural skills. Some of the most common tasks include peg transfer, in which trainees must use laparoscopic tools to pick up porous silicone objects impaled by vertical pegs and place them in a targeted area. Most of the studies found that AR/VR did not significantly differ from traditional learning methods. The most common AR/VR programs used include LAP Mentor (3D Systems; Valencia, California), Minimally Invasive Surgical Training-Virtual Reality (MIST-VR), and dVSS. Participant demographics varied from first-year medical students to surgery-naïve surgical interns. As with anatomy education, procedural learning control groups were highly variable. They consisted of box training, didactic lectures, online training modules, and 3D videos. Standardized outcome measures used included objective structured assessment of technical skill (OSATS), global rating scales (GRS), and various subcomponents such as time to task completion, errors committed, and economy of motion.

Discussion

Noninferiority with Standard of Practice for Learning and Teaching

The studies identified in this review suggest that AR/VR is a suitable surrogate for acquiring the visuospatial skills necessary to be proficient in learning anatomy and simple procedural tasks,[15-36] topics with high relevancy for radiation oncology residency training and potentially ongoing maintenance of certification requirements. While the majority of U.S. medical schools use prosections, cadaveric dissections, and didactic lectures to teach anatomy, a standardized methodology does not exist; instead, anatomy curricula are created per the discretion of each medical school and accredited by the Accreditation Committee for Graduate Medical Education (ACGME). Interestingly, 2 out of 134 medical schools were able to maintain their accreditation even without traditional cadaveric dissections. This suggests that nontraditional means of producing functional anatomy curricula is practical and already in existence.[37] This study specifically sought articles using medical students as participants to examine the largest possible benefit from AR/VR naïve training, and the results are promising. With traditional learning done through the necessary use of live porcine models or expensive cadavers, the medical education community can benefit AR/VR's scalable and cost-effective benefits.

Kucuk et al and Nicholson et al showed that if the control group were taught using 2D lectures without cadaveric dissection, the AR/VR group performed significantly better.[18,23] This suggests that the ability to create 3D anatomical representations are adequately learned through AR/VR training. Interestingly, Moro et al used a control group consisting of a tablet-based 3D representation of neuroanatomical structures, and none of the groups (either VR or AR) performed significantly better than the tablet group.[19] All studies controlled for prior anatomy experience, and only 3 of the studies controlled for previous experience with AR/VR. Time spent with AR/VR supplementation varied significantly across all studies, from as short as 24 minutes to 12 hours. Peterson and his study fall in the latter group, and his data suggest that AR-supplemented training increased standardized scores, even against traditional cadaveric dissection.[21]

Outcomes measured amongst the procedural studies consisted of multiple choice exams and practical exams comprised of standardized scores for procedural effectiveness via time to task completion, errors made, and economy of motion. The results were heterogeneous. Time allotted for AR/VR training varied drastically, from 2 to 12 hours. Overall, VR training did not significantly differ from box trainer in terms of mean time to task completion, errors made, or economy of motion. Instead, they improved a participant's procedural task abilities similarly to box trainers when allowed to train for equal amounts of time. Standard learning curves for procedural tasks are expected to have a high slope early on with eventual plateauing, indicative of diminishing returns based on time put in.[38-41] However, determining the time to proficiency is critical in creating an effective educational course, an outcome not readily measured in these current studies. The advantage to a stereoscopic training environment is that it assists in visualizing a 3D world. However, all studies were tested in 2D laparoscopic view and were still found to be noninferior to laparoscopic box training. Most of the studies used live porcine models, although Tanoue et al and Chien et al tested their participants on box transfer.[24,32]

Heterogeneity of Results

The status of AR/VR research in healthcare is in its infancy. Unfortunately, this means that the studies available are single-center, industry-backed projects with small study populations and heterogeneous-measured outcomes. Even the definition of virtual reality remains ambiguous, as many nonstereoscopic 3D image-based studies from the last decade used it in their title. A need for formalized training procedures on AR/VR can eliminate this problem by standardizing the time required to reach

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proficiency in anatomy education and simple procedural tasks. Additionally, a gold standard for outcome measures based on a standardized time to proficiency needs to be established.

Radiation Oncology Integration

Understanding the representation of accurate 3D visualization of tumor volumes, treatment dose distributions,[12] and radiation damage to healthy tissue on computed tomography (CT), MRI, ultrasound and/or positron emission tomography (PET)/CT is necessary for radiation oncologists who typically have no formalized radiology training. VR has already been used to help teach patients, residents, and radiation therapists about patient positioning using a projector-based virtual reality program.[10] Pilot studies using AR have also been used to help guide the placement of brachytherapy needles.[11] Moreover, intraoperative delivery of radiation treatment or precise positioning of permanent seeds, as well as outpatient HDR insertion techniques, all require technical expertise, which can be difficult to measure during residency and in medical practice. Standardization and practice with procedural techniques could potentially improve safety in high-risk but necessary procedures such as brachytherapy. As brachytherapy fellowships are typically few and rely on an apprenticeship training model, the democratization of high-quality patient care will be limited by the quantity of cases at high-volume cancer centers. As AR/VR is an incredibly versatile and scalable technology, training can be systematically improved and adjusted based on the current standards of practice, with the potential to measure individual proficiency. Corrective training and real-time peer review can then be possible. In addition, treatment can be simulated without causing any patient harm, providing a safe and effective method of training next-generation radiation oncologists and ensuring the ongoing competence of the existing practitioners. AR/VR technology is ready to be integrated into radiation oncology training programs with needed research into how best to optimize such an initial and ongoing approach to ensure competency.

Conclusion

As healthcare shifts with a focus on producing cost-effective practices, healthcare education can benefit from the scalable nature of AR/VR. All of the studies we reviewed demonstrated noninferiority to the current standard of practice regarding training in clinically naïve participants. For radiation oncology residents, this translates into a more immersive learning environment in a field that requires proficient visuospatial and technical abilities. Future integration opportunities may extend far beyond residency education and offer practicing radiation oncologists the AR/VR immersion capability for demonstrating procedural proficiency for ongoing maintenance of certification, ultimately enhancing patient safety and ensuring the highest standards in quality of care.

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Incidental nodal irradiation in locally advanced non-small cell lung cancer treated with involved-field IMRT

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Abstract

Background: Studies using 3-dimensional conformal radiation therapy (3DCRT) show that elective nodal (EN) areas receive substantial incidental irradiation in non-small cell lung cancer (NSCLC) treated with involved-field radiation therapy (IFRT). Due to increasing use of intensity-modulated radiation therapy (IMRT), we performed a dosimetric analysis of 3DCRT vs. IMRT comparing EN incidental irradiation.

Material and Methods: Twenty-three stage IIIA NSCLC patients treated with curative intent IMRT (median dose 72 Gy) were studied. Nodal stations 1-2, 3A, 3P, 4, 5, 6, and 7 were contoured. Comparative 3DCRT plans were generated. Mean dose, V40, V50 and V60 were compared for each station.

Results: PTV V95 coverage was similar between 3DCRT and IMRT plans ($p = 0.20$). No significant differences in incidental irradiation were found except for contralateral 6 and ipsilateral station 5 nodes. For contralateral station 6, mean dose, V50 and V60 were less with IMRT than 3DCRT (43 Gy vs. 55 Gy, $p = 0.01$; 39% vs. 67%, $p = 0.02$; 14% vs. 58%, $p = 0.002$; respectively). IMRT also delivered less dose to ipsilateral station 5 compared to 3DCRT (mean 66 Gy vs. 71 Gy, $p = 0.04$). At a median follow up of 21 months, 6 patients (26%) had isolated locoregional recurrences, with only 1 patient (4%) having an isolated EN failure (station 5, supraclavicular) without intrathoracic progression.

Conclusions: IFRT using IMRT delivers similar incidental irradiation doses as 3DCRT to EN stations and may be safely delivered without theoretical concern for increased EN failures. Caution should be noted when treating with IMRT if there is high risk for subclinical disease in levels 5 and 6.

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The standard of care in locally advanced non-small cell lung cancer (NSCLC) includes concurrent chemotherapy and radiation therapy (RT).[1,2] Major improvements in radiation technology have led to significant changes in radiation delivery for NSCLC, including 3D-conformal radiation treatment (3DCRT) and intensity-modulated radiation therapy (IMRT).These technologies have enabled the delivery of more conformal radiation to spare normal surrounding tissue.

Historically, elective nodal irradiation (ENI) was employed in locally advanced NSCLC to reduce regional failures in the mediastinal lymph node (LN) regions.[3,4]

More recently, treatment has evolved to involved-field radiation therapy (IFRT), in which EN regions are omitted to deliver higher doses of radiation to gross disease while decreasing subclinical treatment volumes to reduce toxicities to the esophagus, lung and heart.[5-7] Multiple studies employing IFRT have demonstrated acceptable locoregional control rates, with 0% to 7% isolated nodal failures in EN stations outside initially involved LN regions, and most failures occurring in-field or distantly.[7-10] A major contributor to low nodal failure rates may be the clinically meaningful incidental irradiation to EN stations delivered with IFRT.[8,9,11,12] However, studies on EN failure patterns to date have primarily utilized 3DCRT, and it is unclear whether these data are applicable to more advanced modalities like IMRT.

IMRT is being increasingly used for NSCLC with the potential for more conformal radiation, with one study demonstrating an increase in IMRT from 2% in 2002 to 25% in 2009.[6,13-17] Furthermore, recent cooperative group trials, including RTOG 0617[18] and RTOG 1308,[19] have allowed IMRT for treatment. However, with the increasing use of IMRT, concerns have emerged that more conformal IFRT techniques may deliver less incidental irradiation to ENs and result in increased nodal failures, potentially compromising tumor control or patient survival. Due to the paucity of data to address this theoretical concern, we performed a dosimetric analysis of 3DCRT vs. IMRT treatment plans to compare incidental irradiation to thoracic nodal stations in locally advanced NSCLC.

Materials and Methods

Patient Selection

We studied 30 stage IIIA-IIIB NSCLC patients treated with curative intent IMRT at the University of Pennsylvania between 2009-2011 after approval from the institutional review board. All patients were staged upfront with PET/CT prior to treatment and treated with IFRT (defined below). Patients were predominantly treated on 2 prospective institutional protocols assessing dose escalation.

Inclusion criteria consisted of patients with histologically proven NSCLC, stages IIIA-IIIB, curative intent treatment, and radiation prescription doses ≥ 50 Gy. Stage IIIB patients with contralateral N3 disease were excluded since nearly all portions of the mediastinum would be comprehensively treated with either 3DCRT or IMRT given contralateral nodal disease. Most patients received chemotherapy, generally with concurrent carboplatin/paclitaxel, carboplatin/docetaxel, or cisplatin/etoposide/nelfinavir (an institutional protocol).

Radiation Treatment Planning

All patients were treated with step-and-shoot IMRT, and plans were created using Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA). Each patient underwent CT-based planning. All fields were treated daily. Patients were simulated supine with arms raised on a wing board using a 4-dimensional CT (4D CT). The gross tumor volume (GTV), clinical tumor volume (CTV), and planning tumor volume (PTV) were defined according to International Commission on Radiation Unit and Measurements (ICRU) 50. Nodal GTV was defined as biopsy-proven nodal disease, radiographic enlargement of LNs > 1 cm on CT, or fludeoxyglucose F18 positron emission tomography (^{18}FDG-PET) positivity (SUV max ≥ 3.0).[20] CTV expansion was 0.8-1.0 cm for primary GTV lesions and 0.3 cm for nodal GTV. An ITV expansion was created for target motion during the breathing cycle. The PTV was generated with a 0.5-cm margin around the ITV. Lung, esophagus, heart and spinal cord were contoured as organs at risk (OAR). OAR dose constraints were as follows: maximum spinal cord dose 50 Gy; total lung (lungs minus PTV) V20 < 35%, lung V5 < 60%, and mean lung dose < 20 Gy; heart V40 < 50%; and esophagus V55 < 30%.

IMRT plans were generated with 4-5 fixed fields, arranged primarily anterior/posterior with obliques to minimize lung dose. Fluence-based optimization with beamlet-based inverse planning was utilized. Each patient had a comparative 3DCRT treatment plan generated using Eclipse software. The 3DCRT beam arrangements were similar to their respective IMRT plans with anterior/posterior and opposed oblique fields with objectives to maximize tumor coverage while limiting lung exposure. The 3DCRT plans were optimized to have comparable PTV coverage while meeting dose constraints for lung, heart, esophagus and spinal cord. Seven patients with medially located gross disease near the spinal cord were excluded from dosimetric analysis as the cord dose constraint was exceeded, which precluded optimal PTV coverage in 3DCRT plans. Our final cohort consisted of 23 patients for dosimetric analysis.

Data Analysis

For the dosimetric analysis, LN stations 1-2, 3A, 3P, 4, 5, 6, and 7 were contoured according to the University of Michigan CT-based atlas of thoracic node regions.[21] These nodal volumes were then truncated from the PTV to generate EN volumes. Dosimetric parameters were calculated for each EN station for both IMRT and 3DCRT plans (n = 46 plans). The mean dose (Gy) and V40, V50 and V60 (mean %) were calculated for each nodal station for plan comparisons. These volumetric dose levels were chosen as they are reflective of EN doses that may provide adequate microscopic disease control.[9,11,22] Clinical outcomes, including locoregional recurrence, distant failures and survival, were assessed at longitudinal follow-up after treatment completion. Locoregional recurrences were defined as occurring in the lung or regional lymph nodes.

Statistical Analysis

Wilcoxon Rank sum test and 2-sample t tests were used to compare lung mean, lung V5, lung V20, cord max, PTV coverage V95, heart V40, esophagus V55, as well as mean radiation dose and V40, V50 and V60 at each nodal station. Chi-squared analysis was used to compare patient demographics, tumor stage and tumor laterality. Differences were considered statistically significant at p value < 0.05. Statistical analysis of data was performed using STATA data analysis software (Version 11 for Windows, College Station, TX).

Results

Patient and Tumor Characteristics

Mean age for the cohort was 62.6 years (range 39-90, median age 62; see **Table 1 and Supplemental Table 1**). Regarding tumors, 13% were T1, 39% T2, 30% T3, and 17% T4; 9% of tumors were N0, 17% N1, 74% N2. All patients had stage IIIA disease. Median prescribed dose was 72 Gy (mean 68.3 Gy, range 50-80 Gy). Of note, this median dose reflects most patients being treated with institutional prospective dose escalation protocols.

3DCRT and IMRT Plan Comparisons

The generated 3DCRT and IMRT plans were compared to ensure that plans were similar in meeting overall dose constraints (**Table 2**). PTV V95 coverage was similar between 3DCRT (92.3%) and IMRT (92.4%) plans (p = 0.20). Mean lung dose and lung V20 were similar between 3DCRT and IMRT plans: 15.3 vs. 15.0 Gy, p = 0.95; and 24.7% vs. 25.8%, p = 0.52, respectively. IMRT plans delivered a higher lung V5 compared to 3DCRT (50.9% vs. 41.7%, p = 0.03). There were no significant differences in the cord max (47.0 vs. 44.3 Gy, p = 0.07), heart V40 (17.7% vs. 13.0%, p = 0.70), and esophagus V55 (24.7% vs. 25.5%, p = 0.85).

Elective Nodal Station Dosimetric Comparisons

The mean dose at each EN station ranged from 27.2 to 71.3 Gy for 3DCRT and 27.5 to 66 Gy for IMRT (**Table 3**). No significant differences in V40, V50 or V60 of most EN stations were found between 3DCRT and IMRT plans, except for contralateral station 6 (right-sided tumors) and ipsilateral station 5 nodes (left-sided tumors). For contralateral station 6, V50 and V60 were significantly less with IMRT than 3DCRT plans (V50: 39.3% vs. 66.6%, p = 0.015 and V60: 13.5% vs. 57.7%, p = 0.002). The mean dose of ipsilateral station 5 and contralateral station 6 nodes were also lower with IMRT vs. 3DCRT: 66 vs. 71.3 Gy, p = 0.038 and 43.4 vs, 54.9 Gy, p = 0.013, respectively (**Table 4, Figure 1**). Aside from these differences in levels 5 and 6 LNs, primary tumor laterality and level/location did not influence incidental irradiation dose to ENs.

Clinical Outcomes

At a median follow-up of 21 months from radiation completion, 8 patients (34.8%) were alive, of whom 5 patients (21.7%) had no evidence of disease. Six patients (26.1%) had locoregional-only recurrences, 5 patients (21.7%) had distant disease at progression, and 3 patients (13.0%) had both locoregional and distant disease. Of the patients with locoregional-only recurrences, only 1 patient (4%) failed in the regional LNs alone without intrathoracic disease progression. Unlike the other patients who were treated definitively, this patient had a stage IIIA (pT2N2M0) right upper lobe adenocarcinoma for which she underwent right upper lobectomy and lymph node dissection demonstrating nodal disease at levels 10R and 4R. Given the pN2 disease, she received adjuvant sequential chemotherapy followed by radiation (total dose 61.2 Gy due to positive margin). The patient subsequently failed in LN regions (supraclavicular, station 5) outside of the initially involved nodal stations. However, of note, the supraclavicular LNs would not have been routinely included in the EN volume for this patient with a stage IIIA right-sided primary tumor.

Table 1. Patient Demographics

		All patients
Age	Mean	62.6
	Median	62
	Range	39-90
Race	White	65.2%
	Black	34.8%
Sex	Female	30.4%
	Male	69.6%
T-stage	1	13.0%
	2	39.1%
	3	30.4%
	4	17.4%
N-stage	0	8.7%
	1	17.4%
	2	73.9%
Stage	IIIA	100%
Concurrent Chemotherapy	Yes	78.3%
	No	21.7%
Tumor Laterality	Right	56.5%
	Left	43.5%
Tumor Level	Upper	69.6%
	Middle	4.4%
	Lower	26.1%

Discussion

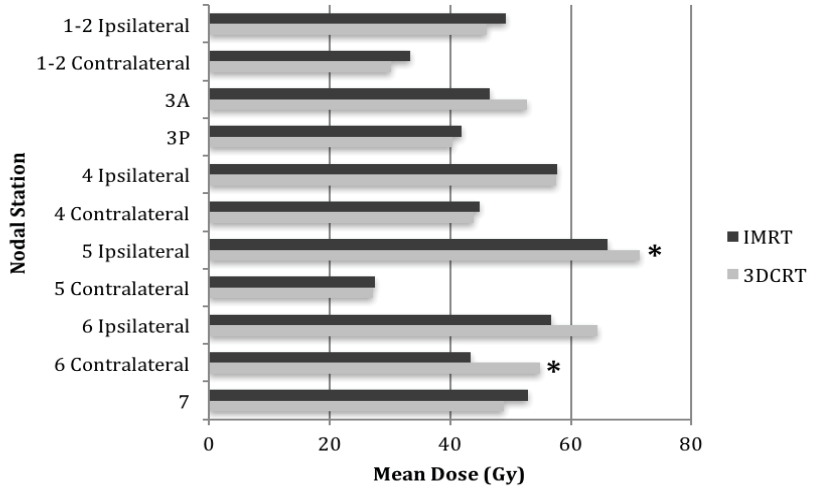
With the demonstration of low EN failure rates when treating locally advanced NSCLC with IFRT using 3DCRT,[7-10] many physicians have chosen to deliver IFRT to avoid the higher rates of esophagitis and radiation pneumonitis associated with ENI.[6,23] However, while IMRT use is increasingly adopted to treat NSCLC, it remains to be established whether IMRT confers the same or similar benefit of incidental irradiation as 3DCRT. Our dosimetric study demonstrates that IMRT can be safely delivered without significant concern for increased risk of nodal failures since EN irradiation does not appear to be compromised. However, caution should be exercised

Table 2. Plan Comparison

	3DCRT	IMRT	p value
PTV Coverage V95	92.26%	92.35%	0.20
Lung Mean	15.33 Gy	14.97 Gy	0.95
Lung V5	41.71%	50.94%	0.0326*
Lung V20	24.71%	25.76%	0.52
Cord Max	47.03 Gy	44.33 Gy	0.068
Heart V40	17.70%	13%	0.70
Esophagus V55	24.67%	25.45%	0.85

*denotes statistical significance ($p < 0.05$)

Table 3. Elective Nodal Station Mean Dose Comparison



*denotes statistical significance ($p < 0.05$); Legend: IMRT = intensity-modulated radiation therapy; 3DCRT = 3-dimensional conformal radiation therapy

when delivering IFRT with IMRT if there is high risk for subclinical disease in the level 5 and 6 nodal regions.[24]

We found that IMRT delivers similar incidental radiation doses as 3DCRT to EN stations 2, 3, 4 and 7. However, IMRT delivered less incidental doses to station 5 and 6 nodes vs. 3DCRT. These differences were particularly profound in the ≥ 50 Gy and ≥ 60 Gy dose regions, where IMRT delivered 41% and 77% less dose, respectively, to level 6 nodes, when compared to 3DCRT. Additionally, the mean dose to contralateral station 6 was more than 10 Gy less with IMRT than 3DCRT. At a median follow-up of 21 months, 6 (26%) of our patients had locoregional disease progression, with only 1 (4%) patient having isolated EN failure. While our study objective and focus are on dosimetric comparisons, our exploration of patterns of regional failure with IMRT in locally advanced NSCLC supports a low rate of EN failures.

The low rates of isolated EN failures when treating NSCLC with IFRT using 3DCRT have largely been attributed to incidental nodal irradiation. Rosenzweig and colleagues studied patients treated with 3DCRT without ENI and demonstrated an EN failure rate of only 6%, with some of those failures occurring in supraclavicular nodes that would not be electively targeted in modern ENI fields.[9] In a prospective study by Yuan et al, stage III NSCLC patients had an EN failure rate of 4% at 5 years in their ENI arm vs. 7% in the IFRT arm.[7] Kimura and colleagues attributed their EN failure rate of only 8% when treating IFRT with 3DCRT to a median incidental nodal dose ≥ 40 Gy in the majority of EN stations.[11] Finally, Kepka et al reported a strong dose-response relationship for EN control, with the majority of failures occurring in nodal regions receiving < 50 Gy.[22] Our study of IMRT, rather than 3DCRT patients, confirms similar findings, with comparable incidental radiation doses overall in the IMRT plans, and only a 4% rate of isolated regional nodal failure.

Given the low rates of nodal failure with IFRT, many physicians have adopted this technique to reduce treatment-related toxicities without compromising clinical efficacy. Our institution and others have demonstrated a lower rate of esophageal and pulmonary toxicity when treating with IFRT vs. ENI while retaining similar rates of EN control, primary tumor local control, and overall survival.[13,25] To further reduce treatment-associated morbidity, more conformal IFRT delivery with IMRT has been increasingly adopted nationwide.[15,17] Randomized data from prospective trials also support decreased toxicity when treating NSCLC with IMRT. In a secondary analysis of RTOG 0617, patients treated with IMRT vs. 3DCRT were found to have less decline in quality of life (21% vs 45%, $p = 0.003$).[18,26]

However, while the adoption of IMRT is increasing,[15,17] the established literature that assesses the impact of IFRT on mediastinal nodal failures has largely emerged during the pre-IMRT era. Fleckenstein et al conducted a dosimetric analysis of incidental nodal irradiation in stage II-III NSCLC patients and reported a lower total dose to adjacent EN stations with

Table 4. Dosimetric Comparison of 3DCRT vs. IMRT Dose at Elective Nodal Stations

Nodal Station		3DCRT mean	IMRT mean	p value
1-2 Ipsilateral	mean (Gy)	46.09	49.27	0.46
	V40 (%)	64.88	67.29	0.93
	V50 (%)	59.00	61.53	0.86
	V60 (%)	45.71	54.47	0.56
1-2 Contralateral	mean (Gy)	30.09	33.39	0.58
	V40 (%)	35.05	41.43	0.73
	V50 (%)	21.76	25.71	0.99
	V60 (%)	13.30	16.55	0.93
3A	mean (Gy)	52.69	46.49	0.16
	V40 (%)	70.77	67.36	0.73
	V50 (%)	60.68	49.77	0.17
	V60 (%)	50.52	35.55	0.06
3P	mean (Gy)	40.27	41.89	0.71
	V40 (%)	56.95	60.36	0.65
	V50 (%)	39.91	36.50	0.63
	V60 (%)	23.05	22.10	0.95
4 Ipsilateral	mean (Gy)	57.49	57.70	0.61
	V40 (%)	76.28	81.93	0.66
	V50 (%)	71.21	77.86	0.82
	V60 (%)	65.14	68.64	0.71
4 Contralateral	mean (Gy)	43.87	44.79	0.82
	V40 (%)	63.00	63.24	0.98
	V50 (%)	52.81	47.14	0.53
	V60 (%)	30.10	27.20	0.89
5 Ipsilateral	mean (Gy)	71.33	66.02	0.038*
	V40 (%)	100.00	98.11	0.32
	V50 (%)	96.44	92.56	0.94
	V60 (%)	87.67	98.50	0.61
5 Contralateral	mean (Gy)	27.17	27.54	0.95
	V40 (%)	31.85	26.92	0.49
	V50 (%)	19.84	11.54	0.47
	V60 (%)	11.15	0.92	0.17
6 Ipsilateral	mean (Gy)	64.39	56.75	0.12
	V40 (%)	90.10	90.30	0.79
	V50 (%)	82.20	63.90	0.28
	V60 (%)	69.67	61.50	0.36
6 Contralateral	mean (Gy)	54.86	43.42	0.013*
	V40 (%)	73.00	62.92	0.75
	V50 (%)	66.62	39.31	0.015*
	V60 (%)	57.69	13.46	0.002*
7	mean (Gy)	48.88	52.90	0.79
	V40 (%)	76.88	80.69	0.97
	V50 (%)	68.5	67.88	0.88
	V60 (%)	35.00	50.31	0.38

*denotes statistical significance ($p < 0.05$); Legend: IMRT = intensity-modulated radiation therapy; 3DCRT = 3-dimensional conformal radiation therapy

IMRT compared to 3DCRT plans (40 vs. 44 Gy, respectively).[27] However in this study, all nonelective LNs were grouped into 1 composite volume, and dose to each station was not compared separately. In our study, we further this dosimetric analysis by assessing a novel comparison of individual EN stations allowing us to better understand which stations are at highest risk for failure when treating with IMRT. Additionally, Martinussen and colleagues reported a low rate of isolated nodal failures (2.2%) in stage III NSCLC patients treated IMRT, though this study did not quantify the incidental radiation dose to EN stations.[28]

To our knowledge, this is the first study that assesses the patterns of nodal failure in locally advanced NSCLC treated with IMRT in the context of dosimetric differences to individual EN stations between 3DCRT vs. IMRT plans for each patient. Therefore, our dosimetric comparison of incidental nodal irradiation is particularly relevant in clinical considerations for the treatment of NSCLC patients with more conformal IMRT. Our study also highlights the importance of mediastinal lymph node staging to appropriately treat all gross nodal disease when ENI is omitted.

A few limitations of our analysis should be noted. First, the retrospective nature of the study leaves it susceptible to selection bias. However, the comparison between 3DCRT and IMRT plans on the same patient allowed all patients to serve as their own internal control. Second, our overall sample size was small due to our strict inclusion and exclusion criteria. However, these narrow criteria allowed us to examine a relatively homogenous cohort, allowing for fewer patients to be needed for a meaningful dosimetric comparison. Furthermore, we excluded stage IIIB patients with contralateral nodal disease because even fewer differences between incidental nodal irradiation would have

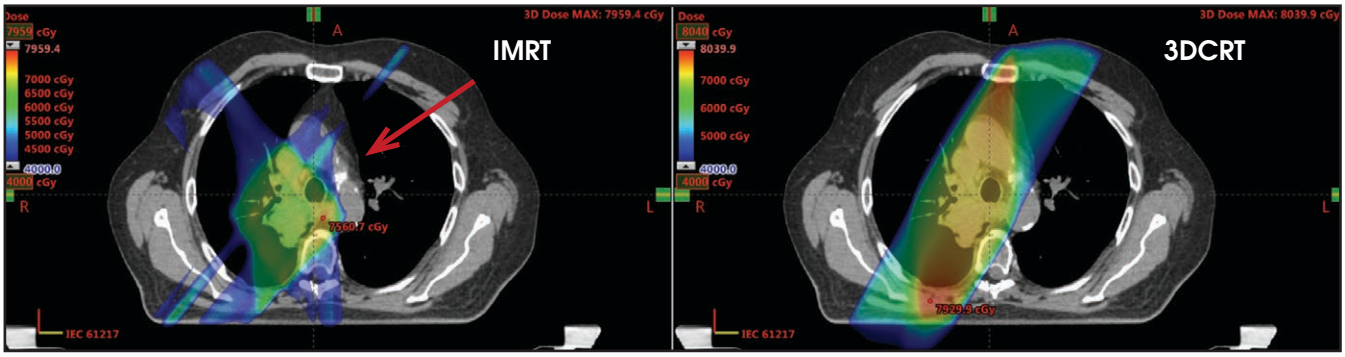


FIGURE 1. *Plan comparison of intensity-modulated radiation therapy (IMRT) vs. 3-dimensional conformal radiation therapy (3DCRT) treatment plans. Comparison of mediastinal lymph node coverage for an IMRT vs. 3DCRT plan on the same patient at the aorto-pulmonary window for the 40 Gy isodose level. Note decreased radiation dose at the aorto-pulmonary window nodal region indicated by red arrow in IMRT plan.*

been seen between IMRT and 3DCRT if these patients were included in this analysis. Given the small sample size, a detailed analysis on variables associated with differences in incidental dose was largely limited. Third, given the difference in techniques, the present analysis cannot be extrapolated to the use of volumetric modulated arc therapy (VMAT) or proton therapy, which is also increasingly being used in locally advanced NSCLC[29,30] but which is also surrounded by a theoretical risk of EN failures. Finally, our patients were treated prior to the publication of RTOG 0617[18] and predominantly on institutional dose escalation protocols resulting in potentially higher prescription doses than may be used today. However, escalated doses are still common today[31] with trials such as RTOG 1308 allowing prescription doses up to 70 Gy.[19]

In conclusion, our dosimetric analysis demonstrates that IFRT using IMRT offers comparable microscopic incidental irradiation doses as 3DCRT to EN regions. These data are encouraging for the continued use of IFRT with IMRT in NSCLC when clinically indicated, and support the promising advantage of IMRT in conformal dose escalation while limiting treatment-related toxicities. However, when treating patients with a high risk of subclinical disease in levels 5 and 6, such as patients with left upper lobe and left central tumors,[24,32,33] IMRT should be used cautiously given the reduced incidental dose to these stations seen in this study with IMRT compared to 3DCRT. While only 1 patient in our study had an isolated nodal failure, given our small sample size future studies should evaluate the clinical correlations of these dosimetric findings to assess EN control after treatment with involved field IMRT.

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Supplemental Table 1. In-depth Patient Characteristics

Patient	Sex	Race	Age	T Stage	N Stage	Stage	Tumor Location	Total Dose	Fractions	Concurrent Chemotherapy
1	Female	Black	47	3	2 I	IIA	Right Lower Lobe	6660	37	Yes
2	Female	Black	55	2	1 I	IIA	Right Middle Lobe	6660	37	Yes
3	Female	Black	44	2	2 I	IIA	Left Upper Lobe	6660	37	Yes
4	Male	Black	50	4	0 I	IIA	Right Upper Lobe	6660	37	Yes
5	Male	Black	49	2	2	IIIA	Right Upper Lobe	7200	40	Yes
6	Male	White	69	1	2	IIIA	Left Upper Lobe	7200	40	Yes
7	Female	White	52	3	2	IIIA	Right Upper Lobe	7200	40	Yes
8	Male	Black	51	4	0	IIIA	Right Upper Lobe	7200	40	Yes
9	Male	White	86	3	2	IIIA	Left Lower Lobe	7200	40	No
10	Male	White	54	3	2	IIIA	Left Upper Lobe	6660	37	Yes
11	Female	White	61	2	2	IIIA	Right Upper Lobe	6120	34	No
12	Male	Black	80	2	2	IIIA	Right Lower Lobe	8000	40	No
13	Male	White	72	2	2	IIIA	Left Lower Lobe	5040	28	No
14	Male	White	66	1	2	IIIA	Left Upper Lobe	7200	40	Yes
15	Female	White	68	2	2	IIIA	Left Upper Lobe	5000	25	No
16	Male	White	90	3	2	IIIA	Right Upper Lobe	7200	40	Yes
17	Male	White	39	2	2	IIIA	Right Upper Lobe	6660	37	Yes
18	Male	Black 6	9	4	1	IIIA	Left Upper Lobe	7200	40	Yes
19	Male	White	78	4	1	IIIA	Right Upper Lobe	6660	37	Yes
20	Male	White	58	3	2	IIIA	Right Upper Lobe	7200	40	Yes
21	Female	White	62	2	2	IIIA	Left Lower Lobe	7200	40	Yes
22	Male	White	67	1	2	IIIA	Right Upper Lobe	7200	40	Yes
23	Male	White	72	3	1	IIIA	Left Lower Lobe	7200	40	Yes

CB-CHOP: A simple acronym for evaluating a radiation treatment plan

Mary Dean, MD; Rachel Jimenez, MD; Eric Mellon, MD, PhD; Emma Fields, MD; Raphael Yechieli, MD; Raymond Mak, MD

Evaluating a radiation plan is an essential task for the radiation oncologist that is becoming more complex due to advances in radiation techniques. Multiple components are required to ascertain the quality and acceptability of a radiation therapy plan, which can be difficult to remember for the radiation oncologist in training. Herein is proposed a systematic approach for plan evaluation to ensure all aspects are properly assessed prior to approval. First proposed by Dr. Raymond Mak at Brigham and Women's Hospital/Dana-Farber Cancer Institute, the approach is described by the acronym CB-CHOP, which stands for contours, beams, coverage, heterogeneity, organs at risk, and prescription.

CB-CHOP Components

Contours

When a radiation plan has been generated for physician review, the radiation oncologist should first review the delineated target volumes and organs at risk (OAR) or normal structures. It is important to ensure that all appropriate OARs are accounted for and contoured accurately, especially when some OAR contouring is delegated to others. The reviewing radiation oncologist may find that a normal structure was forgotten and mistakenly not contoured, or that the isodose lines spill into an OAR initially thought not to be at risk and as such was not contoured. This step is also an opportunity to re-check the target volume contours and ensure that at-risk areas are delineated and provided dose in their entirety. Any expansions should be reviewed for accuracy. For example, a gross tumor volume (GTV) may have been modified without appropriate re-expansion of the corresponding clinical target volume (CTV) and planning target volume (PTV).

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Beam Arrangements/Fields

The next step is to evaluate the radiation therapy (RT) field arrangement and delivery technique, which ranges from simple single or opposed fields to complex volumetric-modulated arc therapy (VMAT) plans. The delivery technique is typically specified by the physician prior to planning, and in modern practice the beam arrangements are left to the discretion of the dosimetrist. One should therefore take note of the beam arrangements used by the dosimetrist to generate the plan.

For 3-dimensional (3D) plans, it is important to ensure that the fields are entering the body at angles that avoid entry through excess normal tissue. In addition, beam shaping with multileaf collimators (MLCs) or other devices should be appropriate for a given target and surrounding OARs. This can be evaluated by directly visualizing each field using the beam's eye view and is also based on 3D isodose lines overlaid on the computed tomography (CT) images. When treating an area in the neck or thorax, for example, one should ensure the beams are not entering through the shoulders/arms or exiting the oral cavity unnecessarily. For intensity-modulated radiation therapy (IMRT) plans, one should consider the number of fields and their point of entry through the body and

fluence patterns. Assessing the field arrangement and collimation may subsequently become important if target volume coverage or OAR dose limits are not optimal and may be improved with additional fields or different beam entry angles.

The number of fields or arcs is also a key factor in the treatment time. A patient undergoing a palliative radiation treatment may not be able to lie on the treatment table for long periods, and a faster treatment may be preferable. Radiation oncologists should also consider that patient mobilization and internal organ motion are increased with longer treatment times.

Coverage

Initially to ensure coverage, the plan should be evaluated qualitatively by review of structure and isodose contours on images. The prescription isodose line should cover its corresponding PTV, and inadequate coverage or excessive dose spillage outside the PTV should be identified and evaluated.

Coverage is then commonly quantified using a dose-volume histogram (DVH) plot where relative (percent) or absolute dose in Gray (Gy) is displayed on the x-axis, and relative or absolute volume in cubic centimeters is displayed on the y-axis. Often coverage is considered adequate when at least 95% of the PTV is treated to the prescription dose or higher, although variations are acceptable depending on the case.

The DVH must be used with caution. The DVH cannot assess the appropriateness of the targets and OARs. The DVH could report 100% coverage of the PTV by the prescription dose, but the PTV could be delineated incorrectly. Alternatively, 95% PTV coverage may not be met, but there may be a compromise between PTV coverage and OAR constraints, with an accepted sacrifice in PTV coverage to avoid unacceptable toxicity to a surrounding critical OAR. Furthermore, there may be excessive dose spillage through structures not reported within the DVH. Because this information cannot be obtained from the DVH alone, we recommend evaluating the 3D graphical plan qualitatively before proceeding to the DVH.

Heterogeneity/Hot Spots

Heterogeneity refers to the variability in dose distribution throughout the plan, and includes examining the minimum PTV dose (cold spot) and the maximum dose both within and outside of the PTV (hot spots). In a conventionally fractionated IMRT plan, the acceptable minimum dose in the PTV is often around 95% with the maximum around 115% of the prescription dose. The heterogeneity in conventionally fractionated 3D plans is typically larger than it is for IMRT plans, and thus greater variability is acceptable in 3D plans while care is taken to limit hot spots near critical OARs. When unsure about the suitable values of heterogeneity parameters, many radiation oncologists reference published or experimental cooperative group protocols that list such values for the particular disease site being treated.

After determining the quantitative values of the cold and hot spots, it is critical to review their locations within the treatment plan. A hot spot within the GTV may be acceptable as opposed to it being in a critical OAR. Similarly, a cold spot at the edges of the PTV is preferred to it being within the GTV or CTV.

Organs at Risk

The first step in evaluating the OARs is to review the objectives assigned to the planner and identify the priority of these constraints. Certain OARs have critical dose thresholds beyond which severe toxicity may occur, and these constraints are not to be violated. For example, a firm constraint for the optic pathway or spinal cord may be much more important to prevent blindness or paralysis than objectives for the parotid gland or oral cavity.

When evaluating OARs, one should review both the DVH as well as the 3D graphic plan. The DVH provides an initial starting point to ensure the maximum dose, the mean dose, and the volume constraints are met. Again, the DVH does not provide information regarding the spatial distribution of dose. As such, it is helpful to review the graphic plan to identify the location of the critical isodose levels for each OAR. One may want to review the location of the 45 or 50 Gy isodose line in relation to the spinal cord, for example. Additionally, by reviewing the location of several critical isodose lines on the graphic plan, a secondary check can be performed to ensure all OARs encompassed within those isodose lines have been contoured.

The graphic plan is also essential to review if an OAR constraint is not being met. It may be that the PTV is encompassing part of the OAR, and to treat the PTV adequately, part of the OAR must be sacrificed. In this situation, the priority of the OAR should again be considered. For example, the PTV may need to be cropped to spare the spinal cord, whereas it may be necessary to treat a portion of the mandible to ensure the tumor volume is covered.

To find values for OAR dose constraints, the most commonly used source for late effects in conventional fractionation is the Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC) data.[1] For hypofractionated regimens, the American Association of Physicists in Medicine (AAPM) TG-101 is also a valuable reference.[2] Recent phase III protocols will also often specify planning objectives and acceptable variations with various levels of evidence supporting their use.

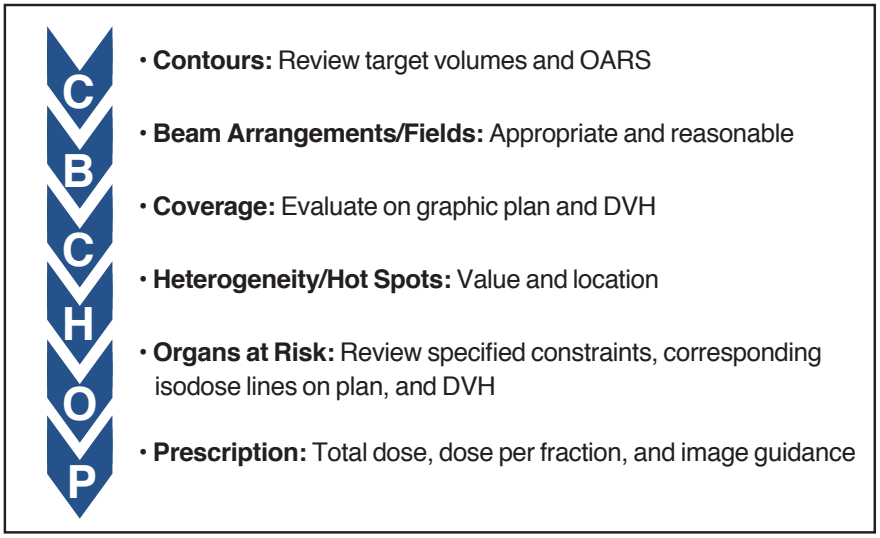

FIGURE 1. *Flowchart diagram summarizing the CB-CHOP acronym and components of plan quality.*

Because constraints vary based on the dose per fraction, it is important to ensure appropriate values are used with biologically effective dose (BED) conversion when appropriate.

Prescription

The last step is to finalize and confirm the prescription. The dosimetrist may have edited the prescription after generating the plan, and one must ensure the total dose and dose per fraction are correctly entered. The treatment details must also be specified, including the type of radiation, energy, delivery method (3D, IMRT, enface, etc.), and delivery schedule (weekdays, every other day, twice daily, etc.).

The image guidance or setup verification imaging should be specified in the prescription. Image guidance requirements and techniques are at times specified by clinical protocols or are selected by the treating physician based on the size of the setup margin. In general, daily image guidance using cone-beam CT (CBCT) may be preferred when treating with smaller PTV margins at 3-5 mm. When treating with a larger margin in more difficult-to-immobilize areas, such as a palliative 3D bone metastasis plan with a 1 cm PTV margin, only portal imaging at the time of setup may be sufficient. In such cases, one must ensure that the PTV margins are appropriate for the image guidance technique, with smaller margins necessitating more frequent and accurate image guidance.

Conclusion

CB-CHOP is an effective acronym that provides a systematic, step-wise approach to analyzing multiple components of treatment plan quality (**Figure 1**). An in-training radiation oncologist can use CB-CHOP as a foundation on which additional skills and thought processes can be built with further experience. Since plan approval is the critical step that transitions from cognitive processes to direct intervention with radiation therapy, CB-CHOP can provide a framework for a pre-intervention safety checklist, which has been shown to reduce errors and improve quality of care in other interventional disciplines.[3] Treatment plan evaluation and approval remain the key responsibility of the physician and, thus, developing a consistent approach is a vital part of training. While current research is investigating objective, mathematical approaches to treatment plan evaluation, to our knowledge these techniques have not yet been implemented into daily clinical practice.[4]

A common pitfall in training or practice is relying on plans generated by a trusted, well-respected dosimetrist who has significant experience. However, mistakes happen, and dosimetrists change with time and institution. Since the final responsibility for a plan's suitability lies with the radiation oncologist, it is important to remain thorough and objective with a standardized method to properly develop and implement plan evaluation skills.

Another key point is that it is common to request a plan revision to improve target coverage or OAR objective doses. While revisions may be requested repeatedly until an appropriate plan is generated, a threshold has been described beyond which further improvements in the plan are minimal and, in fact, may be detrimental due to the delay in initiating treatment.[5] To proceed expeditiously, we suggest making all foreseeable requested changes at the first review. Use of the CB-CHOP framework may help serve as a checklist to ensure all potential areas of improvement are evaluated.

In summary, CB-CHOP is a memorable, simple approach that can be utilized to ensure key aspects of a radiation treatment plan are properly reviewed prior to plan approval and initiation of radiation treatment.

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Enhancing the patient experience

Mary Beth Massat

It's no secret that patient satisfaction improves reimbursement. Just as happy patients keep business coming, the opposite is true: Dissatisfied patients can choose new providers, with their complaints traversing social media and online rating platforms like a fast-spreading virus.

Patient dissatisfaction means tangible reimbursement suffers, too. Consider the Patient Protection and Affordable Care Act of 2010, which includes the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey. Developed by the Centers for Medicare & Medicaid Services (CMS) and the Agency for Healthcare Research and Quality (AHRQ), these survey results are factored into value-based incentive payments in the Hospital Value-Based Purchasing program.[1] Low scores mean lower payments.

Of course, providing good care for the sake of helping others is at the crux of patient satisfaction. In general, boosting patient satisfaction isn't tied to systems and technical or other solutions as much as communicating and interacting with patients—although that may be changing.

Waiting, Decision-making

In his blog, David Craig, MD, medical director at Spruce Health, San Francisco, shares several methods that practices can follow to increase patient satisfaction.[2] Among them is lowering perceived wait time. He suggests: Give patients valuable things to do when waiting; move them through the preprocess or check-in sooner; identify anxious patients and provide reassurance, if possible, while they are waiting; give guidance on expected wait times and explain any discrepancies in wait times; and encourage patients to bring a friend or family to their appointment. Spending time with patients, sitting down to carefully listen to their concerns and explaining their care, and being a good communicator are other methods that clinicians, therapists, and nurses can follow to enhance patient satisfaction.[2]

Shared decision-making can also improve patient satisfaction in radiation therapy. A study of 305 patients undergoing treatment at Abramson Comprehensive Cancer Center of the University of Pennsylvania, found a correlation between patient satisfaction and patient-perceived shared decision-making.[3] Those who experienced shared decision-making or perceived control of treatments were more satisfied with their care than those who did not—a difference of almost 17 percent and 26 percent, respectively. The authors reported a significant association between patient satisfaction with radiation therapy and patient-perceived shared decision-making (84.4% vs. 71.4%) or perceived control over the course of treatment (89.7% vs. 69.2%).

"Most importantly, our findings emphasize the value of patient-physician relationships and communication specifically in radiation oncology, something that hasn't been shown before," said lead author Neha Vapiwala, MD, in a prepared statement.[4] Dr. Vapiwala is an associate professor in the department of radiation oncology at Penn Medicine.

In another study that examined communication skills training for radiation therapists, the authors found that additional training improved the therapist's communication skills with patients. The authors note that additional research in this area is needed. However, the authors propose that "communication skills training, focusing on both preparing patients for radiation therapy and eliciting and responding to emotional cues, may be beneficial to all radiation therapists, reduce patient anxiety and potentially reduce costs to the health care system."[5]

Value of Video in Pediatric Treatment

While enhancing communication is important for adult oncology patients, TV may be more useful for comforting pediatric cancer patients. A study presented at the European Society for Radiotherapy & Oncology 36th Annual Meeting reported that projecting a video directly on the inside of a radiation therapy machine during treatment reduced the need for general anesthesia. The study included 12 children between ages 1-and-a-half years and 6 years. Six were treated before a video projector was installed, and in 83% of the treatments, the patient required general anesthesia. Of the 6 treated after video installation, general anesthesia was used in 33% of treatments. According to co-author Catia Aguas, a radiation therapist and dosimetrist at the Cliniques Universitaires Saint Luc, Brussels, Belgium, video has almost completely replaced anesthesia in her clinic, reducing treatment times and stress for patients and families.

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FIGURE 1. *Decorative ceiling tiles can provide a soothing setting that helps lower anxiety and improve the patient experience. Credit: Ceiling Scenes, Warren, Michigan.*

Environmental Impact

Comforting environments lower stress as well, with physical surroundings strongly influencing a sense of well-being, as described in a paper by Jarvis about the patient experience in radiation therapy.[7] As a result, some providers seek to incorporate the patient's viewpoint into design ideas from the get-go. Visual tweaks can include additional windows, skylights, decorative ceiling tiles (see **Figure 1**), new interior finishes, as well as removing the "visual chaos" created by medical clutter, coffee makers, waste containers, personal displays, etc.[7]

"Good design is the careful orchestration of uplifting and encouraging experiences for patients throughout their entire visit," writes Jarvis. "For providers who achieve this, architecture becomes evidence that they put their patients first."[7]

A Patient-centered Linac

Additionally, more medical equipment manufacturers are embracing a patient-centric approach—in both medical imaging and radiation therapy—to further bolster satisfaction.

In May 2017, Varian Medical Systems, Palo Alto, California, launched its Halycon system, featuring a patient-centered, user-friendly design intended to automate, streamline and simplify a patient's treatment. "We started with the patient and designed the system outwards from there," Mu Young Lee, director of New Product Solutions says. "We asked, 'What technologies could optimize, enhance and personalize the patient experience?'"

Because linacs may appear imposing, Varian selected a form similar to a CT scanner, a familiar design for the patient. In addition to a "familiar form factor," Halycon also addresses patient comfort, noise and lighting. Its 100-cm gantry opening is larger than a standard CT system. The enclosed gantry is capable of rotations 4 times faster than a C-arm gantry, accelerating treatment delivery.

Halycon is also twice as quiet as similar systems thanks to the use of linear motors rather than geared motors that create noise due to their moving parts. The system includes an integrated couch-mounted camera for the therapist to view the patient during treatment, and an integrated sound system so patients and therapists can easily talk. Patients can also have music from their mobile device piped in through the intercom. Ambient lighting was added to the back of the system to help illuminate the room for patient comfort and to assist the therapist with a view of the patient during treatment.

The Abramson Comprehensive Cancer Center of the University of Pennsylvania was the first to install Halycon, and assisted Varian with clinical research during product development. James M. Metz, MD, PhD, chair of radiation oncology at the Perelman School of Medicine, the Henry K. Pancoast Professor of Radiation Oncology, and associate director for Clinical Services and Programs at the Abramson Comprehensive Cancer Center of the University of Pennsylvania, led the team that evaluated Halycon for Varian.

"In general, we are seeing a 50% reduction in beam time for most patients," he says. As an example, a typical head and neck cancer treatment went from 25 minutes on a conventional linac to 13 minutes on Halycon. In fact, Dr. Metz recalls the first case scheduled on Halycon—a head and neck cancer patient. "After 13 minutes of treatment, the therapist went to get the patient off the table and he said, 'That's it?' We had the perception that treatment time could be shorter, but to hear it from our patient validates it," he says. "And that's really our goal—to make this the best possible patient experience."

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RADIATION ONCOLOGY CASE

Management of internal mammary nodal recurrence after palliative mastectomy and postoperative radiation therapy in triple negative breast cancer

Stephanie Rice, MD; Paula Rosenblatt, MD; Steven Feigenberg, MD

CASE SUMMARY

A 61-year-old woman with a medical history of morbid obesity, hypertension, diabetes mellitus, and left ventricular hypertrophy presented with a palpable left upper outer quadrant triple negative (estrogen receptor-negative, progesterone receptor-negative, Her2/neu-negative, Ki-67 60%) infiltrating ductal carcinoma with measurable metastatic disease to the adrenal gland, L5 vertebral body, and sacrum. She began eribulin and denosumab for 2 cycles, which was complicated by hypertensive urgency, pulmonary edema, febrile neutropenia and renal insufficiency requiring hemodialysis.

She underwent a palliative left modified radical mastectomy (ypT-4bN1a triple negative IDC with 3/20 lymph nodes positive with extracapsular extension) followed by postoperative radiation to a total dose of 50 Gy in 25 fractions. The radiation was delivered with a 12 MeV electron beam to her medial chest wall and 6 MV and 18 MV photon beams to the remainder of her chest wall, supraclavicular fossa, and axilla (**Figure 1**). Internal mammary nodal irradiation (IMNI) was not performed due to her heart disease and palliative intent limiting the mean heart dose to 197 cGy.

Dr. Rice *is a medical resident in radiation oncology, Dr. Rosenblatt is a medical oncologist, and Dr. Feigenberg, at the time of submission, was a radiation oncologist at the University of Maryland Medical Center, Baltimore, MD.*
Disclosure: The authors have no conflicts of interest to report.

Our patient suffered an isolated internal mammary nodal (IMN) failure and was salvaged with irradiation to 55 Gy in 11 fractions using a 3-mm expansion from gross tumor volume (GTV) to planning target volume (PTV) with daily KV and cone-beam computed tomography (CBCT) for image guidance. She had no evidence of disease recurrence on her most recent imaging at 3 months post-treatment positron emission tomography/CT (PET/CT) and 6-month chest CT with contrast.

IMAGING FINDINGS

Initial PET/CT demonstrated increased fluorodeoxyglucose (18F) (FDG) uptake in the left breast mass, multiple left axillary lymph nodes, adrenal gland, L5 vertebral body lesion, and sacrum. Repeat PET/CT 6 months after failed chemotherapy showed an interval increase in the size of her left breast mass (8.5 × 7.2 cm) and axillary lymphadenopathy. The adrenal and bony FDG avidity had resolved. CT of the chest, abdomen and pelvis 6 months post-radiation showed an isolated recurrence in the untreated IMN (**Figure 2**). Restaging scans 3 months after treatment showed stable disease with no FDG avidity on her PET/CT scan, and a CT chest scan 6 months later was stable.

DIAGNOSIS

IMN recurrence

DISCUSSION AND LITERATURE REVIEW

The IMN chain is a regional nodal drainage basin in the parasternal region. These nodes represent a site of metastasis in breast cancer with twice the risk of recurrence or death at 10 years in patients with a node-negative axilla and positive IMN nodes.[1] IMN metastases are associated with a significant decrease in 20-year disease-free survival,[2] with incidence ranging from 15% to 42% in older series.[3-6]

Historically, the IMNs were removed as part of the extended radical mastectomy in the hopes that more extensive surgery would be superior to the Halsted procedure, also known as a radical mastectomy. The radical mastectomy consists of removal of the entire breast, supporting pectoral

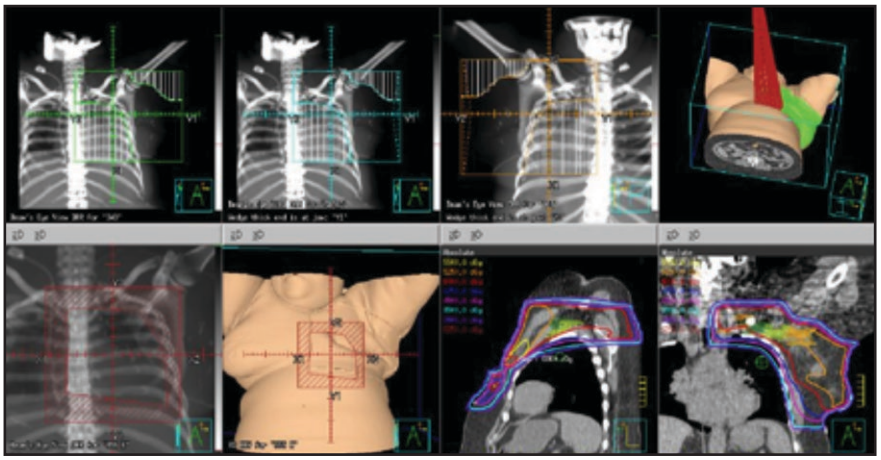

FIGURE 1. *Representative images of chest wall, supraclavicular and axillary nodal irradiation using 6-18 MV photons for coverage of the lateral chest wall, supraclavicular and axillary nodal basins; 12 MeV electrons were used to cover the medial chest wall while purposely limiting coverage to the IMNs to spare cardiac toxicity.*

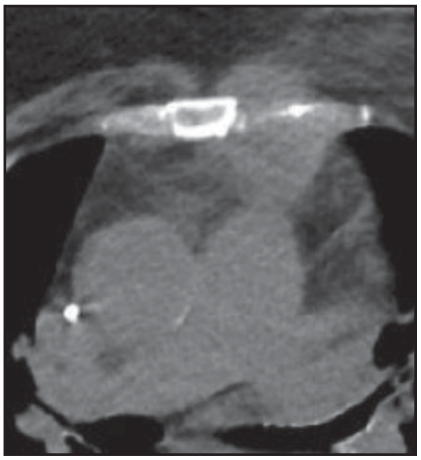

FIGURE 2. *Axial computed tomography (CT) chest image without contrast showing a soft-tissue abnormality in the left parasternal region consistent with an internal mammary lymph node metastasis.*

muscles, and the axillary lymph nodes, while the extended radical mastectomy consists of the aforementioned procedure plus removal of the internal mammary lymph nodes. Lacour et al performed a randomized controlled trial of 1580 patients comparing extended Halsted mastectomy vs. Halsted mastectomy between 1963 and 1968 showing 5-year overall survival (OS) of 72% vs. 69%, respectively (not significant [NS]). Five of 697 (0.7%) patients in the Halsted mastectomy arm had an IMN recurrence. In the node-positive patients with inner or medial quadrant tumors, 5-year survival of 71% and 52% for the extended Halsted mastectomy and Halsted mastectomy was observed, respectively.[7] Ten-year follow-up showed significantly more local recurrences in the undissected IMN group, but no difference in OS or relapse-free survival.[8] Thirty-year follow-up from a similar study by Veronesi et al[9] showed no survival benefit with removal of the IMNs. With no survival benefit, and increased morbidity including pneumothorax due to the intrapleural dissection required, the practice of extended radical mastectomy was largely abandoned.

A reason for under-recognition of this entity lies in the reliance on imaging to report IMN recurrence. Commonly, these abnormalities are referred to as "bone metastases to the sternum," "soft-tissue abnormalities," "parasternal masses," or other vague descriptors that do not identify the IMN basin. Physical examination of the IMN is challenging given the deep location and discomfort associated with deep palpation on the sternochondral junction. Review of physical examination textbooks shows a paucity of data demonstrating a proper technique for examining the IMNs.[10,11]

More recently, randomized data of IMNI has added to a growing body of literature upon which we base treatment decisions. A French randomized controlled trial published in 2013 failed to show a benefit to postmastectomy IMNI in stage I or II adenocarcinoma of the breast and either positive axillary nodes or a medial/central tumor,[12] axillary lymph node status, and adjuvant therapy (chemotherapy vs. no chemotherapy although many believe the study endpoint of a 10% improvement in overall survival to be unrealistic. The MA.20 and European Organisation for the Research and Treatment of Cancer (EORTC) studies published in July 2015 in *The New England Journal of Medicine* evaluated the efficacy of IMNI and medial supraclavicular nodal irradiation in early stage breast cancer.[13,14] MA.20 showed improved 10-year disease-free survival (DFS) (82% vs. 77%, p = 0.01) but no 10-year OS benefit.[13] Subset analysis showed that patients with estrogen and progesterone receptor-negative tumors benefited more from IMNI. The EORTC study, with slightly different entry criteria (stage I, II or III with central or medial primary irrespective of axillary involvement) showed a trend toward 10-year OS benefit for IMNI (82.3% vs. 80.7%, p = 0.06), and statistically significant improvements in 10-year DFS and DDFS as well as breast cancer mortality.[14] Thorsen et al stratified women with right-sided early stage node-positive breast cancer to receive radiation to the chest wall, supraclavicular, axillary and IMNI and those with left-sided disease to receive radiation to the chest wall, axilla, and supraclavicular radiation without IMNI.[15] Eight-year OS was 75.9% vs. 72.2% for IMNI and no IMNI, respectively (p = 0.005). Breast cancer mortality was significantly improved in the IMNI group. This data, taken by itself, would lend

to advocating for IMNI in this triple negative breast cancer case. However, given our patient's morbid obesity, left ventricular hypertrophy (LVH), poor pulmonary function, and multiple risk factors for coronary artery disease (CAD), the risk of radiation dose to the heart and coronary vessels warranted serious consideration. In the palliative setting, it is reasonable not to treat the IMNs based on the data from Darby et al,[16] which shows an increased rate of major coronary events at a rate of 7.4% per gray without an apparent threshold.

While the above-noted trials mainly evaluated disease-free survival and OS as primary endpoints, in the palliative setting it may be more appropriate to consider locoregional recurrence, which could lead to pain, as noted in our patient. The Early Breast Cancer Trialists' Collaborative Group (EBCTCG) meta-analysis evaluated 22 postmastectomy trials.[17] Of the 8134 patients, 1314 had 1-3 positive lymph nodes at the time of axillary dissection, similar to our patient. The addition of radiation in this scenario decreased locoregional recurrence from 20.3% to 3.8%, and risk of any first recurrence from 45.7% to 34.2%. These decreases in local recurrence may prevent painful locoregional recurrence in our patient's case.

Our case required careful consideration regarding the risks and benefits associated with IMNI. Unfortunately, our patient suffered a painful recurrence in the IMNs just 6 months after completing palliative mastectomy and postmastectomy radiation therapy. While her initial cardiac dose was very low at a mean dose of 197 cGy, re-irradiation was challenging as we had to balance the increased risk of CAD with the local control that re-irradiation to the overlying soft tissues offered. Her symptomatic recurrence and inability to receive further systemic therapy made re-irradiation for local control and palliation of her symptoms necessary.

To respect normal tissue tolerance, we used a hypofractionated course of 55 Gy in 11 fractions with a BED_{10} of approximately 70 Gy with daily KV and CBCT to minimize PTV margin (3 mm) and field overlap. She tolerated this treatment exceptionally well with only grade 1 fatigue and radiation dermatitis, according to Common Terminology Criteria for Adverse Events (CTCAE) version 4.0. A restaging PET/CT scan 3 months after completion of re-irradiation demonstrated no avidity in her known IMN recurrence, although longer follow-up will be necessary to evaluate the durability of treatment and long-term morbidity from treatment.

CONCLUSION

This case highlights the complexity of decision-making regarding IMNI even in the setting of recently published data that is more favorable toward IMNI than more historical data. We have demonstrated that failures in the IMNs occur and, in this case, happened rapidly after initial postmastectomy radiation. However, while challenging, treatment of recurrence is possible. Further data on IMNI outcomes and methods to minimize cardiac toxicity in the setting of longer life expectancy and the utilization of cardiotoxic chemotherapy are needed to help guide nodal radiation treatment decisions in the future.

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A case of spermatic cord leiomyosarcoma: Clinical presentation, treatment and literature review

Hassan Beydoun, MD; Benjamin Weinberg, MD; Newton Hurst, MD; PhD, Nabiha Khoury, MD; Shabbir Ahmed, MD; Thomas Kasza, MS; Michael L. Cher, MD; Keqin Tang, MD, PhD, MS

CASE SUMMARY

A 63-year-old man presented to the Emergency Department complaining of a 2-month history of a growing lump in his left inguinal area, initially painless but later uncomfortable. Physical examination revealed a firm, nontender mass. A computed tomography (CT) scan of the abdomen and pelvis (**Figure 1**) showed a large left inguinal hernia containing stool and fluid-filled bowel without evidence of bowel obstruction. Surgery was indicated, during which the left inguinal lump was determined to be related to a mass. A biopsy of the mass showed high-grade sarcoma. He was referred to urology and underwent radical orchiectomy (note that due to his comorbidities there was a 6-week interval between diagnostic CT and surgical resection, thus accounting for the discrepancy in size between imaging and pathologic specimen). Pathology demonstrated high-grade leiomyosarcoma **(Figure 2),** measuring 11 cm in greatest dimension. A focal close margin was < 0.1 mm from the parasper-

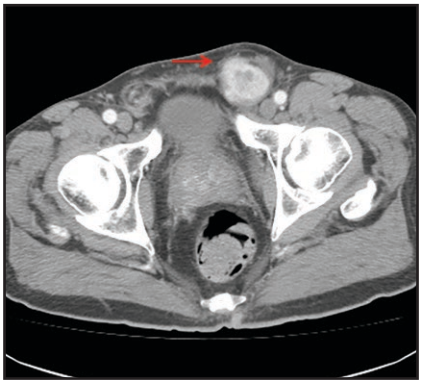

FIGURE 1. *Axial CT slices showing a rounded heterogeneously enhancing mass in the left inguinal canal.*

matic cord soft-tissue resection. There was no lymphovascular invasion. Due to the high-risk features (high grade and close margin), he was offered adjuvant radiation therapy and received 46 Gy at 2 Gy per fraction to the clinical target volume (CTV) including the tumor bed, left scrotal sac, left inguinal canal/nodes, left external and internal iliac lymph nodes, para-aortic lymph nodes, and left renal hilum

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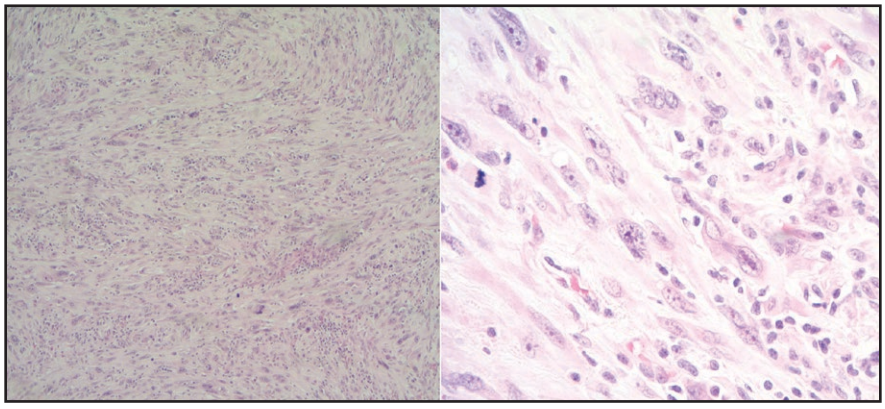

FIGURE 2. *Haemotoxylin and eosin (H&E) staining: The tumor appears as spindle cell morphology and many mitosis with positive immunostains for actin, desmin and caldesmon; all are compatible with smooth muscle differentiation.*

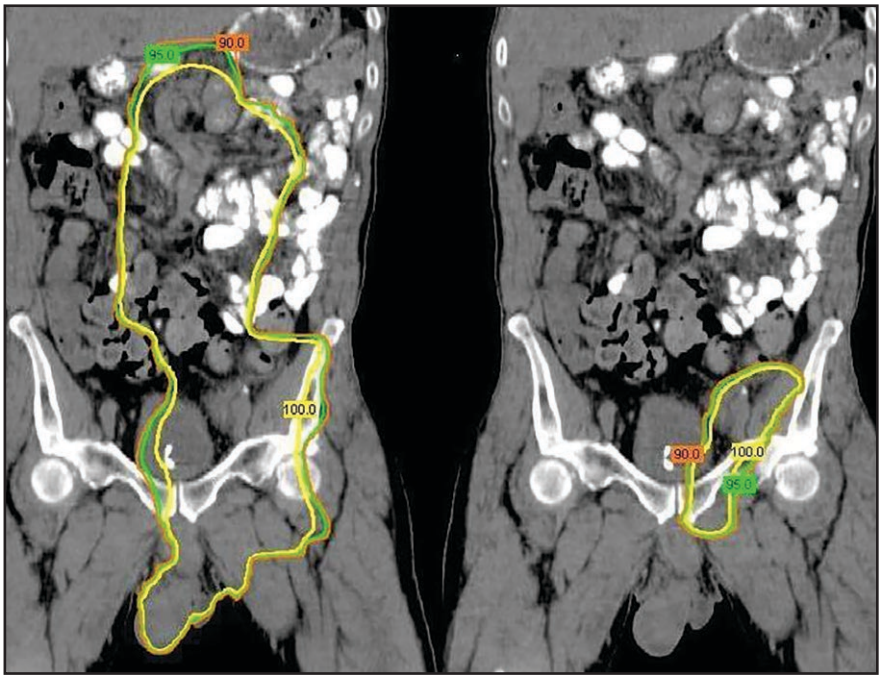

FIGURE 3*. Coronal views showing the isodose lines corresponding to the treatment fields: Left is the large field treated to 46 Gy, right is the boost field treated to a total dose of 60 Gy.*

(**Figure 3**). He then received a boost to the tumor bed with an additional 14 Gy at 2 Gy per fraction to a total dose of 60 Gy.

Since this is a postsurgical case, a preoperative diagnostic CT scan was fused with the treatment simulation CT scan to generate a CTV for the tumor bed and surrounding scar tissue. Next, using Radiation Therapy Oncology Group (RTOG) Atlas guidelines, the CTV for regional lymph nodes was generated. Finally, CTVs for the surgical scar/drainage site, L-scrotal sac, para-aortic nodes and L-renal hilum were generated. These CTV volumes were added together to create the CTV 46. The planning target volume (PTV) 46 is a 1.0-cm expansion of the CTV 46. A 1.0-cm bolus was used over a superficial portion of the PTV 46, which included the tumor bed and surgical scar/drainage site. The CTV 60 consists of the tumor bed and surrounding scar tissue portion of CTV 46. The PTV 60 is a 1.0-cm expansion of the CTV 60. The PTV 60 is also superficial, and a 1.0-cm bolus is used overall.

Three-dimensional conformal radiation therapy (3D-CRT) with 2 opposed fields (AP-PA) for the initial field and 3 fields (AP/RAO/LAO) for the boost field was delivered by a TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, California). The physicist was consulted for an extended source-surface distance (SSD) setup for projected length of large field. During his treatment course, he developed G3 skin toxicity (RTOG score[1]) with patchy moist desquamation along his scrotum after 38 Gy and had a 2-day break. He was also noted to have low blood counts toward the middle of the treatment; his counts had recovered toward the end of the course of the large-field RT and stabilized through his boost course. He was offered adjuvant chemotherapy due to high-grade disease, but declined. On a recent follow-up of 3 years, the patient has no evidence of long-term toxicities related to the treatment. His scans show no evidence of disease recurrence.

IMAGING FINDINGS

A CT scan demonstrated a heterogeneously enhancing 3.9-x-3.8-cm mass in the left inguinal canal (**Figure 1**). There was no additional evidence of regional or systemic disease.

DIAGNOSIS

Final pathology from the radical orchiectomy demonstrated high-grade inflammatory leiomyosarcoma from the spermatic cord measuring 11 cm in greatest dimension with only focal margin < 0.1 mm from the paraspermatic cord soft-tissue resection and

Table 1. Local Recurrence of Spermatic Cord Sarcomas Treated with Surgery Alone vs. Surgery and Radiation Therapy

Study	Methods	No. of patients	Treatments	Outcomes
Ballo et al[9]	Retrospective	32	Surgery vs. Surgery + RT	10-year LR 30% surgery vs. 0% surgery + RT
Fagundes et al[10]	Retrospective	18	Surgery vs. Surgery + RT	5-year LR 37% surgery vs. 0% surgery + RT
Hazariwala et al[11]	Retrospective	15	Surgery + RT	5-year LR 0%

Key: RT = radiation therapy, LR = local recurrence.

no angiolymphatic involvement. Vas deferens, left testicle with cysts of epididymal appendages, and hydrocele were negative for malignancy.

DISCUSSION

Soft-tissue sarcomas of the genitourinary tract are extremely rare malignancies. They account for 2% to 3% of all soft-tissue sarcomas and about 2% of genitourinary tract malignancies with paratesticular tumors being the most common.[2] The most common reported malignant histological types include liposarcomas, leiomyosarcomas, rhabdomyosarcomas, malignant fibrous histiocytoma, and fibrosarcomas.[3,4] They arise from mesenchymal cells of the spermatic cord (vas deferens or cremaster muscle), scrotum (dartos layer) or the epididymis.

A typical presentation of a spermatic cord leiomyosarcoma is a growing testicular mass, firm and painless. The peak incidence is in the sixth to seventh decade. They are often mistaken for an incarcerated hernia. They most commonly arise from the spermatic cord and spread with direct extension through the inguinal canal and into the abdominal cavity; hematogenous or nodal spread is rare.[5,6] Diagnostic tests include sonography (US), CT, or MR.[5] US is the test of choice to rule out acute pathology such as incarcerated hernia or testicular torsion. CT or MRI provide additional information as it relates to the size and extent of the mass, as well as presence of pelvic or retroperitoneal lymphadenopathy.

The primary treatment is surgical resection with radical orchiectomy and high ligation of the spermatic cord. Prophylactic retroperitoneal lymphadenectomy is not necessary unless there is evidence of nodal involvement or for sarcomatous histologies with a propensity for nodal metastasis, such as rhabdomyosarcoma.[7] However, nodal involvement appears to be more common in paratesticular sarcoma than in other soft-tissue sarcomas with reports of nodal failure rates varying 14% to 28%.[1] Due to this high incidence of nodal recurrence and primary location in the left side, we included the regional nodes extensively: left external and internal iliac lymph nodes, left inguinal lymph nodes, para-aortic lymph nodes, and nodes in left renal hilum area, which led to the long large field with more bone marrow in the field, which then likely caused cytopenias. Postoperatively, there are no well-established data on adjuvant therapy. In a review by Blitzer et al,[7] 71% of patients experienced local recurrence suggesting surgical excision alone is not sufficient and adjuvant therapy may be warranted.

The role of adjuvant radiation therapy for spermatic cord sarcomas is not well defined. A review by Catton et al,[8] reported 14% local recurrence for patients treated with radical orchiectomy alone vs. none in patients treated with surgery and adjuvant radiation. In another review by Ballo et al,[9] 8 out of 12 patients developed local recurrence as the only site of relapse, and no relapses were seen in the 3 patients who underwent adjuvant radiation therapy. In another review by Fagundes et al,[10] local failures of patients treated with surgery alone were 37% compared to none for patients treated with surgery and radiation. In another series by Hazariwala et al,[11] 15 patients with intermediate- to high-grade spermatic cord sarcomas were treated with surgery and radiation. With a median follow-up of 7 years, none had local recurrence, 2 patients developed nodal failure, and 1 patient developed distant metastasis. In summary, this data from retrospective studies comprised of relatively few subjects demonstrated that local recurrence rates significantly decreased with adjuvant radiation therapy from 37%-30% down to 0 (**Table 1**). Without more rigorous randomized trial data (although unlikely to be established given the rarity of this malignancy), the role of adjuvant radiation therapy will likely remain uncertain; however, due to high risk of local failure, radiation therapy should be recommended for high-grade tumors, or close or positive margins.

The role of adjuvant chemotherapy for soft-tissue sarcomas is controversial, and more so for spermatic cord

sarcoma, due to scarcity of data. Pervaiz et al[12] in a meta-analysis of 18 randomized controlled trials of adjuvant chemotherapy for soft-tissue sarcoma including 1953 patients, showed Doxorubicin and Ifosfamide did not improve local recurrence (OR 0.66, CI 0.39 to 1.12); but it improved distant recurrence (OR 0.61, CI 0.41 to 0.92), and improved overall survival (OR 0.56, CI 0.36 to 0.85). This suggests a potential benefit for systemic chemotherapy to decrease the rate of distant metastasis and potentially improve survival.

CONCLUSION

Spermatic cord sarcomas are rare malignancies with limited data on optimal management. Surgical resection with radical orchiectomy and high ligation of the spermatic cord is the primary treatment. Adjuvant radiation should be recommended for higher grade tumors or close/positive margins to improve local control. Systemic chemotherapy may be beneficial to decrease the rate of distant metastasis and improve potential survival. Additional studies are required to better understand spermatic cord sarcomas and to develop optimal treatment modalities.

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