Practical Radiation Oncology (2019) 9, 65-72

practical radiation oncology
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Special Article

Standardizing Normal Tissue Contouring for Radiation Therapy Treatment Planning: An ASTRO Consensus Paper

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Received 4 September 2018; revised 29 November 2018; accepted 8 December 2018

Abstract

Purpose: The comprehensive identification and delineation of organs at risk (OARs) are vital to the quality of radiation therapy treatment planning and the safety of treatment delivery. This guidance aims to improve the consistency of ontouring OARs in external beam radiation therapy treatment planning by providing a single standardized resource for information regarding specific OARs to be contoured for each disease site. The guidance is organized in table format as a quality assurance

Note—Earn CME credit by taking a brief online assessment at https://www.astro.org/JournalCME.

Sources of support: This paper was funded by the American Society for Radiation Oncology.

Conflicts of interest: Before initiation of this paper, all members of the Task Force and Review Panel completed disclosure statements. These statements are maintained at ASTRO Headquarters in Arlington, Virginia. ASTRO's Clinical Affairs and Quality Council reviewed these disclosures and determined they do not present a conflict with respect to the Task Force members' work on this consensus paper. Jean Wright: ASTRO (honoraria), International Journal of Radiation Oncology Biology Physics (Associate Editor); Sue S. Yom: ASTRO (honoraria), Genentech, Merck, Bristol-Myers Squibb (research grants), UpToDate, Springer (royalty), American Radium Society (Executive Committee Treasurer, Appropriate Use Criteria Committee Chair), International Journal of Radiation Oncology Biology Physics (Deputy Editor); Raymond Mailhot Vega: Varian (travel expenses) and IBA (travel expenses), George Rodrigues: Demos Publishing Company (royalty), George Rodrigues Medicine Professional Corporation (President, stock).

Supplementary Materials: Tables E1 and E2. Table E1 contains two designations for anatomic sites in the EBRT setting: recommended (structures that are recommended for adult definitive cases and may inform palliative cases) and consider (structures that may be considered depending on the specific clinical scenario). Table E2 is a reference guide for accessing site-specific sources to assist with the delineation of the structures from Table E1.

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https://doi.org/10.1016/j.prro.2018.12.003

tool for practices and a training resource for residents and other radiation oncology students (see supplementary materials).
Methods and Materials: The Task Force formulated recommendations based on clinical practice and consensus. The draft manuscript was peer reviewed by 16 reviewers, the American Society for Radiation Oncology (ASTRO) legal counsel, and ASTRO's Multidisciplinary Quality Assurance Subcommittee and revised accordingly. The recommendations were posted on the ASTRO website for public comment in June 2018 for a 6-week period. The final document was approved by the ASTRO Board of Directors in August 2018.
Results: Standardization improves patient safety, efficiency, and accuracy in radiation oncology treatment. This consensus guidance represents an ASTRO quality initiative to provide recommendations for the standardization of normal tissue contouring that is performed during external beam treatment planning for each anatomic treatment site. Table 1 defines 2 sets of structures for anatomic sites: Those that are recommended in all adult definitive cases and may assist with organ selection for palliative cases, and those that should be considered on a case-by-case basis depending on the specific clinical scenario. Table 2 outlines some of the resources available to define the parameters of general OAR tissue delineation.
Conclusions: Using this paper in conjunction with resources that define tissue parameters and published dose constraints will enable practices to develop a consistent approach to normal tissue evaluation and dose documentation.

Introduction

Background

Comprehensive identification and delineation of organs-at-risk (OARs) are vital to the quality of radiation therapy treatment planning and the safety of treatment delivery. A lack of standardization for normal tissue contouring allows for variations in practice and potentially affects the quality of dosimetric plans.

A major advance was made in the field of radiation oncology over the past decades with increased dose conformality, particularly as the profession moved from 2- to 3- dimensional to intensity modulated techniques. Increased precision in the delivery of radiation has also been influenced by improvements in patient positioning, advances in on-treatment imaging, and motion management techniques. These improvements have yielded 2 major outcomes: improved avoidance of critical structures and an ability to intensify doses. When targeting tumors, there may be adjacent structures for which clinical decision-making can be affected by toxicity risk depending on disease site, patient age, treatment technique, prior radiation, and other variables. Plan optimization and maximal organ sparing ultimately depend on the specification and standardization of OAR definitions, accuracy of OAR delineation, and accounting for organ motion when applicable.

The goal of this guidance is to improve the consistency of contouring OARs in external beam radiation therapy treatment planning by providing a single standardized resource for information regarding specific OARs to be contoured for each disease site.

Scope

The Task Force organized the recommendations into a user-friendly table format as a quality assurance tool for practices and a training resource for residents and other radiation oncology students. Table E1 (available online at https://doi.org/10.1016/j.prro.2018.12.003) contains two designations for anatomic sites in the external beam radiation therapy setting: *recommended* (structures that are recommended for adult definitive cases and may inform palliative cases) and *consider* (structures that may be considered depending on the specific clinical scenario).

Understanding that practices and patients need the best outcomes given possible resource constraints, the *recommended* list is focused on the essential organs needed for each primary site in the definitive setting to provide a basic minimum standard of care. The organs listed in the *consider* category build on the *recommended* list and represent options relevant to specific clinical situations. These should be considered by the radiation oncology team depending on clinical factors such as anatomic location, treatment intent (palliative vs definitive), applicable pediatric cases, use of stereotactic radiation therapy, or requirements for a clinical trial. In the recommended category, the structures center around those organs with widely recognized dose limits. However, for research or planning purposes, individual practices may wish to include other contours for which dose limits have not yet been clearly established. Contouring normal tissues enables documentation of the dose, even when the recommended dose constraints are not available.

Table E2 (available online at https://doi.org/10.1016/j.prro.2018.12.003) is a reference guide to access site-specific sources to assist with the delineation of the structures in Table E1. The list is not exhaustive, and other resources may be available in the medical literature and in clinical trial protocols to assist in OAR delineation for specific clinical scenarios.

Dose constraints for specific OARs are beyond the scope of this paper, but constraints are available using established guidelines published by Emami et al,[1] the American Association of Physicists in Medicine Task Group TG-101 report,[2] and the Quantitative Analysis of Normal Tissue Effects in the Clinic guidelines as examples.[3] Cooperative group protocols for clinical trials involving radiation therapy also provide additional for dose constraints.[4]

The naming convention for tissue labels in Table E1 aligns with the *American Association of Physicists in Medicine Task Group 263: Standardizing Nomenclatures in Radiation Oncology,*[5] which standardized structure names.

Indications and Considerations

Standardization

Dose constraints are an integral part of treatment planning and a part of quality measurement in Medicare billing, but there is a lack of standardization in how organs are selected and contoured across practices and providers. According to ASTRO's publication, *Safety Is No Accident*, "[a] review of target delineation and image segmentation prior to planning deserves more standardization."[6]

Multiple studies have shown variation in the delineation of radiation therapy targets and OARs in such disease sites as the central nervous system,[7,8] head and neck,[9,10] thorax,[11-13] and pelvis.[14,15] Differences in normal-tissue contouring can affect dosimetric plan optimization, dose volume histogram (DVH) results, and potentially normal tissue complication probabilities and clinical outcomes. For example, in a test case from a patient with oropharyngeal cancer, significant interclinician variation in contouring OARs was associated with differences that ranged from -289% to 56% for mean dose, and -22% to 35% for maximum dose.[16]

Similar variability in normal structure delineation was observed for breast cancer radiation therapy planning in a Radiation Therapy Oncology Group (NRG Oncology) multi-institutional study, where structure overlaps between radiation oncologists were as low as 10%, and volume variations had standard deviations up to 60%.[12] Establishing standardized normal tissue contouring assists with dose assessment during radiation therapy planning, particularly in the era of advanced radiation therapy techniques.

Safety

In 2011, ASTRO partnered with the American Association of Physicists in Medicine to develop the Radiation Oncology Incident Learning System (RO-ILS), the only medical specialty society-sponsored incident learning system for radiation oncology. A recent analysis of aggregated RO-ILS data indicates that, to date, 29% of all reported events occurred in treatment planning, with a featured theme of incorrect normal-tissue definition leading to the mis-estimation of radiation dose. From 2016 to 2018, the Radiation Oncology Health Care Advisory Council identified >60 RO-ILS events that contained an issue with contours. These events include plans with critical structures not contoured, and normal tissues incorrectly or incompletely delineated.[17]

Similarly, reported data of radiation therapy patient events submitted to Public Health England between December 2013 and November 2015 identified that 27% of incidents occurred during the pretreatment planning process.[18] Of those events recorded as near-miss, target and OAR delineation was one of the most frequently reported processes (Fig. 1). This report, along with RO-ILS data, suggests a trend in safety event data relating to treatment planning and promotes the need for improved standardization.

Despite the importance of contouring and potential sources of variation, no recommended quality systems exist to ensure accuracy and consistency in normal anatomy contouring. Standardization may allow better quantification of DVH-toxicity relationships and assist in the prevention of avoidable toxicities to normal structures. Failure to include OARs in the planning process may lead to dose-dumping during the inverse planning process, whereby unnecessary and potentially unsafe radiation doses are delivered to OARs that are not defined as part of the planning constraints. This concept extends to the palliative setting, where doses to OARs are generally considered less critical because of lower radiation doses and shorter patient life expectancy. However, reirradiation and higher-dose stereotactic treatments are increasingly common in the metastatic setting, and if cumulative normal tissue dose constraints are not observed, inadvertent toxicity may occur.

Pre-treatment Preparation

Physician documentation

Constraining doses to OARs is a fundamental component of the treatment planning process and should be included in the radiation oncologist's planning directive (order) documented before the initiation of treatment planning. The patient-specific written planning directive should be consistently documented in the oncology information system and must provide sufficient information to guide qualified personnel generating a treatment plan. The ASTRO Accreditation Program for Excellence (APEx) Standard 2.2.1[19] requires practices to document defined patient-specific targets and normal tissues along with their respective dose goals and constraints as an essential evaluation component of the program.

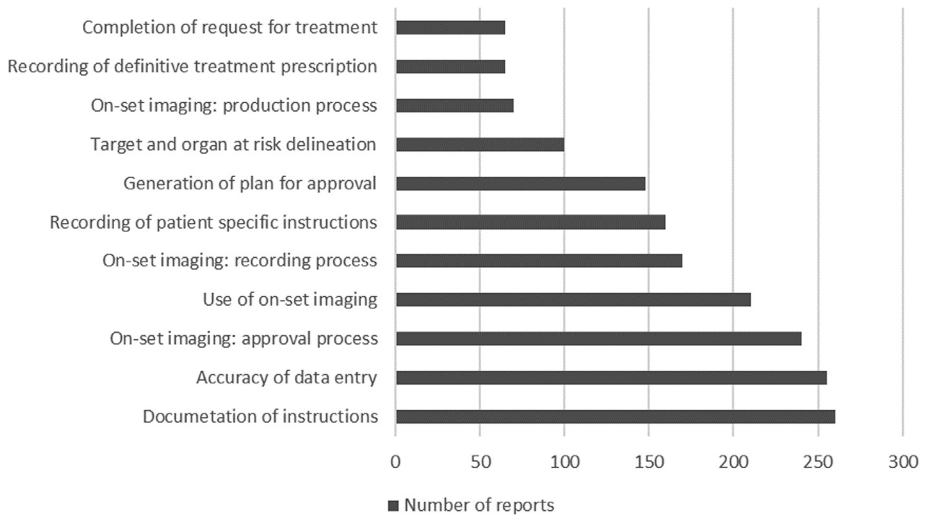

Fig. 1 Public Health England, "*Radiotherapy Errors and Near Misses Data Report (December 2013 to November 2015)*".[18] Reproduced with permission.

Roles and responsibilities of treatment planning staff

ASTRO's *Safety is No Accident* publication highlights the need for all members of the radiation oncology team to maintain proper credentials, skills, and training, and to undergo clinical competency assessments[6] to assure standardization of contouring practices.[20] Ultimately, the radiation oncologist is responsible to review the structures as part of the plan assessment and approval (Fig. 2).

Resources

Tools

Contouring guides (i.e., atlases) are published for different anatomic sites to guide practitioners to define clinical target volumes, and should also be used for visualization of tissue parameters. Disease site-specific contouring atlases published by NRG Oncology (commonly known as Radiation Therapy Oncology Group contouring atlases) are developed by consensus among cooperative groups and disease-site committees. Aside from the NRG atlases, other prominent sources exist as published in the medical literature. These tools should be used to support consistency in practice procedures, as teaching resources, and in situations when planning treatment for an uncommon or infrequently treated disease site. Table E2 catalogs some of the available references, and this document seeks to further encourage use of these important tools to promote practice standardization.

Technology

Modern radiation oncology has experienced rapid changes in software and hardware technology. The ability

	Radiation Oncologist	Medical Physicist	Medical Dosimetrist	Radiation Therapist	Nonphysician Providers (NA/PA)	Oncology Nurse
Interdisciplinary coordination of care	X			X	X	X
Patient positioning and image acquisition	X	X	X	X		
Fusion and registration	X	X	X			
Contouring/segmentation	X	X	X			
Dose-volume constraints	X	X	X			
Dose calculation	X	X	X			
Review of final treatment plan	X	X	X	X		

Fig. 2 Roles and responsibilities of the radiation oncology team.[6]

to create and save templates of structure sets within the treatment-planning system (TPS) aids standardization and can be used to normalize practice between providers, within a health care system, or between institutions. In addition, some TPSs have a built-in anatomic atlas where contours of normal structures are displayed on a scrollable computed tomography (CT) scan. Sagittal/coronal planes and a 3-dimensional view can be used to review and adjust contours. Knowledge and application of recent advances can affect the efficiency and quality of OAR delineation. Artificial intelligence and deep learning are currently being applied to develop more sophisticated predictive models and automatic contouring software with the aim of improving the quality of treatment and the consistency of contours.[21] Auto-contouring features in the TPS can assist with multiple structures including the brain, lungs, spinal cord, and bony structures and may be reliable for certain structures (e.g., high-contrast organs such as femoral heads).

Reports have been published on the efficacy of auto-contouring technology and the differences between automated and manual contouring.[22,23] Aselmaa et al focused on the quality of delineation and the efficiency within the workflow. The mean duration times required to contour a slice were captured for 3 cases. According to their review, quality was more consistent between physicians when automatic contouring technology was used. The study also confirmed the expectation in most cases regarding the time-saving aspect of this technology (Fig. 3).

Skitka et al evaluated the effects of automation bias on treatment planning, which pointed to possible errors associated with automation. This review noted that "participants with an aid made errors of omission (missed events when not explicitly prompted about them by the aid) and commission (did what an automated aid recommended, even when it contradicted their training and other 100% valid and available indicators)."[23]

These technology-reliant contouring tools promise to reduce time, improve consistency, and increase quality; however, as artificial intelligence is still under development in treatment planning, and contours generated from computer-based tools should always be subject to a careful manual review and adjustment before initiating treatment planning, and then formally reviewed as part of the plan approval process by the radiation oncologist.

Treatment Planning Processes

Registration

Changes in anatomy due to possible tumor extension mandate a basic understanding of normal anatomy. To assist with delineating normal tissues, imaging considerations are also important. Certain OARs are better visualized or defined on contrast-enhanced CT scans or magnetic resonance imaging (MRI) scans, compared to CT scans alone. For example, it is easier to delineate the parotid gland on a contrast-enhanced CT due to the enhancing nature of the organ. Similarly, to accurately delineate the spinal cord, particularly for stereotactic planning, a high-resolution T2-weighted MRI or CT myelogram should be used. In the brain, it may be easier to delineate the optic chiasm and nerves using a fused high-resolution T1- or T2-weighted MRI rather than a typical treatment-planning CT. Contrast-enhanced CT scans, and specific sequences in MRI scans for contouring may facilitate delineation of normal tissues from adjacent tumor volumes and more adequately spare OARs compared with non-contrast treatment planning CT scans.

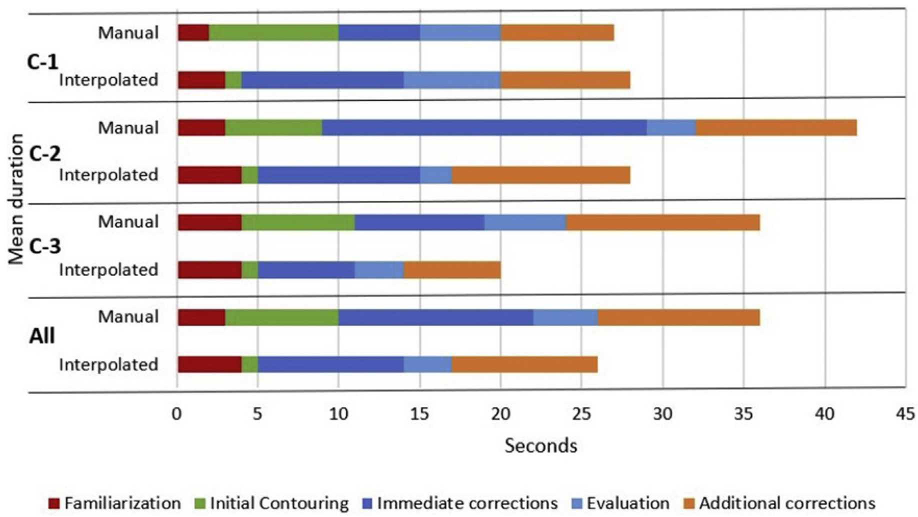

Fig. 3 Mean durations (in seconds) of different workflow steps by slice in case C-1 (easy), C-2 (moderate difficulty), and C-3 (difficult). The type of workflow is labeled as manual or interpolated, meaning semi-automatic contouring.[22] Reproduced with permission via the Creative commons license.

Image registration combines the information obtained from different imaging modalities with the planning CT and should be performed by a suitably trained member of the radiation oncology team.[24] During this process, special consideration must be taken as the patient position and morphology may differ between the diagnostic image and planning CT, resulting in potential uncertainties. As a result, alignment of images may require regional prioritization when variations do occur. All image registration, rigid or deformable, should be assessed for accuracy before contouring commences, including when autoregistration tools are used. Additionally, contours delineated using a registered image must be reviewed and verified on the planning CT before treatment planning commences and be evaluated during treatment plan approval by the radiation oncologist.

Segmentation

Contouring appropriate OARs is essential in the modern era of intensity modulated treatment planning, where specific details regarding tissue parameters are a necessary component of optimization and evaluation. Each organ has its own specific best practice(s) for appropriate contouring. For example, for lung constraints in the setting of definitive radiation therapy for lung cancer, tumor target volumes (eg, gross or clinical target volume) are usually subtracted from the OAR to assess volumetric dose constraints (eg, lung GTV).

Conversely, in the setting of central nervous system tumors, there can be no subtraction of target volumes because the entire organ must be assessed during the dose calculation. One approach when a target volume will be prescribed to a higher dose than the tolerance of an overlapping critical OAR is to create a structure that subtracts the critical OAR from the target (eg, PTV_Eval). This may result in a compromise between adequate tissue sparing and optimal treatment of the target to maximize the therapeutic ratio of treatment.

In the development of guidance for appropriate organ contouring, the roles of artificial devices and surgical interventions in treatment planning were also reviewed. Recommendations to contour cardiac implantable electronic device[25] leads, ostomy bags,[26] and surgical hardware have been published. The presence of an implanted device may require additional consideration in treatment planning and a potential compromise between avoidance structures and optimal treatment plan design. This guidance does not specifically include these devices; however, they should be delineated when clinically appropriate.

In other settings, a planning OAR volume (PRV) provides a margin around an OAR to account for variations in setup, motion, and anatomy when appropriate.[27] A PRV will further ensure the sparing of particularly sensitive OARs, or better shape dose distributions by intentionally constraining an area to a lower dose. This use of a PRV is most common in the treatment of tumors close to critical neural structures (eg, spinal cord or optic structures) to prevent unintentional overdosing of these OARs owing to setup errors (particularly with complex treatment planning techniques). In less complex cases, the spinal canal is commonly used as a surrogate for the spinal cord.

Treatment plan optimization and evaluation

Incorrect contours may result in difficulties with plan optimization for inverse planning or multileaf collimator placement in forward-planned techniques. Ultimately, an error in any planning phase may have a downstream consequence that results in a suboptimal plan producing suboptimal patient outcomes.

In accepting radiation therapy plans, a key step in the process is plan review and 3-dimensional dose-volume outcome analysis. Whether a more meaningful outcome for an OAR is the mean, maximum, or volumetric dose, inherent in the interpretation of that metric is the assumption that the contours represent the OAR. If not, the entire dosimetric treatment plan may be compromised because treatment design aspects including beam angle, location of static beams, and avoidance regions in arcs may be affected. By using a standard set of tissues contoured based on disease site, DVH data can be analyzed confidently.

Some universal suggestions are relevant regardless of disease site. This list is not meant to be exhaustive, but represents some general guiding principles:

- Contour on appropriate density windows (i.e., bone, lung) for each tissue.
- Create structure set templates in the TPS to set standard practice procedures.
- Use contrast-enhanced scans when relevant to assist with tissue delineation. Large areas of contrast may need a density override or a registered noncontrast scan for planning purposes if volumes of contrast significantly influence dose calculations.
- Register relevant imaging (eg, MRI, contrast-enhanced CT) to the planning CT to assist with tissue definition, but always review the final contouring on the primary data set. Ascertain the best region of alignment when there are inconsistencies between the images.
- Review structures in the coronal and sagittal planes when contouring on axial slices to verify completeness of coverage in all dimensions.

Summary

Standardization improves patient safety, efficiency, and accuracy in radiation oncology treatment. This consensus guidance represents an ASTRO-quality initiative to provide recommendations for the standardization of normal-tissue contouring that is performed during external beam treatment planning for each anatomic treatment site. Table E1 defines 2 sets of structures for anatomic sites: those that are recommended in all adult definitive cases and may assist with organ selection for palliative cases, and those that should be considered on a case-by-case basis depending on the specific clinical scenario. Table E2 outlines some resources available to define the parameters of general OAR tissue delineation. Using this paper in conjunction with resources that define tissue delineation parameters and published dose constraints will enable practices to develop a consistent approach to normal-tissue evaluation and dose documentation.

Acknowledgments

This document is endorsed by American Association of Medical Dosimetrists. The authors gratefully acknowledge the peer reviewers: Jennifer Bellon, MD, Nicolas DeNunzio, MD, MS, Avraham Eisbruch, MD, Supriya Jain, MD, Lori Kasuski, RT(R)(T), CMD, Aaron Kusano, MD, Lilie Lin, MD, Simon Lo, MD, Billy Loo, MD, Charles Mayo, PhD, Sasa Mutic, PhD, Tracey Schefter, MD, Abhishek Solanski, MD, Stephanie Weiss, MD, MS, Ying Xiao, PhD, Catheryn Yashar, MD, Sandra Zaky, MD, and Michael Zelefsky, MD. This document was prepared by the American Society for Radiation Oncology (ASTRO) as part of an ongoing quality initiative with the goal of enabling members to consistently deliver the highest quality and value care to cancer patients.

Supplementary Data

Supplementary material for this article can be found at https://doi.org/10.1016/j.prro.2018.12.003.[28-48]

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