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Brief Opinion

FCB-CHOPS: An Evolution of a Commonly Used Acronym for Evaluating Radiation Treatment Plans

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Abstract

Checklists have been used across many fields as a systematic framework to reduce human error and improve safety. In radiation oncology, the CB-CHOP acronym was previously developed as a tool to aid physicians in assessing the quality of radiation treatment plans for approval. This manuscript updates the acronym for the modern era with the addition of F and S to create FCB-CHOPS: fusion, contours, beams, coverage, heterogeneity, organs at risk, prescription, and dose summation. These 2 additions reflect the evolution and importance of image fusion to aid in the delineation of targets and organs at risk and dose summation to reflect the increased incidence of reirradiation and the need to consider prior treatment courses in the final plan evaluation. Utilization of this and similar checklists is critical in maintaining high-quality and safe radiation oncology treatments.

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Introduction

Checklists have been used by pilots since before World War II and have become commonplace in the aviation profession, providing a systematic framework to reduce human error and improve safety. Similarly, the medical field has adopted checklists to ensure quality care for patients. The World Health Organization's Surgical Safety Checklist[1] has demonstrated significant improvements in patient outcomes by reducing postoperative complications and death rates. In radiation oncology, the care team works together to develop plans and provide patients with quality treatments. Per the American Society for Radiation Oncology's Safety is No Accident[2] initiative, cancer care has become increasingly multidisciplinary, and the radiation oncologist's role is evolving to be a team leader for patient safety, a coordinator of a multidisciplinary team, and a champion of lifelong learning for all members of the team.

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Consequently, the CB-CHOP acronym was created as a pretreatment checklist to help physicians assess radiation treatment plans for approval. CB-CHOP stands for contours, beams, coverage, heterogeneity, organs at risk (OARs), and prescription.[3] This manuscript proposes the evolution of CB-CHOP to FCB-CHOPS, incorporating the importance of image fusion (F) review and dose summation (S) of previous radiation therapy courses with the current radiation therapy course, reflecting their importance in modern radiation oncology.

FCB-CHOPS Components

Fusion

Advancements in radiation treatment technology and immobilization methods have led to increasingly accurate and precise treatments. Most treatment planning uses computed tomography simulation scans. However, to fully leverage modern precise radiation delivery capabilities, it is often necessary to use fused or coregistered diagnostic images. These images enhance the delineation of targets and OARs, guide the evaluation of pretreatment disease extent after surgery or systemic therapy, and improve the spatial and biological visualization of tumors. Coregistration errors may cause geographic misses of targets and/or inappropriate doses to OARs if not corrected prior to treatment.

When feasible, images for fusion should ideally be obtained as close to the same orientation and simulation date as possible to minimize anatomic changes. The first step in image fusion is typically rigid registration, especially in sites where organs exhibit limited motion. However, a limitation of rigid registration is its inability to account for the deformable nature of organs. Deformable image registration (DIR) addresses this by displaying spatial correspondence between image sets to correct positional differences between scans. DIR is crucial in adaptive radiation techniques, where plans are modified between treatment sessions. It is important to note that DIR relies on evolving algorithms often based on initial rigid registration and is not a perfect solution. Organ positional changes and other anatomic variations can impede the algorithm's accuracy in deforming the image. Therefore, the accuracy of DIR around the region of interest should be assessed by the treating physician, and its limitations should be carefully considered.[4-7]

Verifying a fusion involves ensuring the imported imaging modality and study time point align with the physician's intent. This assessment may be simple, like verifying spine levels in palliative care, or complex, as in sites with significant anatomic variability (e.g., substantial movement in the chest, abdomen, or pelvis) or precise contouring needs (e.g., reirradiation, stereotactic radiosurgery, SABR). It is important to consider that there are many potential mistakes in evaluating a fusion, including but not limited to correct image upload (correct date and sequence), geometric errors from incorrect anatomic alignment, distortion (ie, when using high-field magnetic resonance images to delineate brain metastases far from the magnet's primary axis), failure to take into account variability of internal organ positions, and misregistration between positron emission tomography and computed tomography images on fused positron emission tomography scans.[8-11]

A recent survey by Turchan et al[12] noted that dosimetrists and/or medical physicists were expected to register diagnostic images with the primary image set 89% of the time, and 67% of respondents relied on automated software assistance. Interestingly, although most respondents asked for physician review when unsure of registration quality, a small subset (9%) of respondents did not ask given concern about the thoroughness and/or accuracy of physician review. This survey highlights the importance of physician proficiency with image registration as physicians are ultimately responsible. Emphasizing fusion/image registration review before contouring and as part of a final checklist before plan approval and treatment is necessary because of its evolving utilization in modern radiation therapy (including its significance in dose summation, discussed later). Important considerations for fusion evaluation are summarized in Fig. 1.

	Become proficient with one's software for image registration, at minimum including manipulation of the registration.
	Obtain optimal pre-radiation imaging, including appropriate modalities (i.e., MRI, PET, etc.) in appropriate orientations at the appropriate timepoints.
	Determine the accuracy of the fusion(s) with the planning scan by assessing multiple anatomic landmarks in multiple planes and adjust the fusion(s) as necessary. Prioritize the region of interest and critical OARs. Consider multiple registrations for different regions as needed.
	Consider the use of deformable image registration as appropriate.[7]
	Review the planning scan (i.e., most often a CT simulation scan) to ensure contoured volumes are appropriate (i.e., do not rely solely on and do account for limitations of the fused images).

Figure 1 Important considerations for fusion evaluation.

Contours

Contouring is fundamental to modern radiation therapy; contoured structures and their respective radiation dose goals determine how treatment plans are generated. During the initial contouring process, physicians must ensure a thorough review of the case, including but not limited to a review of the presentation, staging/grading, pathology report(s), radiology report(s), and operative note(s). Discussions with surgeons, medical oncologists, radiologists, and other providers as well as independent review of any pretreatment images should occur as necessary. Both during initial contouring and during treatment plan review, the treating physician must confirm all relevant structures were drawn appropriately: targets, clinical and planning target volume (CTV and PTV) expansions, and OARs (with appropriate planning risk volumes).[13,14] Review during plan assessment is especially important if various contours were altered or delegated. For example, if the gross tumor volume has been altered at some point during the planning process, physicians should confirm that CTVs and PTVs have been updated appropriately. Critical OARs (e.g., optic structures, spinal cord, bowel, etc), which may be initially contoured by autocontouring software or the dosimetrist, should be double-checked during the final review.

Peer review can be a useful tool for evaluating contours. Studies suggest that peer review at this step may promote willingness to modify contours, identification of major errors earlier, minimization of treatment delays, and decreased waste of planning resources (ie, dosimetry and physics time).[15-20] Rigorous evaluation of target and OAR contours as well as effective peer review of contours ensures confidence in evaluating the dose-volume histogram (DVH) and plan objectives at the final plan approval.

Beam Arrangements/Fields

Evaluating delivery techniques, which can range from a limited number of static fields to more complex intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT), is an important next step. Delivery technique is specified by the treating physician in the radiation prescription. For 3D plans, assessment of beam entry points and angles can help avoid OARs and limit dose to uninvolved tissue. Multileaf collimators help shape radiation dose to maximize coverage and limit OAR exposure. Beam shaping can be visualized directly through the beam's eye view feature and through evaluating isodose lines overlaid on planning images. Adjusting the number, energy, and weighting of the beams can help alter doses received by targets and OARs. For IMRT/VMAT, one should consider angles and entry points to provide optimal dosing, including assessing the use of coplanar and noncoplanar beams. The number of beams can affect treatment time, which in turn can affect the variability of both organ motion and patient motion (ie, palliative patients in severe pain may have difficulty with longer treatments).

Coverage

Spatial visualization of dose using 3D imaging in conjunction with DVH evaluation ensures confidence in coverage. The DVH, which plots dose on the x-axis against volume on the y-axis, quantitatively analyzes dose variation within a structure. Adequate coverage of the target per International Commission on Radiation United and Measurements Report 50 and modern radiation therapy requirements typically entail coverage of the PTV by the 95% isodose line, but definitions and clinical goals may vary.[21,22] Physicians may use clinical judgment to compromise PTV coverage to protect an OAR.

One should not rely solely on the DVH because of its inability to assess the spatial distribution of dose in targets and OARs. The DVH might indicate 100% coverage of the PTV with the prescription dose and adherence to OAR dose constraints but could falsely represent the actual dose distribution because of inaccurate delineation of both the PTV and the relevant OAR. Modern coverage assessment requires visually inspecting 3D dose distribution and reviewing images with overlaid isodose lines to facilitate qualitative assessment. This approach allows the prescriber to ascertain whether the target volumes receive adequate coverage while ensuring that nearby OARs are not exposed to excessive radiation. This review may identify or reinforce specific instructions or cautions to be provided to radiation therapists to help maintain safe treatments. In the context of IMRT/VMAT, visualizing low dose spread can also limit inadvertent and unnecessary dose spillage to OARs.

Heterogeneity

Heterogeneity describes variability in the distribution of dose and should be assessed via DVH and 3D evaluation. High doses are ideally within the target volume and outside of relevant OARs (e.g., spinal cord, bowel, etc.), whereas lower doses are avoided within target volumes. Various techniques have different expectations for heterogeneity. For example, radiosurgery plans are commonly expected to allow significant high doses within the tumor to leverage sharper dose falloff outside the target. Alternatively, a treating physician may accept a lower dose region within a target volume near a critical organ. A dose less than the prescription, when necessary, is preferred to be in the PTV as opposed to the gross tumor volume or CTV.

Organs at risk

Reviewing doses to relevant OARs is essential to minimize treatment-related toxicity and optimize patient outcomes. The first step in evaluating OARs is to ensure an appropriate list of OARs has been delineated and considered in the plan objectives. Subsequently, each OAR needs to be constrained using established guidelines or institutional standards, including limiting the maximum dose or volume of OAR receiving a specified dose. Common constraints can be derived from Quantitative Analyses of Normal Tissue Effects in the Clinic[23] for conventional fractionation, the American Association of Physicists in Medicine Task Group 101 report[24] for stereotactic radiation, and the recent Hypofractionated Treatment Effects in the Clinic[25] effort for hypofractionated regimens. Phase 3 clinical trials may provide constraints based on their treatment scheme. Constraints vary by dose fractionation schedules, and the biologically effective dose (BED) and equivalent dose in 2-Gy fractions (EQD2) should be used when appropriate, recognizing the limitations of such models (especially for high doses per fraction). Serious harm can be caused by using an incorrect dose constraint for a critical structure. By evaluating dose constraints both in the DVH and in the 3D space for each OAR, physicians validate plan safety. This assessment includes weighing the potential benefits of target coverage versus OAR toxicity risks, accounting for short-term and long-term implications. In addition, different OARs will have different priorities depending on the expected toxicity and treatment goals. When appropriate, planning risk volumes should be considered.

Prescription

Validating all components of the prescription upholds treatment goals according to clinical evidence and ensures safe delivery, especially if modifications have been made to intent and/or dose. Identification of any potential discrepancies or errors in dose per fraction and total dose is crucial, particularly since errors could result in an order of magnitude difference in dose delivered. The United States Nuclear Regulatory Commission mandates reporting of events for radiation doses delivered that are 20% above the total prescribed dose or 50% above an individual fractionated treatment.[26]

Components of prescription confirmation include checking treatment site, prescription dose, radiation modality, technique, energy, delivery schedule, and image guidance instructions. Image guidance and setup verification are of particular importance with smaller PTV margins expected in modern radiation treatment, commonly $\leq$5 mm depending on radiation technique. Instructions regarding image guidance should be consistent with the immobilization used, the PTV margin designed, and the movement of targets and OARs. Although not commonly listed in a radiation prescription, physicians should also review if the overall treatment plan involves the use of concurrent systemic therapy.

Dose summation

Many patients are living longer because of advances in cancer treatment, and indications for radiation in recurrent and metastatic settings are expanding. Both scenarios increase the probability of delivering overlapping radiation courses, and improved radiation technology and delivery precision increase physician comfort with reirradiation. Cross-sectional surveys of patterns of reirradiation practice have demonstrated increasing trends of physicians providing reirradiation treatments.[27,28] Adequate risk assessment should be considered to limit toxicities. Evidence to guide reirradiation is growing with more data, and experiences being published.[29-35] A critical first step in evaluating reirradiation is the physician's awareness of previous radiation and due diligence in obtaining/recreating previous radiation courses. Advances in technology and considerations described in the fusion section allow for robust evaluation of reirradiation dosing by overlaying multiple courses of radiation and evaluating the total dose in a single plan. However, one must keep in mind the limitations of fusion, especially deformable registrations, and not rely solely on dose summation in judging, for example, hot spots near the spinal cord.

This topic is also complicated by variations in dose fractionation schedules, radiation technique (e.g., IMRT, SABR, etc), radiation modality (e.g., photons, protons, etc), and length of time between radiation courses. For example, in usual clinical practice, protons have a relative biological effectiveness of 1.1 compared with photons.[36] Different dose fractionation schedules are often used as well, making it difficult to directly summate doses delivered. This situation is clearly illustrated when combining a conventionally fractionated course with SABR. Constraints for OARs may vary depending on how much time has passed between courses of treatment.

When evaluating retreatments, one should use due diligence in searching for similar cases, research potential cumulative dose constraints, and consider BED/EQD2 as applicable because of the utilization of various dose fractionations and particle delivery. Online calculators can help in the evaluation of both BED and EQD2. Although limitations inherently exist with BED/EQD2 in evaluating conventionally fractionated vs hypofractionated or radiosurgical plans, this method is commonly used in the clinic for a consistent frame of reference. However, it is important to recognize that separate models for hypofractionated and single fraction treatments are available.[37] Ultimately, summation of radiation delivered allows

	Determine if the patient has received prior radiation.
	Obtain all available records from prior radiation, including DICOM RT files and radiation prescription and treatment delivery documentation, if possible.
	Fuse DICOM RT files, if available, using best practices for fusion as described above.
	Consider time from prior courses, nearby OARs, varying dose-fractionation schedules, radiation techniques, and radiation modalities to assess areas of overlap.
	Use available published data and clinical judgment to determine expected risk.
	Ensure patients are informed of any specific increased risks in their consent for reirradiation.

Figure 2 Brief checklist for plan summation evaluation.

assessment of situations associated with heightened risks, allowing the treating physician to provide patients with full disclosure. A brief checklist for evaluating dose summations is provided in Fig. 2.

Conclusions

Patient treatment is finalized and approved by the radiation oncologist, who is ultimately responsible for final safety and quality. As the culmination of a multistep, multidisciplinary process, using a checklist ensures a rigorous approach to maintaining high-quality, safe treatments. The updated FCB-CHOPS acronym offers a comprehensive checklist for radiation oncologists to review and approve modern radiation treatment plans. By incorporating fusion and dose summation into the original CB-CHOP acronym, FCB-CHOPS addresses the critical role of image registration and prior radiation therapy courses in the modern radiation oncology landscape. Using FCB-CHOPS as a pretreatment checklist can help ensure that radiation treatment plans are safe, effective, and consistent with the intended clinical goals, ultimately improving patient outcomes.

Disclosures

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