Title
A Framework for Sharing Radiation Dose Distribution Maps in the Electronic Medical Record for Improving Multidisciplinary Patient Management

Journal
Radiology Imaging Cancer, 3(2)

ISSN
2638-616X

Authors
Savjani, Ricky R
Salamon, Noriko
Deng, Jie
et al.

Publication Date
2021-03-01

DOI
10.1148/rycan.2021200075

Peer reviewed

Radiology: Imaging Cancer

BRIEF REPORT

A Framework for Sharing Radiation Dose Distribution Maps in the Electronic Medical Record for Improving Multidisciplinary Patient Management

Ricky R. Savjani, MD, PhD • Noriko Salamon, MD, PhD • Jie Deng, MD, PhD • Martin Ma, MD, PhD • Steve Tenn, PhD • Nzhde Agazaryan, PhD • John Hegde, MD • Tania Kaprealian, MD, MBA

From the Departments of Radiation Oncology (R.R.S., J.D., M.M., S.T., N.A., J.H., T.K.) and Radiology (N.S.), UCLA David Geffen School of Medicine, 200 UCLA Medical Plaza, Suite B265, Los Angeles, CA 90095. Received June 12, 2020; revision requested August 4; revision received October 19; accepted December 3. **Address correspondence to** R.R.S. (e-mail: *rrsavjani@mednet.ucla.edu*).

Authors declared no funding for this work. Conflicts of interest are listed at the end of this article.

See also commentary by Khandelwal and Scarboro in this issue.

Radiology: Imaging Cancer 2021; 3(2):e200075 • **https://doi.org/10.1148/rycan.2021200075** • **Content codes:** **OI** **RO**

Radiation oncology practices use a suite of dedicated software and hardware that are not common to other medical subspecialties, making radiation treatment history inaccessible to colleagues. A radiation dose distribution map is generated for each patient internally that allows for visualization of the dose given to each anatomic structure volumetrically; however, this crucial information is not shared systematically to multidisciplinary medical, surgery, and radiology colleagues. A framework was developed in which dose distribution volumes are uploaded onto the medical center's picture archiving and communication system (PACS) to rapidly retrieve and review exactly where, when, and to what dose a lesion or structure was treated. The ability to easily visualize radiation therapy information allows radiology clinics to incorporate radiation dose into image interpretation without direct access to radiation oncology planning software and data. Tumor board discussions are simplified by incorporating radiation therapy information collectively in real time, and daily onboard imaging can also be uploaded while a patient is still undergoing radiation therapy. Placing dose distribution information into PACS facilitates central access into the electronic medical record and provides a succinct visual summary of a patient's radiation history for all medical providers. More broadly, the radiation dose map provides greater visibility and facilitates incorporation of a patient's radiation history to improve oncologic decision making and patient outcomes.

Supplemental material is available for this article.

The field of radiation oncology has embraced advanced technology to improve treatment delivery for a variety of cancers and disorders, leading to an increase in the number of customized software packages and hardware tools for radiation treatment planning and delivery. However, little to no formal education in radiation oncology exists in medical schools outside of elective clerkships, and even in oncology-focused residencies and fellowships, only modest exposure to radiation therapy planning is provided to radiology, medical oncology, or surgical oncology colleagues (1). Here, we present a Brief Report on a simple yet impactful way in which radiation oncology centers can be more transparent in documenting a patient's radiation history: by sharing the radiation dose distribution map into the picture archiving and communication system (PACS). This report is not a clinical trial nor a prospective study; rather, we wish to communicate with illustrative examples on how making radiation dose volumes available can lead directly to better patient care.

Most radiation oncology practices create a variety of templated notes to document the course of a patient's treatment. Yet, these notes often include radiation oncology–specific jargon, may not include visual information about the treatment field, and can easily remain obscured within the great volume of clinical documentation in the medical record. This presents a critical issue in the field of radiation oncology that has been raised and discussed without implementing a solution to date (2). A key instrument conveying a radiation treatment plan is the dose distribution map. This concisely displays the dose given to all anatomic structures volumetrically using the imaging modality on which the treatment was planned. In most departments, the radiation dose map is a key component in evaluating treatment plans during chart rounds (3). Dose maps are one of the integral pieces of information that relay the potential effectiveness of a treatment, as well as short- and long-term adverse effects from radiation based on dose to organs at risk. In spite of this, these volumes are not shared readily within the electronic medical record at most facilities and thus not seen by anyone outside of a radiation oncology department.

To address this gap, we built a framework in which dose distribution maps are systematically uploaded into the hospital PACS after completion of a radiation therapy course. PACS is a centralized repository that all clinicians use to review imaging. Including dose distribution maps within PACS provides centralized access for all medical providers, increasing the accessibility and potential comprehension of a patient's radiation history (similar to primary cardiology data like electrocardiograms being available electronically for other clinicians to review and incorporate).

Most importantly, having ready access to radiation dose maps can directly improve patient care across many health care settings. In the emergency department,

Abbreviations

DICOM = Digital Imaging and Communications in Medicine, PACS = picture archiving and communication system

Summary

Sharing radiation dose distribution volumes into the picture archiving and communication system facilitates faster and simpler incorporation of a patient's radiation history for diagnostic radiology.

Key Points

- A patient's radiation therapy history is often difficult to find and understand in the electronic medical record.
- Sharing the radiation dose distribution volume into the picture archiving and communication system allows radiologists to see a succinct visual summary of a patient's radiation treatment.
- Diagnostic interpretation of oncologic imaging is improved with easily accessible visualization of radiation dose distribution data, facilitating better incorporation of radiation data into patient care.

Keywords

- Brain/Brain Stem, CNS, MRI, Neuro-Oncology, Radiation Effects, Radiation Therapy, Radiation Therapy/Oncology, Radiosurgery, Skull Base, Spine, Technology Assessment

knowing precisely when and where a patient may have had previous radiation to the spine can help triage a patient with spinal cord compression to the most appropriate treatment more rapidly. The emergency department physician, neurosurgeon, radiologist, and radiation oncologist can all have central access to the same volumes and can infer directly from it, eliminating the additional steps of retrieving and sharing these records and delaying potentially urgent treatment. In the outpatient setting, being able to visualize the dose to the rectum from a recent prostate external-beam radiation therapy can avoid the endoscopist from unnecessarily retrieving a biopsy from an already friable tissue, for example. And even in the dentist's office, understanding the dose distribution to the maxilla from a prior head and neck treatment can facilitate decisions regarding safe dental extractions. In all of these settings and several more, the radiation dose map is already being requested—by sharing these maps centrally into PACS, patients who have undergone radiation therapy can simply receive better care.

We piloted the sharing of the dose distribution maps by systematically sharing all radiation dose maps for patients who underwent stereotactic radiosurgery within the central nervous system (brain and spine). This is perhaps one of the most important areas in which prior radiation therapy field information can be helpful for differentiating radiation treatment effect from tumor progression. Additionally, we highlight specific cases in which colleagues requested images obtained from our department to help with patient management.

Materials and Methods

Most radiation therapy centers have established a connection in which designated computer(s) in the department can query and retrieve images from the hospital PACS. This allows clinical diagnostic imaging scans to be downloaded and used in the treatment planning software to assist with contouring target lesions and organs at risk. However, these same computers are usually not authorized to upload images onto PACS, as pushing data onto PACS is a carefully vetted process by the hospital infrastructure. We worked with colleagues from information technology services to grant permissions of our department's treatment planning computers to send images to PACS (Fig 1).

We then configured our treatment software (MIM 6.8.5; MIM Vista, Cleveland, Ohio) to include PACS as a Digital Imaging and Communications in Medicine (DICOM) location. A radiation therapy–specific DICOM standard (DICOM-RT) has been constructed to allow for radiation-specific file storage (eg, contours, beam configurations, and doses) (4–7). However, the DICOM-RT specification is not read by PACS implemented in most hospital infrastructures. Furthermore, there are several DICOM-RT structure sets that would not be particularly useful to radiologists and may burden their clinical workflow. Instead, we configured MIM to send images as a secondary capture (DICOM OT [Other], Slice-by-slice) DICOM structure set. This method takes each section in the desired plane exactly as it appears on the screen in MIM and compiles them into a composite single-standard DICOM file. This DICOM file can then be uploaded to PACS and viewed by all health care providers. We have provided a README file to instruct other radiation oncology departments on how they can set up MIM to send images to PACS (Appendix E1 [supplement]).

Although MIM is used by several radiation oncology departments including our own, many centers use other commercially available software (eg, Mosaiq [Elekta, Stockholm, Sweden], Eclipse [Varian Medical Systems, Palo Alto, Calif]). To provide a more generic, vendor-agnostic framework for sharing radiation dose maps, we demonstrate how this can be done using open source software packages as well. Namely, we show how to interact with data and convert radiation dose maps from DICOM-RT to standard DICOM by using 3D Slicer (8) and the SlicerRT extension (9). We additionally demonstrate how radiation dose maps can be pushed onto PACS using DICOM toolkit (*https://dicom.offis.de/dcmtk.php.en*). Further, for institutions working with MATLAB (MathWorks, Natick, Mass), the Computational Environment for Radiological Research (CERR: *https://github.com/cerr/CERR*) toolbox provides several utilities for manipulating and converting DICOM-RT files. And we also reference a very valuable tool for file format conversions: plastimatch (*https://plastimatch.org/plastimatch.html*). These resources demonstrate how an institution can share dose maps to PACS using open source tools, and we provide documentation and example code on how this can be achieved: *https://github.com/rsavjanimdphd/push2pacs*.

We chose to systematically name files as: RT_Dose_Fractionation_TreatmentEndDate (eg, RT_18Gy_1Fx_04.23.2020). If the dose map is fused onto a follow-up study, we add the prefix "PRIOR" to emphasize that the dose map is from a prior treatment. There is a choice of what the underlying volume is for the dose map. We chose to use the scan that was most crucial for contouring to best visualize the anatomy (eg, MRI brain for all intracranial cases). The registrations for these volumes to the CT simulation were done for clinical purposes, so the registration was simply applied for the dose maps from CT

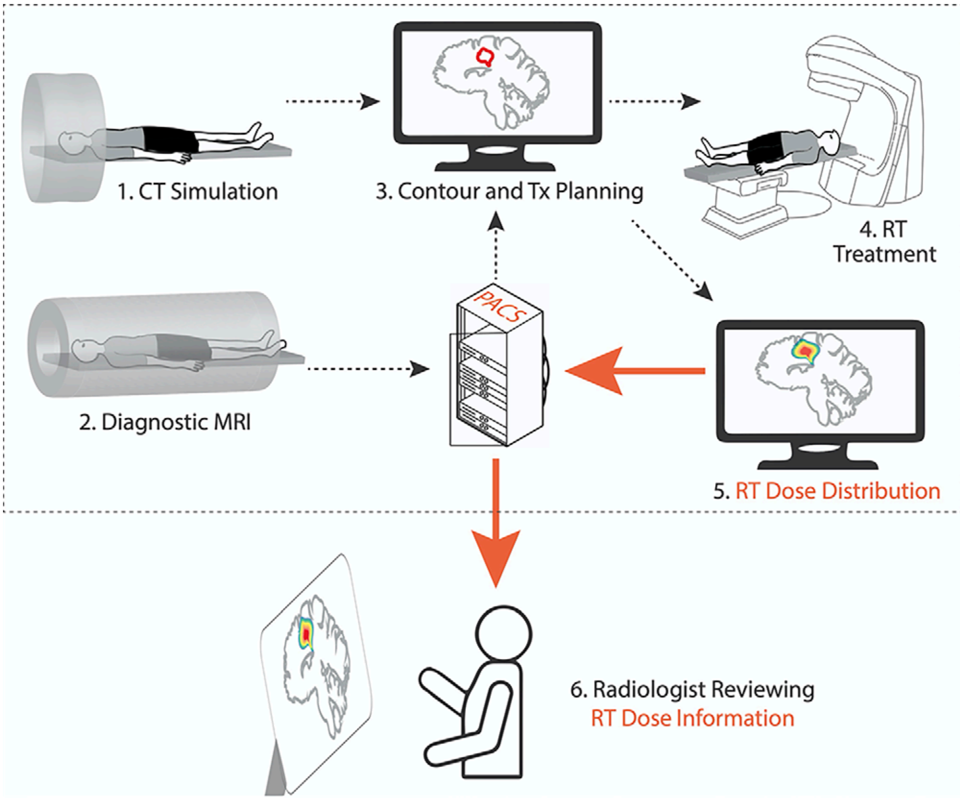

Figure 1: Connecting radiation oncology departmental computers to upload treatment plan images data into a picture archiving and communications system (PACS) enables sharing of radiation oncology–specific data with all medical providers. The radiation oncology workflow (top dotted box) includes obtaining diagnostic imaging and CT simulation scans, contouring and treatment planning, and the actual treatment delivery. This workflow largely remains as a black box to those outside of the field of radiation oncology. By exporting the radiation therapy (RT) dose distribution map to PACS (solid orange lines), the volumetric radiation history of a patient can be seen by radiologists for interpretation, by other oncologists for clinical evaluation, and in group settings such as tumor boards for multidisciplinary decision making.

simulation to the appropriate volume. For follow-up studies, we fuse a prior radiation therapy dose map to the new study, to say help differentiate progression from pseudoprogression, for example. In these cases, the medical physicist typically performs the fusion, and the physician reviews the fusion as well as the overlay of the radiation therapy dose map. The radiation therapy dose map is uploaded onto PACS as a new sequence with that nomenclature in the same series in which the underlying scan exists. This structured approach allows radiologists to consistently know where to retrieve the radiation therapy images for incorporation into their diagnostic evaluation. That is, if the underlying volume is an MRI brain, the radiation therapy dose map will appear as a new sequence within this series in PACS. If the underlying scan is a CT simulation, the CT simulation volume and dose map can be uploaded to PACS, as well. Institutional practices do vary on how radiation therapy studies are stored and/or read in PACS, but this framework allows for great flexibility. Formal radiology reads of the volumes and dose maps are not required but certainly could be requested, if desired. By allowing the dose map to be displayed on a variety of underlying volumes and allowing any study to be uploaded in PACS allows institutions freedom on how to systemically structure the sharing.

Notably, a dosimetrist, physicist, or medical resident physician reviews the case after the completion of treatment for quality assurance and prepares the radiation therapy dose distribution map to upload to PACS. The dose map is never uploaded until *after* the patient has completed treatment, ensuring that planned or incorrect dose maps are not erroneously sent. Quality assurance involves ensuring dose maps are appropriate, appear aligned to the underlying anatomic volume, and are correctly labeled. After upload to PACS, the volumes are retrieved in the PACS viewer and are inspected again to ensure the upload was successful.

Results

We demonstrate use cases of having these radiation dose distributions in our PACS with four real-world cases (Fig 2). These cases were discussed in real time at our multidisciplinary stereotactic radiosurgery conference in which the radiation dose maps were shown in PACS by the presenting radiologist. Many providers were intrigued by this display, as they had never before so easily been able to see these maps in real time during patient discussion. In these example cases, we were able to more rapidly decide the clinical actions right in the room during the conference *together*.

In addition to dose distribution maps, we also enabled the ability to send radiation oncology–specific imaging to PACS. These include daily onboard imaging such as cone-beam CT, CT, kilovoltage images, and megavoltage images—any DICOM data can be shared on PACS in the same manner. While these images are primarily used for positioning and alignment, sometimes they can capture important aspects of treatment responses. In addition, as radiation oncology departments continue to adapt new imaging technologies including MRI-linac (MRI-guided linear accelerator), these images can also be shared on PACS and provide a completely new set of data while the patient is undergoing radiation therapy. We have not implemented the routine practice of sending all image-guided radiation therapy images into PACS; rather, we can readily share these images as they may be clinically warranted (eg, to assess acute treatment effects and possible shrinkage in tumor size while the patient is undergoing radiation therapy).

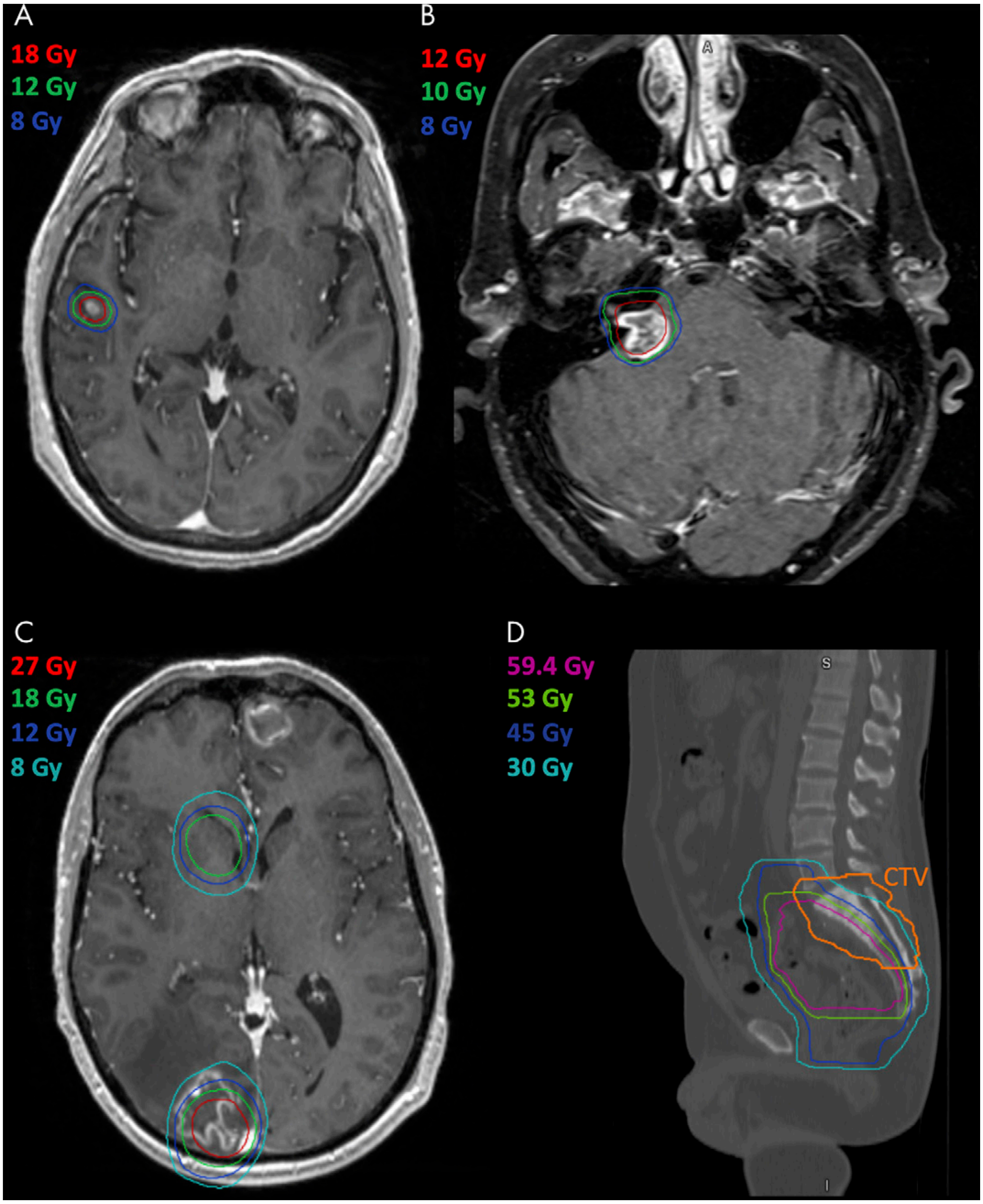

Figure 2: Isodose lines on a treatment planning MR image can be viewed on a picture archiving and communications system to allow radiologists and oncologists to readily know if a lesion received prior radiation treatment. Four example cases are shown in which the prior radiation dose aided in medical decision making. *A,* A previously treated lesion in the right superior temporal gyrus with SRS to 18 Gy 8 months prior showed residual enhancement at follow-up MRI. However, the new area of enhancement falls all within the 18-Gy isodose line, providing reassurance that the cause is likely radiation treatment effect. *B,* A right vestibular schwannoma was previously treated with 12 Gy at SRS 9 months prior with follow-up MR image now showing enhancement in the right cerebellopontine angle with increased size. The case was reviewed at our SRS conference, and consensus was made that the lesion shows radiation treatment effect given relation to prior isodose lines. *C,* A right occipital lesion was seen with enhancement after resection and postoperatively (SBRT) with 27 Gy to the resection cavity 12 months prior. The multidisciplinary team reviewed isodose lines without clear consensus whether the lesion represented treatment effect versus recurrence; consensus was made to try bevacizumab (Avastin) with possible reresection if no response. *D,* A previously treated colorectal adenocarcinoma to 59.4 Gy 3 years prior presented with sacral spine metastases. The CTV including S1-S3 was viewed on the CT simulation scan in relation to prior isodose lines, without significant prior overlap, giving confidence to proceed with 30 Gy in five fractions to the sacral spine. CTV = clinical target volume, SBRT = stereotactic body radiation therapy, SRS = stereotactic radiosurgery.

Discussion

We developed a framework and workflow in which after a patient completes a radiation therapy treatment course, we systematically upload the radiation dose distribution map for all medical providers to have access for review. This process has enabled better cross-disciplinary communication and understanding of the radiation history of a patient.

We piloted uploading radiation therapy dose distribution on our stereotactic radiosurgery cases, as these cases often require the most critical review of radiation history given the presentation of recurrences and multiple lesions within the brain and spine. By visualizing the isodose lines from treatment, the neuroradiologists can more systematically incorporate prior radiation therapy courses into their impression without relying on text or two-dimensional snapshots for assessment. We have also started routinely uploading prior radiation doses for review at our multidisciplinary stereotactic radiosurgery conference. Having the previous radiation therapy readily available has allowed management recommendations between radiation oncology, neurosurgery, and neuroradiology to be clearer, with less reliance on further review following the conference on dedicated radiation oncology software.

Radiation oncology as a specialty will likely continue to adopt dedicated imaging for therapeutic purposes that is distinct from diagnostic imaging. Currently, our image-guided radiation therapy images (imaging while the patient is on the treatment table) are never shared outside of our department. However, a cone-beam CT with the overlaid clinical target volume can often reveal the radiation treatment effect in tumor size reduction during the course of treatment. As these are simply DICOM images in our department, these can also readily be shared onto PACS through the same methods we present here. Moreover, with an MRI-guided linac in our department, we not only conduct MRI simulations but also have several custom MRI sequences that are used to delineate tumor characteristics during the course of a patient's treatment. These images combined with dose or contour information can now be shared on PACS, as well. Last, the future of radiation oncology will likely involve much more adaptive planning, which will utilize more and more imaging of the patient while the patient is on the treatment table. These images can also now be readily added to the patient's record in PACS.

While there are several advantageous aspects of sharing radiation dose with our colleagues, we must also responsibly use this tool. If incorrect dose information is shared, there could be negative consequences due to adverse medical decision making. For this reason, we chose not to fully automate uploading of dose information onto PACS at this time. Rather, a dosimetrist, physicist, or medical resident reviews the case at the end of treatment and uploads to PACS after verification of treatment completion. Nonetheless, the creation of the fused dose maps is largely automated, but we have deliberately not scripted the sending of radiation dose maps to PACS to enforce quality review. While this is a manual process, the process can be rapidly deployed, and a treatment course can be uploaded to PACS in approximately 2 minutes. Additionally, fusions of dose maps onto posttreatment imaging depend on being able to reliably register the prior and posttreatment imaging. If anatomy significantly changes (from weight loss, tumor shrinkage, surgical hardware, etc), this can pose a significant challenge. We have faced this issue and have been able to use deformable image registration to permit the fusion in several cases; however, these cases particularly need to have thorough quality assurance delivered. In some cases, fusions may not be feasible, but we can still provide radiation dose maps on the prior imaging and send this information to PACS.

Importantly, there is some concern that sharing radiation dose maps with providers without radiation oncology expertise may subject the information to misinterpretation. This is certainly possible, but we emphasize that sharing radiation dose maps is an excellent opportunity to open the door for further communication with radiation oncology departments. If the neuroradiologist, surgeon, or medical oncologist have any questions regarding the interpretability or decisions based on this new information, we would welcome discussions. As radiation oncologists, we could help shed light on the details of acute, subacute, and late radiation changes; the impact of the fractionation regimen; and the clinical consideration of integral dose to organs at risk—all in the aims of providing better management for the individual patient. Further, our early experiences have already revealed that this is not a one-way stream—our neuroradiologists have also been educating us on how they radiographically differentiate effects of radiation changes versus progression, which is now made easier by having the dose information on the diagnostic studies.

We were ultimately motivated to build this framework because it became apparent to our colleagues (and to us) that the medical record was lacking a critical component of a patient's radiation therapy history—a three-dimensional viewable radiation dose distribution map. Dose maps can now be systematically and rapidly uploaded to PACS for all medical providers to review. We document how we implemented this in a vendor-specific format through MIM at our institution as it fit our clinical workflow best, but we also provide how open source tools can be leveraged to enable sharing radiation therapy data onto PACS in a vendor-agnostic manner. In our early experience, this has been greatly appreciated by radiologists for improving the ease and accuracy of image interpretation, as well as by medical and surgical oncology for case discussion. Sharing dose information will also help improve the visibility of radiation oncology in the medical record, inviting new innovations across disciplines. Most crucially, the radiation dose map serves as a central insight into a patient's history, which can now be used more to improve patient care.

Acknowledgment: We thank Li Chang in our department of Information Services & Solutions team at UCLA for working with us to enable our department computers to interface with the hospital PACS infrastructure.

Author contributions: Guarantors of integrity of entire study, R.R.S., S.T., J.H., T.K.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, R.R.S., J.D., J.H.; clinical studies, R.R.S., N.S., N.A.; experimental studies, S.T.; and manuscript editing, all authors

Disclosures of Conflicts of Interest: **R.R.S.** Activities related to the present article: disclosed no relevant relationships. Activities not related to the present article: institution received fellowship award sponsored by the American Society of Radiation Oncology and Varian to conduct a research fellowship during residency; trainee editorial board member of *Radiology: Imaging Cancer*. Other relationships: disclosed no relevant relationships. **N.S.** disclosed no relevant relationships. **J.D.** disclosed no relevant relationships. **M.M.** disclosed no relevant relationships. **S.T.** Activities related to the present article: disclosed no relevant relationships. Activities not related to the present article: institution received grant from Brainlab; author received honorarium from Brainlab. Other relationships: disclosed no relevant relationships.

N.A. Activities related to the present article: disclosed no relevant relationships. Activities not related to the present article: institution received grant from Brainlab (clinical research agreement unrelated to this work); author received payment from Brainlab for occasional lectures and webinars; author paid for lecturing at Brainlab Academy in Munich; author expert panel member of Novalis Accreditation. Other relationships: disclosed no relevant relationships. **J.H.** Activities related to the present article: disclosed no relevant relationships. Activities not related to the present article: Soylent Nutrition sponsored a nutrition clinical trial for which author is principal investigator. Trial involves evaluating a novel nutritional supplement during head and neck chemoradiation, which is outside of the scope of this manuscript. Other relationships: disclosed no relevant relationships. **T.K.** disclosed no relevant relationships.

References

1. Shaverdian N, Yoo SM, Cook R, et al. Gaps in Radiation Therapy Awareness: Results From an Educational Multi-institutional Survey of US Internal Medicine Residents. Int J Radiat Oncol Biol Phys 2017;98(5):1153–1161.
2. Pan HY, Mazur LM, Martin NE, et al. Radiation Oncology Health Information Technology: Is It Working For or Against Us? Int J Radiat Oncol Biol Phys 2017;98(2):259–262.
3. CB-CHOP: A simple acronym for evaluating a radiation treatment plan. https://appliedradiationoncology.com/articles/cb-chop-a-simple-acronym-for-evaluating-a-radiation-treatment-plan. Accessed May 9, 2020.
4. Blodgett K, Luick M, Colonias A, Gayou O, Karlovits S, Werts ED. Image storage in radiation oncology: What did we learn from diagnostic radiology? In: Siddiqui KM, Liu BJ, eds. Proceedings of SPIE: medical imaging 2009—advanced PACS-based imaging informatics and therapeutic applications. Vol 7264. Bellingham, Wash: International Society for Optics and Photonics, 2009; 726414.
5. Law MYY, Liu B, Chan LW. Informatics in radiology: DICOM-RT-based electronic patient record information system for radiation therapy. RadioGraphics 2009;29(4):961–972.
6. Law MYY, Huang HK. Concept of a PACS and imaging informatics-based server for radiation therapy. Comput Med Imaging Graph 2003;27(1):1–9.
7. Law MYY, Liu B. Informatics in radiology: DICOM-RT and its utilization in radiation therapy. RadioGraphics 2009;29(3):655–667.
8. Fedorov A, Beichel R, Kalpathy-Cramer J, et al. 3D Slicer as an image computing platform for the Quantitative Imaging Network. Magn Reson Imaging 2012;30(9):1323–1341.
9. Pinter C, Lasso A, Wang A, Jaffray D, Fichtinger G. SlicerRT: radiation therapy research toolkit for 3D Slicer. Med Phys 2012;39(10):6332–6338.