Published in final edited form as:

AJR Am J Roentgenol. 2017 February ; 208(2): W31–W37. doi:10.2214/AJR.16.16845.

Radiology Reports With Hyperlinks Improve Target Lesion Selection and Measurement Concordance in Cancer Trials

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Abstract

OBJECTIVE—Radiology reports often lack the measurements of target lesions that are needed for oncology clinical trials. When available, the measurements in the radiology reports often do not match those in the records used to calculate therapeutic response. This study assessed the clinical value of hyperlinked tumor measurements in multimedia-enhanced radiology reports in the PACS and the inclusion of a radiologist assistant in the process of assessing tumor burden.

MATERIALS AND METHODS—We assessed 489 target lesions in 232 CT examinations of 71 patients with metastatic genitourinary cancer enrolled in two therapeutic trials. We analyzed target lesion selection and measurement concordance between oncology records (used to calculate therapeutic response) and two types of radiology reports in the PACS: multimedia-enhanced radiology reports and text-only reports. For statistical tests, we used the Wilcoxon signed rank, Wilcoxon rank sum test, and Fisher method to combine *p* values from the paired and unpaired results. The Fisher exact test was used to compare overall measurement concordance.

RESULTS—Concordance on target lesion selection was greater for multimedia-enhanced radiology reports (78%) than the text-only reports (52%) (*p* = 0.0050). There was also improved overall measurement concordance with the multimedia-enhanced radiology reports (68%) compared with the text-only reports (38%) (*p* < 0.0001).

CONCLUSION—Compared with text-only reports, hyperlinked multimedia-enhanced radiology reports improved concordance of target lesion selection and measurement with the measurements used to calculate therapeutic response.

Keywords

hyperlinks; multimedia; radiology reports; Response Evaluation Criteria in Solid Tumors (RECIST) 1.1; tumor assessment

Cross-sectional imaging and objective criteria such as the Response Evaluation Criteria in Solid Tumors (RECIST) 1.1 [1, 2] are used to assess tumor burden in cancer patients on clinical trials. This assessment involves measuring selected malignant target lesions consistently over time. However, obtaining quantitative tumor assessments can be a tedious, time-consuming process, and these assessments may be difficult for oncologists to manage.

Metastatic target lesions are often inconsistently selected in radiology reports, and the target lesions selected in radiology reports often differ from the target lesions that are documented in the electronic medical records (EMRs) by medical oncologists and used to determine therapeutic response. Many tools [3] and workflows have been developed to minimize this variability [4] and improve lesion quantification by radiologists [5, 6]. However, oncologists and radiologists often disagree on the radiology reporting quantitative content [7, 8] and on target lesion selection, which often results in oncologists measuring lesions independently or needing an additional consultation with radiologists. Duplicated efforts lead to target lesion selection differences, measurement discrepancies, and inefficiency.

At the National Institutes of Health Clinical Center, radiology reports were previously text only, and metastatic lesions were randomly selected for measurement. Thus, the evaluation of tumor burden in patients on clinical trials often differed between radiologists and oncologists.

In this study, we compared text-only reports with multimedia-enhanced radiology reports that included hyperlinked measurements with the help of a radiologist assistant (RA) to see whether we could improve the concordance of tumor response assessments (Fig. 1).

Published medical oncology surveys support the use of multimedia-enhanced radiology reports that include hyperlinked measurements and additional supplemental tumor reports with graphs and tables [9, 10]. After initial testing of hyperlinked reports, we presented preliminary data in a separate study and of a different cohort that showed that oncologists are better able to find lesion measurements when the measurements are linked to their textual descriptions in radiology reports [11].

Materials and Methods

In collaboration with the vendor of our PACS workstation, we codeveloped the capability to include hyperlinks in our reports in the PACS (VuePACS, version 12.0, Carestream Health). Since February 2015, our radiologists have routinely generated multimedia reports that include hyperlinks to images of the measured lesions. Clicking on the hyperlink in the text that lists the lesion measurements and slice and image numbers sends the clinician directly to the precise image on which the measurements were made.

In this HIPAA-compliant institutional review board (IRB)–exempt study, we retrospectively assessed CT examinations of the chest, abdomen, and pelvis and reviewed previously selected target lesions in 71 consecutive patients with metastatic genitourinary cancer. These patients were enrolled in two IRB-approved therapeutic clinical trials (NCT01688999 and NCT02496208) with RECIST 1.1 available data from September 2015 to February 2016.

We analyzed 232 CT examinations of 71 patients with genitourinary cancer (55 patients with urothelial carcinoma, five with urachal adenocarcinoma of the bladder, four with small cell carcinoma of the bladder, three with squamous cell carcinoma of the bladder, three with germ cell tumor, and one with sarcomatoid differentiated bladder cancer) for a total of 489 target lesions. See Figure 2A for the distribution of the target lesions by anatomic location.

An RA—in this case, a postdoctoral research assistant—compared the target lesions selected by the oncologist and the lesions reported in the final radiology reports (text-only radiology reports vs multimedia-enhanced radiology reports) and calculated target lesion measurement concordance as a percentage of matched measurements (i.e., number of target lesion measurements in radiology reports that match target lesion measurements recorded by oncologists).

Workflow

Target lesion measurements on follow-up CT examinations are compared with target lesion measurements on the baseline CT examination either semiautomatically (on the basis of x,y image, z table space, and local computer-aided detection [12]) or manually (by an RA, in our case) [13]. See Appendix 1 for more detail about how comparisons of these measurements allow RECIST 1.1 calculations and graphing lesion size over time.

Our new workflow empowers an RA to close communication gaps between oncologists and radiologists by verifying target lesion selection and ensuring that the proper baseline date is set in the PACS (Fig. 1). Lesion measurement data from prior or current examinations are stored in Bookmark Tables available to radiologists and referring clinicians. The end product is a multimedia-enhanced radiology report that includes measurements of target lesions with automated RECIST 1.1 calculations presented in tables and graphs to show lesion size changes over time (Fig. 3).

Statistical Analysis

We assessed the level of agreement between lesion identification reports of individual patients made by radiologists and oncologists and noted if the reports were multimedia-enhanced radiology reports, text-only reports, or a combination of both in baseline and follow-up examinations. If a patient's lesions were measured and reported in both multimedia-enhanced radiology reports and text-only reports, the percentage of matched lesions (radiologist-determined and oncologist-determined lesions) was subtracted (text-only reports minus multimedia-enhanced radiology reports) within each patient, and the difference was then tested for statistical difference using a Wilcoxon signed rank test. For patients whose lesions were measured using one or the other method but not both, the percentage of matched lesions was compared between the two groups using an exact Wilcoxon rank sum test. Finally, the two separate p values from both tests were combined using the Fisher method for combining p values to obtain an overall measure of the impact of multimedia-enhanced radiology report evaluation on assessing lesion matching between the oncologist and radiologist. Overall measurement concordance fractions within multimedia-enhanced radiology reports and text-only reports on a per-lesion basis were compared using the Fisher exact test.

Results

For both paired (both types of reports) and unpaired (one type of report) groups, target lesion selection and measurement concordance were greater with the multimedia-enhanced radiology reports than with the text-only reports (Table 1). Results for the 13 patients with paired reports slightly favored multimedia matches, with a suggestion toward a higher percentage of matches with multimedia-enhanced radiology reports than with text-only reports; the mean per-patient percentage of matches with the multimedia-enhanced radiology reports exceeded that of the text-only reports by 9.4% ($p = 0.19$).

For the 58 patients with only one type of report (15 multimedia-enhanced radiology reports and 43 text-only reports), there was a significant difference in matched percentages favoring the multimedia-enhanced radiology reports. For the 15 patients with only multimedia-enhanced radiology reports, the mean fraction of identified lesions per patient was 80%, whereas it was 52% per patient for those with text-only reports ($p = 0.0031$).

After combining the results using the Fisher method, the overall concordance between the radiology reports and EMRs showed a statistically significant difference: A higher overall percentage of matching results was obtained with the multimedia-enhanced radiology reports than with the text-only reports ($p = 0.0050$) (Fig. 4A). On a per-lesion basis, the overall measurement concordance was significantly higher with the multimedia-enhanced radiology reports (concordance: 87/128 lesions [68%]) than with the text-only reports (64/167 lesions [38%]) ($p < 0.0001$, Fisher exact test) (Fig. 4B). Figure 2 shows the anatomic distribution of target measurements reported by radiologists (combined multimedia-enhanced radiology reports and text-only reports) that were discrepant from EMR measurements. We should mention that, as part of routine clinical workflow, multiple radiologists reported on these patients over time, whereas only one oncologist reviewed these cases from an oncologist's perspective.

Discussion

Target Lesion Concordance

At the NIH Clinical Center, radiologists' target lesion selection and measurements made in the PACS often are verified independently by oncologists or are verified by oncologists in additional consultations with radiologists. Before the use of multimedia-enhanced radiology reports, target lesion selection and measurements were inconsistent in approximately half the cases. Even when the target lesions in the radiology reports matched the target lesions in the EMRs, they were often measured differently, resulting in discrepant lesion measurements in the radiology reports and oncology records [14].

In this study, the use of multimedia-enhanced radiology reports yielded significantly improved target lesion selection and measurement concordance with the records used to calculate therapeutic response. This concordance is especially important now that reports from both radiologists and oncologists may be available to patients in patient portals because discrepancies could lead to patient frustration, confusion, and other potential unintended consequences [15].

Our analyses suggest that multimedia-enhanced radiology reports with hyperlinks improve the consistency of radiologists' selection of target lesions, while providing measurement tables and graphs of lesion size changes over time. The measurement tables and graphs make the radiology reports more informative for oncologists. This information is a high priority because oncologists use temporal changes in target lesion size to determine therapeutic response, which is recorded in the EMR. The increased use of hyperlinks and new workflow design improved agreement of radiology reports with EMRs on measured lesions. Notably, discrepancies were not errors or oversights but, rather, were workflow-dependent and variable choices of target lesions, similar to cases reported in the literature [16–18].

Coregistration of examinations over time is based on anatomic recognition [19, 20] in our PACS, allowing easier follow-up of lesions measured [21] because the prior measurement annotations remain on the prior examination. An important feature in these systems is that the annotations can be toggled off during visual interpretation to minimize distractions.

We chose to compare exact matches in measurement concordance: Any difference in lesion measurements, even differences of 1 mm, constituted a mismatch and further indicated that oncologists do not rely on radiologists' measurements. Analyzing possible causes for measurement variability was not an objective of this study. However, we found that of the discordant measurements reported in radiology reports, 33% were measurements of lymph nodes, probably because lymph node lesions are more likely to change shape over time and tend to be smaller (Fig. 2B). We believe the improved measurement concordance in multimedia-enhanced radiology reports is partially a result of the oncologists using the hyperlinked measurements because these measurements are easier to find. Our oncologists' experience using multimedia-enhanced radiology reports for 2 years supports the increased use of radiologists' measurements. We assessed the percentage of matched measurements because fewer discrepancies result in less time needed for correcting the discrepancies in the PACS and for discussing measurement differences in consultation.

It was nearly three times faster for the RA to extract measurement data from the multimedia-enhanced radiology reports than from the text-only reports (Fig. 4C); these results are similar to those of previous quality improvement pilot studies mentioned earlier. Further studies addressing the timing and efficiency of multimedia reports and new workflows involving digital data management are warranted. Furthermore, we are confident that managing lesion measurements in PACS will make the overall tumor assessment process more efficient and that, ideally, all measurement data could be exported directly from the PACS once a therapeutic cancer trial is complete [22], which would eliminate handwritten reporting, reduce reporting errors, and increase efficiency.

The use of an RA further improved communication in the tumor assessment workflow. The RA was often able to measure lesions before a scheduled radiology consult, allowing real-time review of response and making radiology-oncology consultations more effective.

Study Limitations

Although this study was conducted only in patients with genitourinary cancers, other cancer teams at our institution have also adopted this new workflow, which suggests a wide application for the multimedia-enhanced radiology reports system. This system is available to departments that have a PACS manufactured by Carestream Health if they request this capability. This capability depends partly on the technologic feature of linking reports to images. Until this possibility of multimedia reporting is widespread and compatible across vendors, an RA can be included in the workflow to help be an intermediary between oncologists and radiologists.

Because workflow was modified simultaneously with a PACS upgrade, it is not possible to attribute our results to one change over the other (i.e., potential confounding factors). Our primary objective was to improve consistency of target lesion selection and measurements in radiology reports and EMRs while providing more meaningful reports and not to determine the effects of isolated interventions.

As with any technologic advances, there are often disruptive incompatibilities, such as hyperlinks not working in our EMRs or patient portal. This problem was remedied by disabling hyperlinks while keeping the text. We also enabled the importing of series and slice numbers automatically to allow this information to remain in our reports when sent with the images to outside facilities. In our experience, inclusion of this information improves the radiologist's efficiency by reducing the time needed to cross-check measurements and slice and image numbers.

The annotations and markups made in our PACS appear to follow the current conformance requirements of the Annotation Image Markup (AIM) initiative, which was created to standardize metadata such as measurements and other annotations and calculations in a way that allows intervendor accessibility; requirements and specifications for this standard continue to develop [23]. After several years of collaborating with our PACS vendor and urging our PACS vendor to adhere to the AIM initiative, we believe that data acquisition and exportation are flexible enough to be ready for transfer to an outside institution that uses a different PACS vendor. For example, exportation formats include tab-delimited comma-separated values, HTML, and so on.

Conclusion

Our results show that multimedia reports with hyperlinked measurements with tables and graphs improve target lesion selection and measurement concordance. Thus, multimedia-enhanced radiology reports provide more information for oncologists than text-only radiology reports.

Our new workflow allows radiologists to consistently measure target lesions while an RA mitigates any discrepancies, achieving 100% precision in the PACS to allow management of all measurement data in the PACS. This system also shows the feasibility of direct data exportation. We believe managing target lesion measurements in the PACS with direct data exportation will further improve efficiency by potentially eliminating handwritten

measurements on paper forms and subsequent separate data-entry steps and by obviating the need for a third-party application.

Acknowledgments

L. R. Folio and L. B. Machado are associate investigators in a research agreement with Carestream Health (Rochester, NY).

The content of this article is the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

This research was supported in part by the Intramural Research Program of the NIH Clinical Center.

We thank Andrew Dwyer for manuscript review and Deneise Francis and Elizabeth Lamping for record review.

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APPENDIX 1

Step-by-Step Tasks for Study and Details About Study Design

Record data from electronic medical records (EMRs) of patients in a clinical trial and select chest, abdomen, and pelvis CT examinations.

- 1 Patient cohort: Genitourinary cancer patients who were enrolled in one of two institutional review board–approved treatment protocols from September 2015 to February 2016 and whose EMRs included Response Evaluation Criteria in Solid Tumors (RECIST) 1.1 evaluations.
- 2 Objective: To compare radiology reports with oncology records (i.e., EMRs).
 - a. Baseline and follow-up dates provided.
 - b. Recorded the following information for the target lesions selected by the oncologists and documented in EMRs: location, measurements, and RECIST 1.1 calculations.
 - c. Recorded target lesions reported by radiologists that matched location and measurements of target lesions in EMRs (i.e., target lesions selected by oncologists).
- 3 When patients exhibited a best response (nadir), data were exported to Microsoft Excel and baseline date was reset.
 - a. We were able to do both calculations in the PACS on each follow-up by resetting the baseline in the Bookmark Table.
- 4 When a patient needed to undergo CT because of clinical signs and symptoms or because of worsening symptoms, this CT examination was counted as a follow-up examination only if it included the target lesions and if the timing was appropriate.
- 5 Verify and update information for the PACS database (part of our new workflow).
 - a. Set the baseline date provided by the oncologist in the Bookmark Table.
 - b. Verify lesion selection and lesion measurements listed in the EMRs.

- c. Remeasure lesions and label measurements as information is provided by the oncologist.
 - d. Compare target lesions and nontargets over time by defining follow-up sets.
 - e. Save key images of verified target lesions with correct measurements.
 - i. Save key images of other findings including nontargets.
 - ii. Include these other findings in tumor report with graphs and target lesion table.
 - f. Compare RECIST 1.1 calculations made by oncologist's team versus calculations made automatically by PACS after lesions have been verified.
 - g. Correct any discrepancies to achieve 100% accuracy in PACS to show the feasibility of direct data exportation (series and slice numbers) regardless of whether it is a target lesion or other finding, regardless of anatomic location (lung, liver, or lymph node mass or mass in another location), baseline date, creator, and so on. Similar to oncologist, radiologist needs baseline date to assess tumor progression to further close communication gaps.
- 6 Export data. From Bookmark Table, Tumor Report is exported by Full-Featured Editor Format (MIME HTML [MHTML]) into Microsoft Excel (Match Destination Formatting).
- 7 Save tumor report.
- a. A radiologist assistant labels CT examinations when they are ready to be saved.
 - b. The radiologist opens the CT examinations in the PACS and verifies measurements performed and identifies key images containing relevant findings.
 - c. Preview Report option is checked.
 - d. Radiologist saves report.
 - e. A pop-up alerts the radiologist that the report has been saved.
-

Fig. 1.

Top row shows old workflow, and bottom row shows new workflow. For old workflow, typical tumor assessment started with selection and measurements of index (arbitrary) lesion by radiologist. Lesion selected by radiologist and lesion measurements were often different from information in electronic medical records, which indicated duplicated efforts.

Inconsistent text-only radiology reports that compare measurements with measurements from only prior examination (instead of baseline examination) were not adequate for oncologists to assess tumor burden. To record measurement data, oncology registrars (nurse practitioners, physician assistants, oncologists) would handwrite data on Response Evaluation Criteria in Solid Tumors (RECIST) 1.1 worksheets. Later, staff would type data from worksheets into cancer central clinical database. For new workflow design, radiologist assistant helps close communication gaps between radiologists and oncologists by verifying date of baseline examination, selection and measurements of target lesions, and comparisons of lesions over time. Hyperlinked measurements facilitate observation and analysis of target lesions for oncologists, potentially obviating need for handwriting and dual data entry.

Fig. 2.

Bar graphs show distributions of target lesions recorded in electronic medical record (EMR) and in radiology reports, regardless of report type, by anatomic location. Other = muscle, kidney, spleen, pancreas, and adrenal glands.

A, Target lesions recorded in EMR. Of target lesions recorded in EMRs, 40% were lymph node lesions; 28%, lung lesions; 12%, liver lesions; and 20%, other.

B, Of target lesions reported in radiology reports in which measurements were discrepant with EMR, 33% were lymph node lesions; 30%, lung lesions; 10%, liver lesions; and 27%, other.

FINDINGS:

Chest CT: Heart: Normal size and chamber morphology allowing for age. No pericardial effusion.

Mediastinum: Unchanged small mediastinal nodes right paratracheal right hilar (1.3 cm x 1.2 cm) (series 3, image 37)

Left retrocrural nodes (1.5 cm x 1.1 cm) (series 3, image 67)

Lungs, pleurae: Cavitory right lower lobe nodule decreased in size (2.0 cm x 1.8 cm) (series 5, image 283)

Abdomen CT: Liver, spleen, biliary, gallbladder: Normal size liver and spleen without concerning focal lesions. Intact gallbladder normal in appearance.

Pancreas, GI upper abdominal hollow organs: Pancreas is normal size and enhancement without ductal dilatation. Allowing for variation in contrast opacification, stomach and duodenum normal.

GU Kidneys, adrenal glands: Post left nephrectomy.

GI Small and large bowel, mesentery, peritoneum: Limited by incomplete bowel opacification. No evidence bowel dilatation, mesenteric mass or peritoneal mass or fluid.

Pelvic CT: Central pelvis, sidewalls: Normal for age, gender.

Osseous structures, soft tissues: No skeletal or soft tissue findings of concern, age related changes..

Lymph nodes, vascular: No peripheral adenopathy or retroperitoneal adenopathy.

IMPRESSION:

Decrease in right lung mass. Stable mediastinal adenopathy.

A

Fig. 3.

Sample multimedia-enhanced radiology report shows data from baseline and four follow-up CT examinations of 59-year-old man with metastatic urothelial carcinoma.

A, Sample multimedia-enhanced radiology report in which hyperlinked measurements (arrows) direct oncologists to each measured lesion (3D location, lesion name, series number, and image number). Radiologist dictates “hyperlink” after PACS measurement that automatically imports hyperlink along with series and slice numbers, saving time and reducing errors. Radiologist is also prompted to target lesions that are followed by oncologists. In this case, radiologist identified three target lesions: B01 (F06), B03 (F01),

and B24 (F05). Hyperlinks and annotations in coregistered images also direct radiologists to measure same lesions on next follow-up examination for consistency. GU = genitourinary, GI = gastrointestinal.

Sample multimedia-enhanced radiology report shows data from baseline and four follow-up CT examinations of 59-year-old man with metastatic urothelial carcinoma.

B, Table shows metadata for three target lesions B01 (F06), B03 (F01), and B24 (F05) including measurements, lesion names, series and image numbers, and automated Response Evaluation Criteria in Solid Tumors (RECIST) 1.1 calculations for baseline and four follow-up examinations. Numbers indicating lesion sizes and size changes over time are plotted on graph that radiologist and oncologist can read quickly. Data in parentheses show changes compared with baseline. Dashes (--) indicate not applicable. RT = right, LT = left, DT = doubling time, B23 = finding (lesion measurement) on current follow-up examination.

Fig. 4.

Target lesion selection (**A**), measurement concordance (**B**), and mean time for tumor measurement extraction from radiology reports (**C**).

A, Multimedia-enhanced radiology reports improved target lesion selection concordance over text-only reports (78% vs 52%, respectively).

B, Multimedia-enhanced radiology reports improved target lesion measurement concordance compared with text-only reports (68% vs 38%).

C, Mean time to extract individual lesion measurements from multimedia-enhanced radiology reports was almost one third of that required to extract individual lesion measurements from text-only reports for radiologist assistant.

TABLE 1

Text-Only Radiology Reports and Multimedia-Enhanced Radiology Reports Created by Radiologists and Interpreted by Oncologists: Target Lesions Recorded by Oncologists and Number of Target Lesions Matched by Radiologists in Their Reports

Reader or Interpreter	Type of Report							
	Text-Only Reports (<i>n</i> = 166)				Multimedia-Enhanced Radiology Reports (<i>n</i> = 66)			
	Target Lesions Reported		Matched Measurements ^a		Target Lesions Reported		Matched Measurements ^a	
	No.	%	No.	%	No.	%	No.	%
Radiologist	167	52	64	38	128	78	87	68
Oncologist	324	100			165	100		
								Total No. of Target Lesions
								295
								489

^aFor example, a target lesion in the radiologist's report is listed as measuring 2.4 cm, and the same lesion is also reported as 2.4 cm in the EMR. Note that the oncologist's matched measurements are blank because the oncologist's interpretation is the basis for the comparison because it is listed in the EMR and used for calculating therapeutic response.