Radiologist Adoption of Interactive Multimedia Reporting Technology

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Abstract

Purpose: To determine if radiologists find enough value in available interactive multimedia reporting technology to routinely adopt it into clinical practice.

Materials and Methods: Our institution’s reporting application (Vue Reporting, Carestream Health) allows the incorporation of multimedia elements, including active hyperlinks, into clinical reports, but would radiologists find enough value in this technique to change their practice? We retrospectively reviewed 559,841 diagnostic reports issued July 2016 to February 2018 for the presence of text hyperlinks that interactively connect to imaging findings in the PACS. Results were subdivided by modality, reporting radiologist role (ie, resident, fellow, attending physician), and subspecialty. Average percentages over the final 6 months were chosen to represent established adoption rates.

Results: For each modality, the 6-month average percentages of reports containing hyperlinks to imaging findings subdivided by the role of the radiologist who created the report were found to be as follows: CT: residents = 27.6%, fellows = 19.5%, attending physicians = 26.0%; MRI: residents = 26.6%, fellows = 8.7%, attending physicians = 5.1%; and PET/CT: residents = 53.3%, fellows = 46.7%, attending physicians = 19.4%. Rates were 0% to 4% among ultrasound, radiography, and nuclear medicine reports, regardless of radiologist role. The 6-month average percentages of CT and MRI reports with hyperlinks to imaging findings varied by subspecialty from 5.4% to 57.1%.

Conclusion: Our radiologists found enough value in available interactive multimedia reporting technology to adopt it into their clinical practice, commonly inserting hyperlinks into their CT, PET/CT, and MRI reports to create interactive connections to key imaging findings in the PACS.

Key Words: Interactive, multimedia, reports, reporting, hyperlinks

INTRODUCTION

One powerful feature of interactive multimedia reporting is that it creates a tight connection between the written imaging report and the image data within the PACS. This connection enables the radiologist to automate the insertion of image-related information into the report, and in turn, this information remains connected back to the images themselves via active hyperlinks within the report. These hyperlinks can then be clicked downstream by any report consumer, including care providers, the patient, or a radiologist reading a follow-up study (Fig. 1) [1,2]. Activation of a hyperlink launches the relevant annotated image and full scrollable study within the PACS; hence the term interactive.

Our institution enabled interactive multimedia reporting, including the ability to add hyperlinks to reports, in our clinical environment in 2016. We hypothesized that our radiologists would see enough value in this technique to change their practice of reporting. The purpose of this retrospective study is to quantify the presence of active hyperlinks in our clinical imaging reports, which
connect interactively with imaging findings in the PACS, to determine if our radiologists routinely adopted interactive multimedia reporting technology into practice.

MATERIALS AND METHODS

This HIPAA-compliant study did not require formal review by our institutional review board because it qualified as a quality improvement project.

Our department is comprised of approximately 50 attending radiologists, 40 residents, and 20 fellows reporting roughly 400,000 examinations per year. We implemented interactive multimedia reporting capabilities in 2016 via native reporting within our existing PACS (Vue PACS with Vue Reporting, version 12, Carestream Health, Rochester, New York).

We retrospectively analyzed diagnostic imaging reports \( (n = 559,841) \) issued consecutively over a 20-month period (July 2016 to February 2018). We included reports from diagnostic examinations from the following modalities: MRI, CT, radiography, ultrasound, general nuclear medicine, and PET/CT. We did not exclude reports from these groups, though by the nature of our criteria, we did not include interventional or fluoroscopic procedures or breast imaging reported with a different application.

We initially did not introduce interactive multimedia reporting techniques to our radiologists to ease the transition into the new reporting system. Our study period began 7 months after implementation of the new reporting application. Brief training in interactive

**IMPRESSION:**

1. Status post T10-L3 PSIF and multilevel vertebroplasty with small extravasated cement in the right anterolateral epidural space at T11.
2. L1 burst fracture with 75% central height loss and retropulsion contributing to severe spinal canal narrowing, unchanged.
3. Moderate multilevel degenerative changes of the thoracic and lumbar spine as described and findings consistent with DISH.
4. Left upper lobe spiculated lung nodule \((1.7 \text{ cm x } 1.4 \text{ cm})\) \( (\text{series } 4, \text{ image } 151) \) is suspicious for potential malignancy though alternative differential diagnosis exists. Two small 6 mm rounded lymph nodes are noted within the adjacent mediastinum. This was discussed with chest radiology division and recommend formal CT chest for complete evaluation.
5. Right L1 transverse process fracture, left L1 lamina fracture and spinous process fracture, unchanged

**NOTIFICATION:** The spiculated nodule in the left upper lobe results of this study were discussed, and acknowledged by telephone on 2/7/2018 at 1:53 PM. EPIC in basket message.

**Recommendation:** Chest CT for spiculated left lung nodule.
multimedia reporting technique took place in month 3 of our 20-month study.

We collected the following data for each report: date of study, modality, presence of hyperlinks to imaging findings, role of the radiologist (ie, resident, fellow, or attending physicians) who created the first report draft (and thus likely inserted the hyperlinks), and the subspecialty of the attending radiologist.

**Technique of Inserting Hyperlinks Into Reports**

The process of inserting hyperlinks into reports begins with the creation of a bookmark, or reference point, on the images. The radiologist annotates an important imaging finding in the PACS (eg, bidimensional measurements are drawn on a lung mass, or an arrow is added to identify a labral tear), and this annotation becomes a bookmark, either automatically or manually, depending on the radiologist’s preference. The radiologist then gives a voice command to insert hyperlinked text into the report, which is automatically connected to the most recent bookmark. The hyperlink command also automatically inserts relevant image-related information into the report. In the example of bidimensional measurements of a lung mass, both measurements, as well as the series and image numbers, are automatically inserted into the report without the radiologist dictating this information (Fig. 1). This report text is hyperlinked, making it stand out as an important finding in the report (Fig. 1), and it is also active so that report consumers can click the link to launch an image viewer displaying the bookmarked image. The user can then scroll through other images of the study, if desired.

**Data Visualization and Statistical Analysis**

Imaging report hyperlink utilization was quantified on a monthly basis by calculating the number and the percentage of imaging reports that include one or more active hyperlinks. Monthly imaging report hyperlink utilization was determined by modality, reading radiologist role, and attending subspecialty level. The average monthly percentage of reports containing hyperlinks to bookmarked imaging findings from the final 6-month period (September 2017 through February 2018) was used to represent established reporting habits.

We hypothesized that our residents would create reports with hyperlinks more often than our faculty, because (1) more of them received training, and (2) they have less-established reporting habits. Null hypotheses related to subgroup comparisons of imaging report hyperlink utilization were tested by way of binomial

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**Fig 2.** Monthly percentages of imaging reports created with one or more active hyperlinks to bookmarked imaging findings in the PACS, presented by modality over the 20-month study period with exact 95% confidence intervals (A) and simplified visually via generalized estimating equation regression modeling (B). Radiologist training is denoted in month 3 by the gray hash-marked rectangle at the bottom left. NM = nuclear medicine; PT = PET/CT; US = ultrasound; XR = radiography.
generalized estimating equation (GEE) model Wald statistics.

Imaging report hyperlink utilization regression time profiles were estimated via binomial GEE regression models to identify temporal trends in imaging report hyperlink utilization. Within the different imaging modalities, reading radiologist roles, and attending subspecialties, the imaging report hyperlink utilization was estimated on the logit scale as a continuous restricted cubic function of calendar time. The time-dependent predictions of the binomial GEE regression model were transformed from the logit scale to the probability scale and then multiplied by 100% so that the predictions for imaging report hyperlink utilization could be displayed on the percentage scale as a function of calendar time.

RESULTS

Our 559,841 imaging reports were evenly distributed throughout the study period, with each month contributing 4.7% to 5.5% of the reports. The imaging reports were distributed among modalities as follows: CT 103,379 (18.5%), MRI 66,280 (11.8%), general nuclear medicine 4,061 (0.7%), PET/CT 3,894 (0.7%), ultrasound 49,230 (8.8%), and radiography 332,997 (59.5%). Similar distributions by modality were observed each month. Of all reports, 264,178 (47.2%) were first drafted by residents, and the remainder were first drafted by fellows (70,424; 12.6%) and attending physicians (225,239; 40.2%).

Figure 2 graphically depicts the percentages of imaging reports containing active hyperlinks by modality in monthly intervals throughout the study period. Adoption by radiologists by modality is represented by the final 6-month frequencies of reports containing hyperlinks (Table 1).

Table 1 also summarizes utilization of the reporting technique by radiologist role. For PET/CT reports, residents (53.3%) were more likely to draft reports with hyperlinks to imaging findings, subdivided by modality and by radiologist role that drafted the first report. This is one way to represent adoption rates because it reflects sustained elective usage (or lack thereof) long after completion of training.

Table 2. Final 6-month (ie, months 15-20) frequencies of reports containing hyperlinks to imaging findings, subdivided by signing radiologist subspecialty for modalities (MRI, CT) that commonly were associated with hyperlinks to images in their reports. This represents long-term adoption rates because it reflects sustained elective usage (or lack thereof) long after completion of training. PET/CT is included within the row for CT to present data from nuclear medicine.

<table>
<thead>
<tr>
<th>Role</th>
<th>PET/CT</th>
<th>CT</th>
<th>MRI</th>
<th>US</th>
<th>NM</th>
<th>XR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident</td>
<td>53.3%</td>
<td>27.6%</td>
<td>26.6%</td>
<td>2.2%</td>
<td>1.3%</td>
<td>0.4%</td>
</tr>
<tr>
<td>(49.6%, 57.1%)</td>
<td>(27.0%, 28.3%)</td>
<td>(25.2%, 28.1%)</td>
<td>(1.9%, 2.5%)</td>
<td>(0.7%, 2.1%)</td>
<td>(0.4%, 0.5%)</td>
<td></td>
</tr>
<tr>
<td>377 of 707</td>
<td>4,966 of 17,966</td>
<td>1,047 of 3,931</td>
<td>185 of 8,398</td>
<td>14 of 1,107</td>
<td>163 of 38,730</td>
<td></td>
</tr>
<tr>
<td>Fellow</td>
<td>46.7%</td>
<td>19.5%</td>
<td>8.7%</td>
<td>0%</td>
<td>3.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td>(41.8%, 51.7%)</td>
<td>(19.2%, 21.5%)</td>
<td>(8.2%, 9.3%)</td>
<td>(0%, 0.5%)</td>
<td>(0.1%, 19.6%)</td>
<td>(0.1%, 0.3%)</td>
<td></td>
</tr>
<tr>
<td>190 of 407</td>
<td>969 of 4,958</td>
<td>969 of 11,101</td>
<td>0 of 764</td>
<td>1 of 26</td>
<td>13 of 7,807</td>
<td></td>
</tr>
<tr>
<td>Attending</td>
<td>19.4%</td>
<td>26.0%</td>
<td>5.1%</td>
<td>0.8%</td>
<td>0%</td>
<td>0.4%</td>
</tr>
<tr>
<td>(10.8%, 30.9%)</td>
<td>(25.0%, 26.9%)</td>
<td>(4.5%, 5.7%)</td>
<td>(0.5%, 1.0%)</td>
<td>(0%, 5.1%)</td>
<td>(0.4%, 0.6%)</td>
<td></td>
</tr>
<tr>
<td>13 of 67</td>
<td>2,158 of 8,313</td>
<td>247 of 4,851</td>
<td>41 of 5,388</td>
<td>0 of 70</td>
<td>224 of 53,372</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49.1%</td>
<td>25.9%</td>
<td>11.4%</td>
<td>1.6%</td>
<td>1.3%</td>
<td>0.4%</td>
</tr>
<tr>
<td>(46.2%, 52.0%)</td>
<td>(25.4%, 26.4%)</td>
<td>(10.9%, 11.8%)</td>
<td>(1.4%, 1.8%)</td>
<td>(0.7%, 2.0%)</td>
<td>(0.4%, 0.4%)</td>
<td></td>
</tr>
<tr>
<td>580 of 1,181</td>
<td>8,093 of 31,237</td>
<td>2,263 of 19,883</td>
<td>226 of 14,550</td>
<td>15 of 1,203</td>
<td>400 of 99,909</td>
<td></td>
</tr>
</tbody>
</table>

NM = nuclear medicine; US = ultrasound; XR = radiography. *95% confidence interval.

**Table 1.** Final 6-month (ie, months 15-20) frequencies and 95% confidence intervals of reports containing hyperlinks to imaging findings, subdivided by modality and by radiologist role that drafted the first report. This is one way to represent adoption rates because it reflects sustained elective usage (or lack thereof) long after completion of training.

**Table 2.** Final 6-month (ie, months 15-20) frequencies of reports containing hyperlinks to imaging findings, subdivided by signing radiologist subspecialty for modalities (MRI, CT) that commonly were associated with hyperlinks to images in their reports. This represents long-term adoption rates because it reflects sustained elective usage (or lack thereof) long after completion of training. PET/CT is included within the row for CT to present data from nuclear medicine.

<table>
<thead>
<tr>
<th>Modality</th>
<th>Chest</th>
<th>NM</th>
<th>Body</th>
<th>Peds</th>
<th>MSK</th>
<th>NCV</th>
<th>Neuro</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT or PET/CT</td>
<td>57.1%</td>
<td>49.1%</td>
<td>29.7%</td>
<td>29.1%</td>
<td>5.8%</td>
<td>34.8%</td>
<td>5.4%</td>
</tr>
<tr>
<td>(55.8%, 58.4%)</td>
<td>(46.2%, 52.0%)</td>
<td>(28.7%, 30.7%)</td>
<td>(22.5%, 36.3%)</td>
<td>(5.0%, 6.7%)</td>
<td>(33.3%, 36.2%)</td>
<td>(5.0%, 5.9%)</td>
<td></td>
</tr>
<tr>
<td>3,423 of 5,994</td>
<td>580 of 1,181</td>
<td>2,376 of 7,996</td>
<td>52 of 179</td>
<td>165 of 2,850</td>
<td>1,548 of 4,454</td>
<td>529 of 9,764</td>
<td></td>
</tr>
<tr>
<td>MRI</td>
<td>40.0%</td>
<td>40.1%</td>
<td>18.5%</td>
<td>5.9%</td>
<td>8.8%</td>
<td>6.5%</td>
<td></td>
</tr>
<tr>
<td>(21.1%, 61.3%)</td>
<td>(38.3%, 42.0%)</td>
<td>(14.2%, 23.4%)</td>
<td>(5.3%, 6.5%)</td>
<td>(6.7%, 11.8%)</td>
<td>(6.1%, 71%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 of 25</td>
<td>1,130 of 2,816</td>
<td>54 of 292</td>
<td>329 of 5,608</td>
<td>45 of 512</td>
<td>695 of 10,630</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MSK = musculoskeletal; NCV = noninvasive cardiovascular; Neuro = neurology; NM = nuclear medicine; Peds = pediatric. *95% confidence interval is provided in parenthesis.
hyperlinks than fellows (46.7%) or attending physicians (19.4%) \((P < 0.001 \text{ for both})\). For MRI reports, residents (26.6%) were again more likely to draft reports with hyperlinks than fellows (8.7%) or attending physicians (5.1%) \((P < 0.001)\). Meanwhile, for CT reports, attending radiologists (26%) were of similar likelihood as residents (28%) and fellows (20%) to produce reports with hyperlinks.

Table 2 summarizes radiologist adoption of the reporting technique by subspecialty in the final 6 months of the study, focusing on the three modalities with reports that commonly included hyperlinks (ie, PET/CT, CT, and MRI). Figure 3 graphically depicts subspecialty utilization throughout the entire study period.

**DISCUSSION**

We sought to determine if our radiologists found available interactive multimedia reporting technology to be user friendly and potentially impactful enough to electively adopt it into clinical practice. We found that radiologists changed their reporting habits and

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**Fig 3.** Monthly percentages of imaging reports including one or more active hyperlinks to bookmarked imaging findings in the PACS when divided by subspecialty (body, chest, musculoskeletal, noninvasive cardiovascular, neurology, nuclear medicine, and pediatric) for (A) MRI with exact 95% confidence intervals; (B) MRI simplified to generalized estimating equation (GEE) regression predictions; (C) CT or PET/CT with exact 95% confidence intervals; and (D) CT or PET/CTs simplified to GEE regression predictions. Radiologist training is denoted in month 3 by the gray hash-marked rectangle at the bottom left of each figure part. The decrease in utilization by the pediatric division (gray) late in the study is felt to be related to the timing of significant staff turnover and replacement. MSK = musculoskeletal; NCV = noninvasive cardiovascular; NM = nuclear medicine; Peds = pediatric.
commonly elected to create interactive multimedia reports containing active hyperlinks to imaging findings in the PACS. By the final 6 months of our study, we observed that hyperlinks were included into 49.1%, 25.9%, and 11.4% of PET/CT, CT, and MRI reports, respectively. We found that use of the new technology was dependent on some training. Our reporting application supported the insertion of hyperlinks into reports at least 7 months before the beginning of our study; however, our radiologists were not exposed to training in the technique until study month 3. Our radiologists simply did not use it without training. We observed that adoption varied by modality, role of the radiologist creating the report, and subspecialty of the attending radiologist.

In the era of the ACR’s Imaging 3.0 initiative [3], the concept of interactive multimedia reporting has appeared in publications regarding how radiologists can improve the quality and value of their clinical work, improve communication, increase efficiency, and potentially influence provider referral patterns [4-9]. Despite these potential gains, there is very limited adoption of such technology. The hindrance may simply be limited market penetration. Interactive multimedia reporting requires a tight connection between the reporting application and the viewing application (ie, the PACS). This can be challenging in the widespread and traditional model where a third-party reporting application is integrated with another vendor’s viewer. A newer approach is to hybridize the reporting and viewing applications into one, creating leverage to more easily connect image data with report text, and vice versa. Implementations of interactive multimedia reporting technology using this newer approach have been described qualitatively at two independent institutions [1,2]. Our results build upon these reports by quantifying adoption of similar technology.

Our study has limitations. We studied only the radiologists at one institution, which limits generalizability. We observed variations between subspecialties and radiologist roles but can only speculate on the reasons for differences between study groups. Additionally, except in the example of a report dictated by an attending physician, we did not determine with absolute certainty which radiologist role created the report hyperlinks. Rather, the creator of the first draft, which was the trainee, was presumed to be the person who inserted the hyperlink into the report.

We found that radiologists with minimal training commonly adopted interactive multimedia reporting technology, routinely inserting hyperlinks into their CT, PET/CT, and MRI reports to actively connect text with imaging findings in the PACS. The continued growth in adoption late in our study suggests that this change in practice takes time. As other sites acquire such interactive multimedia reporting capabilities, their radiologists may similarly choose to adopt this technology. Although we demonstrated that our radiologists adopted interactive multimedia reporting, we do not yet have data on how often our referring providers and patients actually click on the report hyperlinks that we create. We know anecdotally that when reviewing a prior study, our radiologists find it helpful or time-saving to click the hyperlinks in the previous report, but we have not studied this impact directly. A next step is to quantify the impact of the interactive multimedia reports themselves—do report consumers click the hyperlinks, do they save time, and do they improve their understanding?

**TAKE-HOME POINTS**
- Interactive multimedia radiology reporting is not in widespread use despite the reported potential to add value, improve communication, increase efficiency, and influence provider referral patterns. This may relate to limited market penetration of available technology that hybridizes viewing and reporting functions into one application.
- Interactive multimedia reporting is enough of a departure from traditional plain-text–only style of reporting that adoption by our radiologists did not occur before training, even though the technology was available.
- Over time, and after training, interactive multimedia reporting was commonly adopted by our radiologists into their clinical practice. This elective and sustained change in care delivery implies that they found enough value in the result to make the effort.
- Our radiologists commonly created interactive multimedia reports for complex studies like CT, PET/CT, and MRI; however, they infrequently did so for ultrasound, radiography, and general nuclear medicine studies.
- Residents were overall more likely to create interactive multimedia reports than attending radiologists; however, attending radiologists still commonly created such advanced reports.
ACKNOWLEDGMENTS
The corresponding author has a research grant from Carestream Health. The corresponding author also shares a provisional patent with Carestream Health but has no financial stake in the patent.

ADDITIONAL RESOURCES
Additional resources can be found online at: https://doi.org/10.1016/j.jacr.2018.10.009.

REFERENCES