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PORTER: a Prototype System for Patient-Oriented Radiology Reporting

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Abstract To empower patients to participate in their medical care and decision-making, effective communication is critical. In radiology, the clinical report is the primary medium of communication. Although radiologists historically have authored reports with the referring provider as the intended reader, patients increasingly access the reports through portals to electronic health record systems. We developed a system named PORTER (Patient-Oriented Radiology Reporter) to augment radiology reports with lay-language definitions. Our IRB-approved, HIPAA-compliant study protocol analyzed 100 knee MRI reports from an academic medical center to identify the most commonly utilized terms. A glossary of 313 terms was constructed to include definitions of the terms and, where available, links to reference sources and public-domain images. Flesch-Kincaid readability scores were computed to assure that definitions were readable at or below 10th-grade reading level. The system provided an interactive web site to view outpatient knee MRI exams. After logging in with their exam ID number and date of birth, patients viewed their report annotated with definitions from the glossary. Applicable images were displayed when the user's mouse hovered over a glossary term. This patient-oriented system can help empower patients to better understand their radiology results.

Keywords Quality improvement · Patient-centered care · User interface · Reporting · Radiology reporting

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Introduction

Effective communication is critical to help patients participate in their medical care and decision-making. Many healthcare institutions have offered patients access to their electronic health record (EHR) through web-based patient portals, which enable patients to access information about their medications, appointments, and test results [1, 2]. Despite their increased access, patients have limited understanding of radiology reports due to the reports' length and technical language. Information systems offer a potential approach to promote patient-centered care and improve communication between radiologists and patients.

Various information resources define terms used in radiology, but many are geared to medical professionals rather than lay patients. The RadiologyInfo web site, produced jointly by the Radiological Society of North America and the American College of Radiology, explains imaging procedures for patients and includes a glossary of radiology terms (www.radiologyinfo.org/en/glossary/glossary1.cfm). A study has suggested that the site's information may be too difficult to read for many patients [3]. The RadiologyExplained.com web site provides a patient-oriented glossary of imaging terms (www.RadiologyExplained.com), but its authors are not identified, nor are the terms cross-referenced. BI-RADS®, the ACR's lexicon of breast imaging, provides a standardized and well-defined vocabulary that can serve as a

model for other domains in radiology [4, 5]. Glossaries for thoracic imaging [6], imaging technology [7], lumbar disc disease [8], and medical devices and procedures [9], have been created predominantly for medical professionals, and may not be suitable for patients.

To accommodate American adults with average reading skills, the US Department of Health and Human Services and the American Medical Association have recommended that Internet-based patient education materials be written at or below a 7th-grade reading level [10, 11]. We selected magnetic resonance imaging (MRI) of the knee as a clinical domain due to the clinical expertise of one of the authors (S.C.O.). We developed a set of lay-language definitions of key terms in radiology reports and established an application to annotate clinical reports with the defined terms that appeared in their reports. Here, we describe the development and preliminary evaluation of the pilot system. To our knowledge, no system similar to ours has been created for diagnostic radiology.

Materials and Methods

Our prototype system, PORTER (Patient-Oriented Radiology Reporter), incorporated three modules: a glossary of terms, a module to upload the text of radiology reports to its database, and an interactive web-based user interface to display annotated reports.

Lay-Language Glossary

The authors created a lay-language glossary of common and clinically important terms in the domain of knee MRI. The study protocol was approved by the Institutional Review Board at the authors' organization and complied with the Health Insurance Portability and Accountability Act of 1996. One hundred knee MRI reports from three hospitals affiliated with a single university health system were analyzed for the most frequent words and word-pairs after excluding stopwords (commonly occurring words such as "a," "of," and "the"). Based on this analysis, 285 initial terms were identified. Lexical variants of the terms, such as synonyms, plurals, abbreviations, and adjectival forms, were identified and added as needed. For example, terms included "meniscus" (with its plural form "menisci"), "anterior cruciate ligament" (with its abbreviation "ACL"), and "patella" (with its adjectival form "patellar"). The glossary admitted multiple forms of a term, such as both "patellas" and "patellae" as plural forms of "patella." Terms included anatomic structures (e.g., "medial collateral ligament"), localization (e.g., anterior, posterior, medial, lateral), imaging findings (e.g., "marrow edema"), pathology (e.g., "radial tear"), and common phrases (e.g., "within normal limits" and "non-specific finding").

Each glossary entry was classified as a primary or variant term. Each primary term included a lay-language definition; if available, the term included a link to a Wikipedia page and an exemplary public-domain image. Each variant term specified its primary term and its relationship to that term (abbreviation, plural, adjective, etc.). The glossary was constructed as a shared spreadsheet using the Google Documents service, which allowed the authors to create and edit the document collaboratively. The spreadsheet included the set of terms and their definitions.

Online medical dictionaries and Wikipedia entries served as initial source materials. Although definitions from these sources were considered precise and helpful to medical professionals and well-educated readers, they often exceeded the 7th-grade level guideline for readability. Definitions were evaluated using the Flesch-Kincaid Readability Index and the Flesch-Kincaid Grade-Level formula, which estimated the grade level of a text based on the average number of words per sentence and the average number of syllables per word [12]. The glossary's definitions were edited to reduce the number of words overall, reduce the number of words per sentence, and decrease the complexity of sentences. If deemed too complex, definitions were edited to improve readability. Lay terms were used instead of or in addition to formal medical terms. For example, the medial meniscus was defined as a tissue "between the thigh bone (femur) and shin bone (tibia)."

As part of the system's modular design, the glossary was made available as a web service using Representational State Transfer (REST) architecture [13]. This web service consumed the spreadsheet's data from a private URL and produced output as a JavaScript Object Notation (JSON) document. Correct syntax was confirmed using a JSON validation service (*jsonlint.com*). A portion of the output information is shown in Fig. 1.

Report Uploading

A secure REST web service (using the HTTP POST method) was developed to upload radiology reports. The server was hosted by a commercial service outside of the institution's firewall; hence, no protected health information was stored. The web service accepted the 8-digit numeric examination ID (termed the "accession number"), the patient's date of birth, the report text, and an identifier for the interpreting radiologist. The exam ID and date of birth were combined, encrypted, and stored as a single 32-character hash code, which was used to index the reports. The report text was stored without encryption. The radiologist identifier was used to display the radiologist's name and photograph on the web site.

Report Display

We developed a web-based user interface to allow patients to view reports. To access a report, the patient entered his or her exam ID code and date of birth, which were combined,

```
{
    "ACL": {
        "form": "abbrev.",
        "mainTerm": "anterior cruciate ligament"
    },
    "anterior": {
        "defn": "Towards the front of the body. ",
        "wiki": "Anatomical_terms_of_location#Anterior_and_posterior",
        "img": "http://upload.wikimedia.org/wikipedia/commons/e/e7/
                Blausen_0019_AnatomicalDirectionalReferences.png"
    },
    "anterior compartment": {
        "defn": "One of the knee's three compartments. It's the front part of the knee
                 between the knee cap (patella) and thigh bone (femur). Also called
                 the patellofemoral compartment. ",
        "wiki": "Knee"
    },
    "anterior cruciate ligament": {
        "defn": "A strong ligament of the knee that extends from the inner back
                 portion of the thigh bone to attach to the lower leg bone.",
        "wiki": "Anterior_cruciate_ligament",
        "img": "http://upload.wikimedia.org/wikipedia/commons/0/09/Knee_diagram.svg"
    },
    . . .
}
```


Fig. 1 Part of the output in JSON of the glossary web service. For example, the term "ACL" is shown as an abbreviation ("form": "abbrev.") for "anterior cruciate ligament," which itself has a definition ("defn"), a Wikipedia entry ("wiki"), and a link to an image ("img")

encrypted, and matched against the hash code entries in the database's table of reports. The corresponding report text was retrieved; glossary terms were identified within the text and displayed with a dashed underscore (Fig. 2a). The text-matching algorithm sought to maximize the number of words in the matching string. Thus, a report that contained the text "medial meniscus" matched glossary entries for "medial," "meniscus," and "medial meniscus," but the report text would be highlighted only by the last one. When the user hovered over or clicked on a highlighted term with the mouse, PORTER displayed the term's definition as a pop-up "tool-tip" balloon (Fig. 2b). If the highlighted term was not a primary term, the primary term was shown; for example, for "ACL," the balloon read "anterior cruciate ligament (abbrev. ACL)" with the primary term's definition. A link to a Wikipedia page was displayed if defined for that term. If an image was available, it was displayed alongside the text of the report; the image was updated as the user hovered over different terms.

Evaluation

To provide a preliminary evaluation of the system, we explored usability of the system and readability of its definitions. The system was demonstrated to several physicians and non-physicians, and informal feedback was solicited about usability. Those users described the system as self-explanatory and easy to use. The inclusion of reference images was considered to be helpful. No significant defect or difficulty in the user interface was identified.

The glossary contained a total of 313 terms, of which 190 were primary terms. To evaluate the glossary, 175 randomly selected knee MRI reports generated at our institution were processed using PORTER. The reports contained 13,005 instances of glossary terms (range, 12 to 125 term instances per report; median, 75). Each radiology report included 10 to 64 unique glossary terms (median, 44 unique terms). Readability of the definitions was assessed using a variety of metrics, most of which were based on the length of sentences and/or length of words in a text sample. The Flesch-Kincaid Grade-Level score of the applicable definitions, calculated using the *readability-score.com* web site, ranged from −3 to 12.3 (median 5.8; mean 5.6). Negative scores resulted from very short, monosyllabic definitions; for example, the term 'contusion' had the definition, "A bruise," which resulted in the −3 grade-level score. All but two of the terms had readability scores below the 10th-grade reading level.

Discussion

The radiology report is being shaped by recent movements towards patient-centered care, in part due to increasing online access to EHR portals [14]. Patients can become more actively involved in their care through the use of EHR patient portals, but the complexity of medical text, such as radiology reports, presents a barrier [15]. Radiology results are one of the most accessed portions of the clinical record, but also one of the most difficult portions of the electronic health record to understand [16, 17]. Radiology reports frequently include long sentences, complex polysyllabic technical terms, and unfamiliar vocabulary; they may be nearly impenetrable to the average patient. Patients frequently request an explanation of the report in lay terms and have expressed a preference for reports in lay language [18, 19]. Investigators have explored systems to translate clinical text into lay language using an open-access, collaborative consumer health vocabulary [20]. Online information resources offer an opportunity to promote health literacy and engage patients in their own care [21].

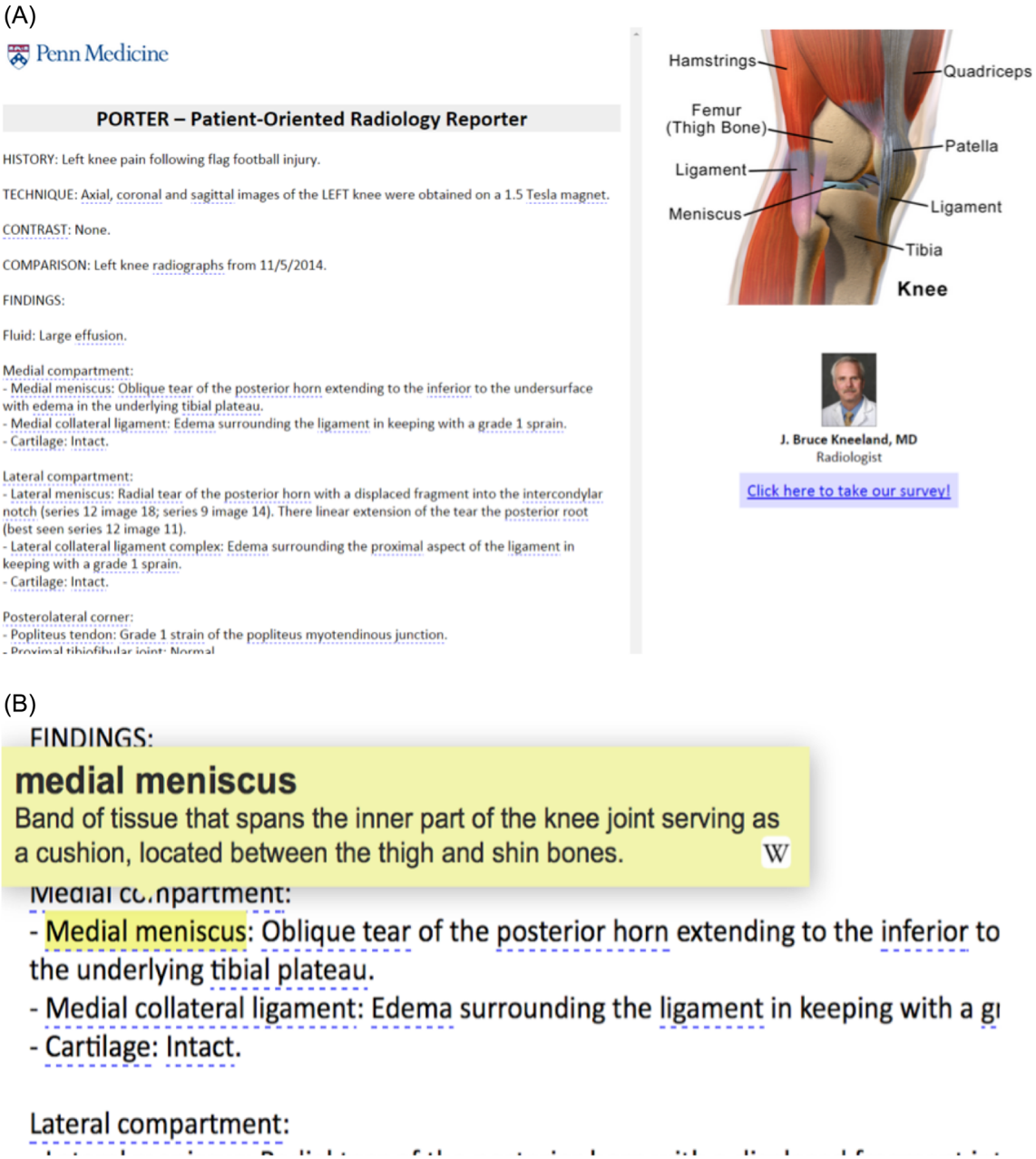

Fig. 2 PORTER user interface. **a** Glossary terms are underlined. **b** When the user's mouse hovers over a term, a "pop-up" balloon appears with the term's definition. If the term is associated with an image, that image appears on the right pane. The "W" image in the yellow box is a link to the corresponding Wikipedia entry

Further evaluation of PORTER is underway. The system records the user's log-in time, the terms over which the user hovers, and the amount of time spent on each term. Patients are invited to participate in a survey instrument to assess their opinions about the system. We have added a statement to our department's standard knee MRI reporting template to provide PORTER's uniform resource locator (URL) and the exam's ID number. Thus, when patients view their knee MRI reports on our institution's patient portal or receive a printed copy of the report, they have the opportunity to view the annotated report on the PORTER web site.

We also are exploring expanding the system to other imaging modalities and organ systems. The methodology used to develop, store, and access the terms and definitions should scale appropriately to other domains and a larger set of terms. General medical terminologies such as the Systematized Nomenclature of Medicine Clinical Terms (SNOMED CT) [22] and Logical Observation Identifier Names and Codes (LOINC) [23] offer relatively little coverage of the radiology domain. As we expand PORTER's domain coverage, we envision incorporating a subset of about 3100 RadLex terms for which definitions are available, primarily from the US

National Library of Medicine's Medical Subject Headings (MeSH) [24, 25].

Conclusion

We present our efforts to promote patient-centered care, improve patients' understanding and awareness of radiology, and narrow the gap between the radiologist and patient by providing a platform to augment radiology reports with illustrations and lay-language definitions. We have developed and deployed successfully a prototype web-based system to highlight key terms in knee MRI reports and define them in lay language. Evaluation is underway to determine the extent to which PORTER improves patients' understanding of and satisfaction with radiology reports.

Compliance with Ethical Standards The study protocol was approved by the Institutional Review Board at the authors' organization and complied with the Health Insurance Portability and Accountability Act of 1996.

References

1. Arnold CW, McNamara M, El-Saden S, Chen S, Taira RK, Bui AA: Imaging informatics for consumer health: towards a radiology patient portal. J Am Med Inform Assoc 20:1028–1036, 2013
2. Bruno MA, Petscavage-Thomas JM, Mohr MJ, Bell SK, Brown SD: The "open letter": radiologists' reports in the era of patient web portals. J Am Coll Radiol 11:863–867, 2014
3. Hansberry DR, John A, John E, Agarwal N, Gonzales SF, Baker SR: A critical review of the readability of online patient education resources from RadiologyInfo.Org. AJR Am J Roentgenol 202: 566–575, 2014
4. Burnside ES, et al: The ACR BI-RADS experience: learning from history. J Am Coll Radiol 6:851–860, 2009
5. Langlotz CP: ACR BI-RADS for breast imaging communication: a roadmap for the rest of radiology. J Am Coll Radiol 6:861–863, 2009
6. Hansell DM, Bankier AA, MacMahon H, McLoud TC, Muller NL, Remy J: Fleischner Society: glossary of terms for thoracic imaging. Radiology 246:697–722, 2008
7. Cogbill TH, Ziegelbein KJ: Computed tomography, magnetic resonance, and ultrasound imaging: basic principles, glossary of terms, and patient safety. Surg Clin N Am 91:1–14, 2011
8. Fardon DF, Williams AL, Dohring EJ, Murtagh FR, Gabriel Rothman SL, Sze GK: Lumbar disc nomenclature: version 2.0: recommendations of the combined task forces of the North American Spine Society, the American Society of Spine Radiology and the American Society of Neuroradiology. Spine J 14:2525–2545, 2014
9. Hunter TB, Taljanovic MS: Glossary of medical devices and procedures: abbreviations, acronyms, and definitions. Radiographics 23:195–213, 2003
10. How to write easy-to-read health materials. Available at www.nlm.nih.gov/medlineplus/etr.html. Accessed 22 May 2015
11. Weiss BD: Health literacy: a manual for clinicians. American Medical Association Foundation, American Medical Association, Chicago, IL, 2003
12. Kincaid JP, Fishburne RP, Rogers RL, Chissom BS: Derivation of new readability formulas (Automated Readability Index, Fog Count, and Flesch Reading Ease Formula) for Navy enlisted personnel. CNTECHTRA Research Branch Report 8–75. U.S. Navy, Washington, DC, 1975
13. Fielding RT, Taylor RN: Principled design of the modern Web architecture. ACM Trans Internet Technol 2:115–150, 2002
14. Walker J, Darer JD, Elmore JG, Delbanco T: The road toward fully transparent medical records. N Engl J Med 370:6–8, 2014
15. IOM (Institute of Medicine): Best care at lower cost: the path to continuously learning health care in America. The National Academies Press, Washington, DC, 2013
16. Weingart SN, Rind D, Tofias Z, Sands DZ: Who uses the patient internet portal? The PatientSite experience. J Am Med Inform Assoc 13:91–95, 2006
17. Keselman A, et al.: Towards consumer-friendly PHRs: patients' experience with reviewing their health records. AMIA Annu Symp Proc:399–403, 2007
18. Gunn A, Mangano M, Sahani D, Boland G, Choy G: Structured feedback from patients on actual radiology reports: a novel approach to improve reporting practices. Available at: http://archive.rsna.org/2014/14011827.html. Proc. Radiological Society of North America Scientific Assembly and Annual Meeting: Chicago, IL, 2014
19. Johnson AJ, Easterling D, Nelson R, Chen MY, Frankel RM: Access to radiologic reports via a patient portal: clinical simulations to investigate patient preferences. J Am Coll Radiol 9:256–263, 2012
20. Zeng-Treitler Q, Goryachev S, Kim H, Keselman A, Rosendale D: Making texts in electronic health records comprehensible to consumers: a prototype translator. AMIA Annu Symp Proc:846–850, 2007
21. Hansberry DR, Agarwal N, Baker SR: Health literacy and online educational resources: an opportunity to educate patients. AJR Am J Roentgenol 204:111–116, 2015
22. SNOMED CT: Available at http://www.ihtsdo.org/snomed-ct/. Accessed 31 Jul 2015
23. McDonald CJ, et al: LOINC, a universal standard for identifying laboratory observations: a 5-year update. Clin Chem 49:624–633, 2003
24. Lowe HJ, Barnett GO: Understanding and using the medical subject headings (MeSH) vocabulary to perform literature searches. JAMA 271:1103–1108, 1994
25. Rubin DL: Creating and curating a terminology for radiology: ontology modeling and analysis. J Digit Imaging 21:355–362, 2008