Integration of Imaging Signs into RadLex

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Abstract Imaging signs form an important part of the
language of radiology, but are not represented in established
lexicons. We sought to incorporate imaging signs into
RSNA's RadLex® ontology of radiology terms. Names of
imaging signs and their definitions were culled from books,
journal articles, dictionaries, and biomedical web sites.
Imaging signs were added into RadLex as subclasses of the
term "imaging sign," which was defined in RadLex as a
subclass of "imaging observation." A total of 743 unique
imaging signs were added to RadLex with their 392
synonyms to yield a total of 1,135 new terms. All included
definitions and related RadLex terms, including imaging
modality, anatomy, and disorder, when appropriate. The
information will allow RadLex users to identify imaging
signs by modality (e.g., ultrasound signs) and to find all
signs related to specific pathophysiology. The addition of
imaging signs to RadLex augments its use to index the
radiology literature, create and interpret clinical radiology
reports, and retrieve relevant cases and images.

Keywords Knowledge representation · Information storage
and retrieval · Image retrieval · RadLex · Imaging signs ·
Ontology

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Introduction

RadLex® is a standardized vocabulary of radiological terms
[1]. The goal of RadLex is to establish a uniform, consistent
language for radiology to improve communication of
results and to better integrate clinical practice with
education and the scientific literature. The vocabulary is
expressed as an ontology, which is a representation of a
terminology that emphasizes hierarchical organization,
attributes of each term, and relationships between terms
[2]. Ontologies allow for better analysis and improvement
of the vocabulary as it is being developed. Furthermore,
automated systems can apply the knowledge encoded in the
ontology, and human users can search and browse the
ontology in a straightforward manner.

The RadLex vocabulary includes highly detailed terms
for anatomy, pathology, and radiological observations.
Many of these terms are not found in other controlled
vocabularies, such as the Systematized Nomenclature of
Medicine Clinical Terms (SNOMED CT). RadLex current-
ly lacks a comprehensive set of terms for imaging signs.
Imaging signs provide concise, memorable, and often easily
recognized descriptions of imaging findings (e.g., the
"drooping lily sign"). In many cases, they narrow the
differential diagnosis because signs were usually originated
to be specific indicators of particular diseases.

Imaging signs comprise a specialized vocabulary that is
absent from more general biomedical lexicons. The
National Center for Biomedical Ontology (NCBO) Bio-
Portal site (bioportal.bioontology.org) hosts 201 ontologies,
including very large lexicons such as RadLex, SNOMED
CT, the Foundational Model of Anatomy, and the Gene
Ontology. The term "pneumoperitoneum," for example, is a
well-recognized disease concept, and appears in 11 NCBO
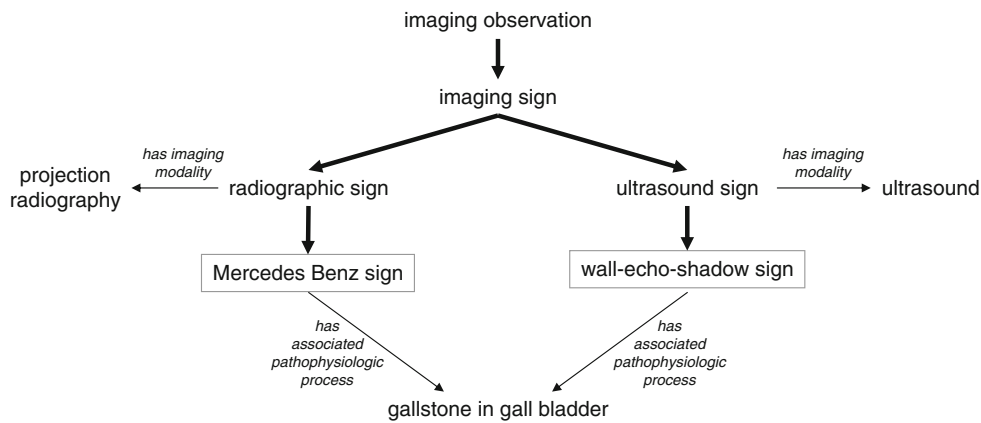
Fig. 1 Illustration of the relationships between imaging signs and other RadLex terms. The *thick arrows* designate subclass relationships. For example, the RadLex term "imaging observation" has the subclass "imaging sign"; thus, an imaging sign *is-a* imaging observation. The terms "Mercedes Benz sign" and "wall-echo-shadow sign" both are associated with the pathophysiologic process "gallstone in gall bladder." Because a term inherits properties from its parent, the wall-echo-shadow sign, for example, is known to be associated with ultrasound because that relationship is defined for its parent, "ultrasound sign." This structure allows users to identify all imaging signs related to a particular disorder, such as gallstones, or an imaging modality, such as ultrasound

ontologies. In contradistinction, the imaging signs "football sign" and "Rigler sign" are specific to radiology, and neither appears in any of the NCBO ontologies. Hence, given their widespread use in reporting, imaging signs would occupy an important position in a radiological ontology.

The inclusion of imaging signs into a radiological vocabulary presents several challenges. One sign may be known by several names throughout the literature; thus, it is necessary to capture as many of the signs' synonyms and abbreviations as possible. Some signs may be specific to particular imaging modalities, or to particular images acquired by a specific modality, such as lateral chest radiographs or T2-weighted MR images. This information is vital to the description of the imaging sign. Our goal was to augment the RadLex vocabulary by integrating a set of imaging signs with their definitions and related terms.

Materials and Methods

We identified a variety of sources of imaging signs from books, journal articles, dictionaries, and online references. We incorporated imaging terms from books focused specifically on listings of imaging signs [3, 4] and descriptions of imaging signs in a radiology textbook [5]. The "Signs in Imaging" series in *Radiology* [6] constitutes a collection of 118 articles, published from 1999 to 2008, such as "Hawkins sign" [7] and "enlargement of the hilar periportal space" [8]. We incorporated terms and definitions from 10 review articles [9–18] and from online references such as CHORUS [19, 20], the Interactive Atlas of Signs in Musculoskeletal Radiology [21], Medcyclopedia [22], Radiopaedia [23], and RadsWiki [24]. These resources were selected as they represent the core resources that itemize radiology signs.

For each imaging sign, we specified a preferred name, alternate names when available, and a concise definition.

Table 1 Imaging signs classified by imaging modality

Imaging modality		
Angiography	31	4%
CT	82	11%
MR	29	4%
Nuclear medicine	12	2%
Ultrasound	50	7%
Radiography	518	70%
Other/multimodality	21	3%
Total	743	100%

"Nuclear Medicine" includes positron emission tomography. "Radiography" includes fluoroscopy and contrast procedures (e.g., barium enema, excretory urography), but not angiography. Signs that are detectable by more than imaging modality (such as the "drooping lily" sign, seen at both radiography and CT) were generally classified by the modality for which they were described originally
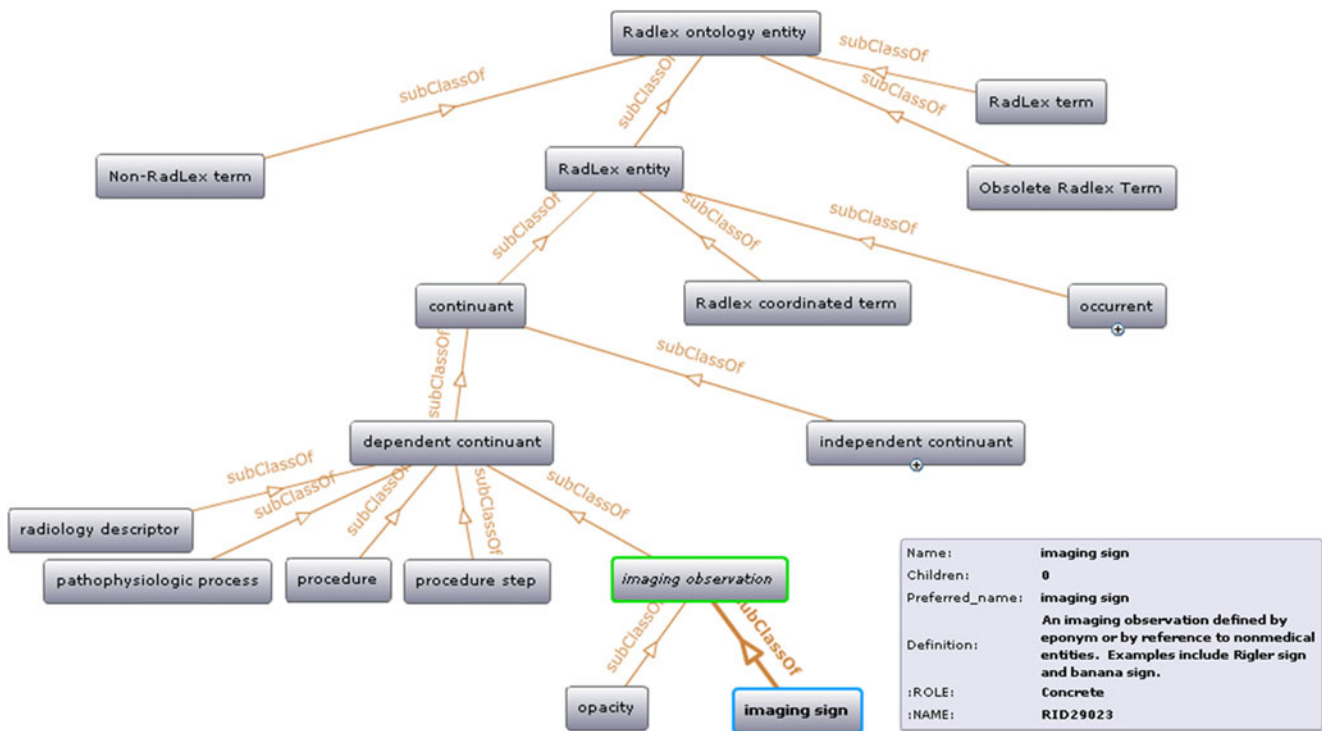
Table 2 Imaging signs classified by organ system

Organ system		
Breast	6	1%
Cardiopulmonary	143	19%
Gastrointestinal	145	20%
Genitourinary	102	14%
Head and neck	12	2%
Musculoskeletal	195	26%
Neurological	46	6%
Obstetrical/gynecological	21	3%
Vascular	25	3%
Other	48	6%
Total	743	100%

Fig. 2 Schematic diagram showing relationship of RadLex terms for "imaging observation" and "imaging sign." More general terms are shown superiorly in the diagram

When multiple names were used, the preferred name was determined to be the name to appear first historically or the name deemed most appropriate based on notoriety and accuracy of description. The sign's definition described the imaging appearance of the sign and a pathophysiologic explanation if the sign was highly suggestive of a certain process. We included in the definition information about the imaging modality, view, and/or other imaging parameters specific to each sign.

We also identified RadLex terms to link the imaging signs to relevant anatomy, diseases, and imaging modalities. For example, the entry for the imaging sign "bamboo spine" included links to the terms for spine, ankylosing spondylitis, and radiography. These linkages between terms allow the RadLex user to both directly find a description of "bamboo spine" and find "bamboo spine" by searching for radiographic signs of ankylosing spondylitis. Consequently, different signs of a similar disease, organ, or modality may be grouped together for comparison.

We defined an imaging sign as an imaging observation that has been accorded a name, often an eponym (e.g., "Rigler sign") or a reference to a visually similar, often nonmedical entity (e.g., "bamboo spine"). Each imaging sign was added to RadLex as a subclass of the RadLex term "imaging sign" using the "*is-a*" (subtype) relationship. Thus, "bamboo spine" *is-a* "imaging sign," which *is-a* "imaging observation." To ensure correctness of our

representation of signs, the names, definitions, and related terms were reviewed by two board-certified radiologists, both with more than 10 years of experience.

Results

We added to RadLex 1,135 terms that defined 743 unique imaging signs and 392 synonyms. There were a variety of reasons why a particular imaging sign was known by more than one name. Terms that were originally identified in another language are sometimes referred to by their foreign names (e.g., "coeur en sabot" and "boot-shaped heart"). In addition, some foreign-language names have more than one transliteration (e.g., the German name for "cloverleaf skull" can be written "Kleeblattschädel" or "Kleeblattschaedel"). Somewhat abstract signs that resemble various shapes may be described by multiple names (e.g., "coffee bean sign," "bent inner tube sign," and "kidney bean sign"). Occasionally, a sign is simply referred to by a variety of wordings (e.g., "anterior drawer sign" and "anterior tibial translocation sign"). Finally, terms differ by use of the noun or adjective form of an anatomical entity. Because the ultimate goal of RadLex is to improve communication, the identification of all common synonyms was essential to this effort. For consistency, eponymous imaging signs did not include the possessive form of names (e.g., "Rigler sign," not "Rigler's
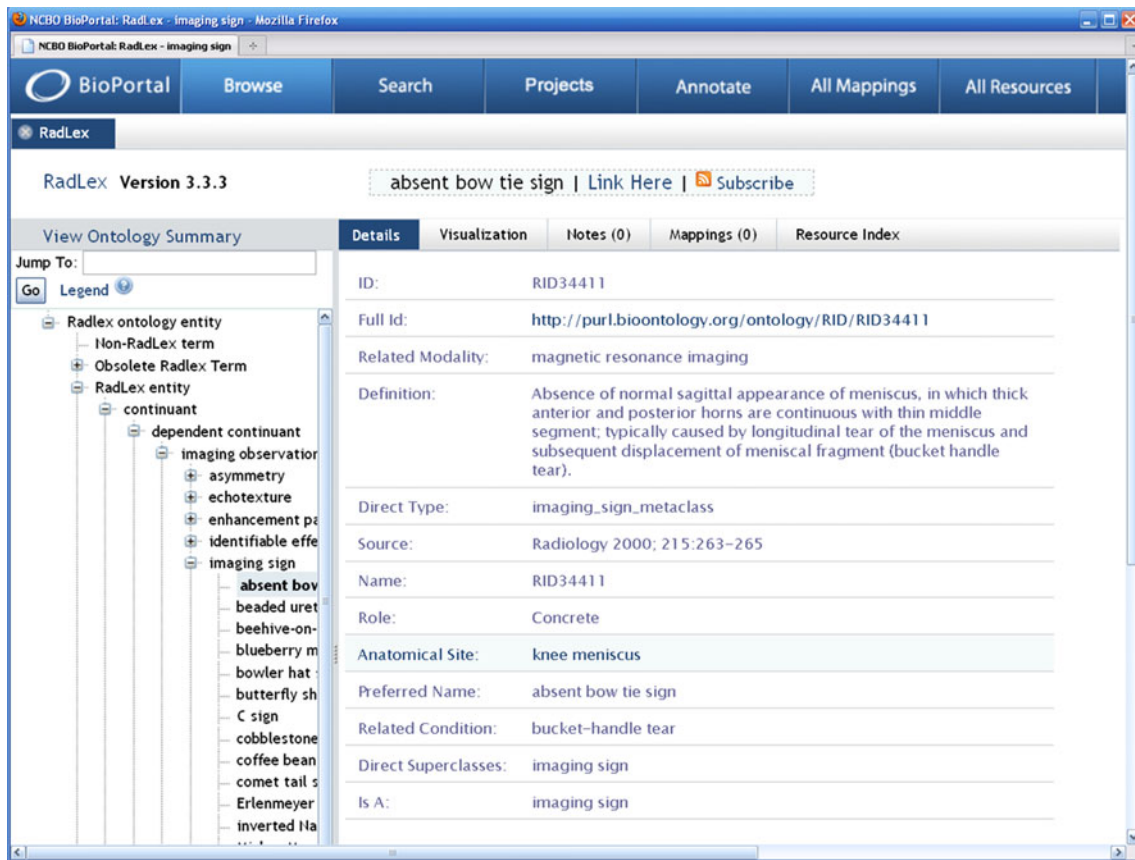
Fig. 3 Details of RadLex entry of the imaging sign, "absent bow tie sign." Note that the entry includes the term's RadLex ID (RID34411), definition text, and RadLex terms for related imaging modalities, anatomic sites, and conditions. Screenshot from National Center for Biomedical Ontology (NCBO) BioPortal web site

sign"), and hyphens were not used unless the imaging sign's name included a prepositional phrase (e.g., "egg-on-a-string sign").

Determining the related terms presented another challenge. A number of signs are pathognomonic of certain conditions. The "double wall sign," for example, is a reliable indicator of pneumoperitoneum. Some, however, are less definitive. Often, a sign is reported but later found to be nonspecific; the "shaggy heart sign," once considered diagnostic of pertussis, now includes asbestosis and viral infection in its differential diagnosis. In many cases, only the most common pathological conditions were listed as clinically related terms. Several signs were deemed so nonspecific that they were not linked to any terms.

The ability to aggregate similar terms greatly enhances the value of RadLex as an educational tool. Imaging signs may be grouped by similar anatomy, pathology, or imaging modality. For example, a RadLex user may search for the "Mercedes Benz sign," find it as a radiographic sign of cholelithiasis, and note that the "wall-echo-shadow sign" is an ultrasound sign of the same condition (Fig. 1).

We classified the imaging signs by imaging modality (Table 1) and by organ system (Table 2). Radiographic signs were the most frequent, and constituted 70% of all signs identified; this category included gastrointestinal and genitourinary procedures that used contrast materials, such as esophagography and excretory urography. Angiographic procedures were reported separately. The predominance of signs for this imaging modality likely reflects that fact that many of the signs were named before advanced imaging modalities were developed.

Discussion

Imaging signs—with their names, synonyms, definitions, and related concepts—provide an important contribution of radiological knowledge to RadLex. Many imaging signs have names derived from reference to nonmedical concepts (e.g., "bamboo spine", "lemon sign") or eponyms (e.g., "Rigler sign"). The incorporation of imaging signs into RadLex adds to the ontology as a knowledge source, and will allow students and practitioners of radiology to retrieve information efficiently. Although a small subset of the larger domain of radiological terms, imaging signs are of obvious significance to the study of radiology. The

integration into the RadLex vocabulary of these terms will have both academic and clinical implications by enhancing the retrieval as well as the indexing of information.

What is an imaging sign? Descriptions of the term are almost as imaginative as the names of some of the more colorful examples. Imaging signs have been described as the "spices of medicine… savored by the diagnostic gourmet" [3], a "secret language" [3], and a radiologist's stock in trade [12]. Hundreds of imaging signs play a unique role in diagnostic expression by describing radiological observations through the use of eponyms, metaphors, and sometimes, esoteric or outdated references. In RadLex, an imaging sign is defined as a subclass of "imaging observation" (Fig. 2).

An extensive list of signs allows for greater communication between physicians. A radiologist may recognize the implications of a sign but not necessarily know it by name. For example, free intraperitoneal air may be recognized and described using conventional terminology rather than a name it once had been given in the literature. In these cases, when reading a case report that includes an unrecognized term, the brief definition will be of great value in avoiding confusion. One can use the RadLex ontology to show, for example, that the "cupola sign" is a radiographic sign of pneumoperitoneum.

The imaging signs do not add differential diagnosis "gamut" lists to RadLex. Imaging signs include links to diseases only if the imaging sign is pathognomonic or highly suggestive of a diagnosis. A brief differential diagnosis is occasionally provided in the definition, particularly when the imaging sign was once thought to be diagnostic of one condition but is now known to be produced by several conditions. Because an ontology is meant to represent only facts that are "tautologically true," gamuts are better expressed using other knowledge representation formalisms that capture probabilistic relationships.

The inclusion of all known variations of a term assures semantic interoperability across disparate information systems. A list of related anatomical and pathological terms helps integrate the imaging sign within the framework of RadLex by creating links in multiple dimensions. The "absent bow tie sign" (Fig. 3) serves as an example that specifies both the related imaging modality (magnetic resonance imaging) and the related condition (bucket-handle meniscal tear).

The imaging signs described here have been submitted to the RadLex staff, and gradually are being added into the vocabulary. Thus, the majority of the signs we identified have not appeared yet in the production version of RadLex at either radlex.org or the NCBO BioPortal website. Because many of the imaging signs were identified from journal articles, there are opportunities to link the terms with exemplary images from the published radiology literature.

Once the addition of imaging signs to RadLex has been completed, radiologists will be able to search the RadLex vocabulary to identify imaging signs by name, imaging modality, relevant anatomy, or associated pathophysiology. Thus, a radiologist who performs a study for a suspected finding could identify that finding's known imaging signs using the specified modality, and include the terminology in a report of the procedure. Also, the addition of imaging signs into RadLex improves the power of natural language processing tools to understand the content of narrative ("free text") radiology reports.

Conclusions

A large number of imaging signs, with their synonyms and definitions, were identified from the radiology literature. Although the signs spanned a variety of imaging modalities and organ systems, the greatest number related to projection radiography and the musculoskeletal system. Information such as imaging modality, pathophysiological process, and/or anatomic site allowed the imaging signs to be integrated into the RadLex vocabulary. The addition of imaging signs should help augment RadLex as an educational tool, a clinical aid, and a means to normalize clinical reporting and indexing.

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