Automated Data Mining of Exposure Information for Dose Management and Patient Safety Initiatives in Medical Imaging[1]

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The Institute of Medicine and other professional and consumer organizations have long called for health care providers to implement quality improvement initiatives aimed at improving the quality and safety of medical care (1). This imperative applies equally to the practice of radiology, where education about and experience with practice quality improvement programs are required components of the American Board of Radiology's maintenance of certification program (2–5). An essential element of any practice quality improvement project includes the selection of appropriate metrics and collection of baseline data (6). Armed with credible information about the current level of performance, and whether measuring a metric of safety, accuracy, or workflow, proponents can examine the data and determine where quality improvement initiatives might be most beneficial. Without a sufficiently large set of accurate baseline data, neither the current performance nor changes in performance can be quantified.

The level of interest and concern regarding the topic of radiation exposure from medical imaging has led to a number of quality improvement initiatives and strategies. Professional initiatives such as the Image Gently and Image Wisely campaigns (7–11) focus on educating both the general public and imaging providers. The goal for imaging providers is to use doses that are as low as reasonably achievable, while maintaining the necessary level of imaging quality and diagnostic accuracy. Professional societies outside of radiology also provide practice guidelines and a wealth of continuing education opportunities (12). These efforts are essential and have led to a high level of awareness regarding the need to use radiation in imaging in as safe a manner as possible.

To adequately monitor the use of radiation in medical imaging, however, practice-specific auditing of the dose levels used in facilities is essential. Studies have shown that wide variation can exist among and within imaging centers, at times reflecting substantial differences in how individual practices and practitioners utilize radiation-producing equipment (13). Users may simply not be aware that they may not be using best practices until some measure of their performance is compared with regional, national, or international benchmarks. Thus, the availability of data describing the amount of radiation used for different examinations or procedures, stratified by patient size and clinical indication, is foundational for quality improvement initiatives in the field of radiation dose utilization.

In the articles by Sodickson et al (14) and Ikuta et al (15) appearing in this issue of *Radiology*, the authors describe the methods and potential uses of two systems for collecting exposure data on a large scale, the first with respect to computed tomographic (CT) imaging and the second with respect to nuclear medicine imaging. The authors are to be applauded for taking on such a task; in their CT analysis, they examine a cohort of 54549 patient encounters, and in their nuclear medicine analysis, they examined their institution's entire 25.5-year archive of 204561 nuclear medicine reports. The wealth of data that can be quickly extracted—once the necessary systems were created and validated—is remarkable, as is the speed at which they can be accomplished. When using a standard desktop computer, it took just under 11 minutes for their data mining tool to process their entire 25.5-year institutional archive of nuclear medicine reports. While not perfect, both systems achieved a very high rate of success in being able to automatically extract and categorize either CT dose index metrics or administered radiopharmaceutical

See also articles by Ikuta et al and Sodickson et al in this issue.

activity. Of these two systems, the CT data extraction algorithm faced the more difficult challenge, having to not only extract dose index values from several different manufacturer-specific data screens by using optical character recognition, but more importantly, having to automatically assign each scan series to a specific anatomic region. This required several levels of definitions and mappings. The process could, and should, be simplified for all users by adoption of standardized Digital Imaging and Communications in Medicine (DICOM) fields that are automatically and accurately populated with the relevant anatomic information.

The American College of Radiology's Dose Index Registry (16), as well as a number of institution-specific databases, is being populated with tens of thousands of dose index values from CT examinations. This wealth of information is critical for assessing where a practice lies with regard to peer institutions and for providing baseline data by which to measure practice improvements. An example of the type of changes an institution would hope to see after initiation of a quality improvement intervention, such as protocol review or user education, would be an overall decrease in mean and median dose index values, as well as a decreased range in such values, which would imply both lower exposure levels and less variation. But as discussed in the article by Sodickson et al (14) and by those associated with the CT Dose Index Registry (16), having a large sample of dose index values is not enough. To appropriately and meaningfully interpret these data, each dose index value must be accurately associated with not only a specific anatomic region but also a specific patient size and diagnostic task. Comparing CT dose index values from examinations in obese patients with those of normal to small body habitus results in the appearance of much greater variation within a practice than might actually exist. It is the standard of care that scanner radiation output be adapted according to patient size. Hence, an automated measure of patient size needs to be standardized

and implemented industry wide and stored in a DICOM header field so that dose index values can be automatically stratified according to patient size.

The same type of stratification is essential for anatomic regions. Comparing dose index values for scans of the thorax with those of the pelvis would, and should, show relatively large differences that reflect the relatively large difference in attenuation of these body regions.

Finally, a system to specify the specific diagnostic task is imperative. The Radiological Society of North America's RadLex Playbook is an important tool toward this end (17). Dose index values from a low dose lung cancer screening CT examination of the thorax would, and should, be much lower than those from a CT examination over the thorax for the purpose of diagnosing pulmonary emboli or coronary artery stenoses. Each of these three diagnostic tasks has substantially different image quality requirements. The same differences in image quality requirements, and hence exposure requirements, can be seen in CT examinations of the abdomen and pelvis, for example, comparing screening CT colonography, CT for the detection of renal stones, routine oncologic follow-up scans, and CT of the liver to identify small low contrast lesions such as hepatocellular carcinoma.

One of the exciting capabilities demonstrated in the articles by Sodickson et al (14) and Ikuta et al (15) is the ability to examine dose metrics across time; between facilities, manufacturers, and scanner models; between specific protocols; and even for a specific patient. In their nuclear medicine study, authors graphically demonstrated the changes in administered activity subsequent to a departmental protocol change, quantifying the decrease in patient dose that their change accomplished. The richness of the data provided and the potential uses for quality improvement initiatives are compelling and should motivate professional societies, standard organizations, regulators, and manufacturers to adopt standardized measures of patient size, anatomic scan region, and diagnostic

task as quickly as possible. This will allow the tremendous power of benchmarking one's data against data from other practices to be realized, without having to expend the tremendous effort that these authors expended to obtain such critically important measures of the dose performance of their practice.

The authors demonstrated considerable wisdom in their approaches. They emphasized that indeed neither the dose indexes reported by using a CT scanner nor the administered activity in a nuclear medicine examination are measures of patient dose (18), but as their article titles imply, are measures of the exposure that the patient receives. Conversion of these exposure metrics to meaningful patient-specific doses requires additional steps that incorporate the anatomic region exposed and patient morphology (19). They also pointed out the importance of using well-defined and easily verifiable metrics for patient exposure and discourage the use of effective dose for any sort of measuring, reporting, tracking, or averaging doses related to individual patients (20,21). Finally, they are to be applauded for implementing the informatics tools described in their work by using open-source software code, potentially allowing others to make use of the fruits of their labor. Until the data elements and DICOM fields required to extract these important metrics of patient exposures are standardized and made readily available to all users, we can expect to see an increasing number of software solutions being made available or sold to collect, stratify, and analyze dose metrics. The variability in algorithms, function, and features of these software tools will introduce variation into the collected data and somewhat confound the comparison of information between users of different systems. These differences will be resolved only when standardized DICOM fields are universally populated by equipment manufacturers. I very much look forward to that day and to focusing on the actual quality improvement initiatives, as opposed to developing the tools to collect and collate the underlying data.

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