Opportunities for Radiation-Dose Optimization Through Standardized Analytics and Decision Support

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Although the potential for adverse clinical outcomes related to medical radiation have been well documented for over a century, several relatively recent trends have increased awareness of radiation safety in medical imaging. These include expanded CT applications and utilization, increased patient attention on radiation carcinogenesis, and a wide array of legislative and societal radiation initiatives, created partly in response to media reports of CT-induced radiation complications. With this heightened radiation awareness and scrutiny comes a unique and timely opportunity for the collective medical-imaging community to incorporate comparative radiation metrics and analysis directly into routine workflow and reporting. If properly performed, a number of benefits could in theory be derived, including improved clinical outcomes, creation of data-driven best practice guidelines, opportunities for enhanced education and research, dose-reduction technology innovation, and reversal of existing commoditization trends.

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STRATEGIES FOR RADIATION-DOSE OPTIMIZATION

The central theme for radiation-dose optimization is ALARA, which indicates that radiation dose should always be kept "as low as reasonably achievable" to accurately and confidently answer the clinical question posed. To date, radiation-dose management has largely focused on CT, owing to its rapidly expanded utilization and the higher associated radiation doses [1, 2]. Current radiation dose-reduction strategies largely fall into 2 broad categories: utilization and technique. Various opportunities are available to reduce radiation dose through improved utilization: decreasing the number of unnecessary exams, reducing the need for repeat exams, and selecting nonionizing imaging exams when clinically applicable [3-5]. From the technical perspective, several CT dose-reduction strategies have been advocated, including decreasing peak kilovoltage (kVp), decreasing the number of images, automating tube current modulation, automating tube potential selection, performing reconstruction iteratively, using noise reduction software, decreasing the length of exam coverage, and increasing pitch [4-9].

Additional opportunities are available for radiation-dose optimization related to the collective imaging chain, patient imaging history, individual patient attributes, and clinical context. If one were to view radiation-dose optimization as a multistep process, then individual steps, stakeholders, and technologies in the imaging chain could be tracked and analyzed (Table 1), with the hope of identifying multiple intervention opportunities within a single exam. The next consideration for dynamic radiation optimization is to view the historical imaging/radiation records of each patient to take into consideration cumulative radiation dose, the presence and timing of historical imaging data, previous report findings, and the radiation dose/quality metrics of prior exams. If, for example, a patient who is ordered to have a chest CT to re-evaluate known pathology (eg, lung nodule, cancer) had a prior chest CT within the past 3 months, it would be wise to leverage the baseline data and select a more aggressive radiation dose-reduction protocol. Analysis of the patient's historical imaging database might also provide decision support for protocol optimization.

The next dynamic factor for consideration is the patient, who plays a critical role in radiation strategy. One could in theory create a patient profile that takes into account various attributes and variables that may affect radiation-dose strategy for each patient. Although patient body habitus is a well-documented factor affecting radiation dose [10, 11], other less-studied variables may also play a role in quantifying radiation sensitivity, such as genetic predisposition, occupational and environmental radiation exposure, emotional state, prior

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Table 1. Standardized grading system for radiation dose as a measure of medical imaging safety

1: The calculated exam radiation dose is in the lowest 10 percentile of all comparable exam radiation dose measurements.
2: The calculated exam radiation dose falls in the range of 10.1-29.9 percentile of all comparable exam radiation dose measurements.
3: The calculated exam radiation dose falls in the range of 30-70th percentile of all comparable exam radiation dose measurements.
4: The calculated exam radiation dose falls in the range of 70.1-89.9% of all comparable exam radiation dose measurements.
5: The calculated exam radiation dose is in the highest 90th percentile and above of all comparable exam radiation dose measurements

medical history, and health literacy. A patient who is highly concerned over radiation dose may request that more-aggressive radiation-dose strategies be employed, and this should be taken into account when devising a dynamic strategy for that patient. Thus, radiation-dose strategy needs to take into account each individual patient's unique attributes and preferences, to provide a customized approach utilizing all available data. The end goal is the creation of standardized radiation databases that can be referenced and that take into account clinical context, patient attributes, available technology, and historical imaging/radiation data.

RADIATION-DOSE REPORTING

Several computer-derived CT radiation-dose metrics can be automatically calculated and incorporated into the radiology report, including the CT dose index, dose length product, and effective dose [12-14]. Studies have shown that a large percentage of radiologists and clinicians have little understanding and knowledge of the impact these radiation metrics have on clinical care [15,16]. Current practice and legislative standards call for the reporting of "excessive" radiation-dose metrics to designated health care agencies and regulators, to ensure that radiation safety standards are maintained. Deficiencies in current reporting practice and data analysis include limitations in scope (ie, not all imaging providers document these data in the radiology report), binary analysis (ie, only radiation-dose metrics exceeding predefined thresholds are acted on), absence of clinical and patient context, and inability to provide comparative reference data.

An alternative approach would be to cross-reference exam-derived radiation-dose data with "comparable" statistical meta-data from large, standardized databases that can be referenced (eg, radiation-dose registries). Such cross-referencing could provide valuable context to health care providers and consumers as to how the exam-specific radiation-dose estimates relate to those of comparable exams. Exam comparability could be defined in accordance with several variables, including (but not limited to) exam type, anatomy, patient attributes, clinical context, institutional service provider characteristics, and technology used.

One example of how such a standardized radiation reference measure can be created and reported is given in Table 1. Using an incremental grading scale of 1-5, the derived radiation metric data would be categorized based on the percentile of radiation dose calculated relative to all comparable peer data. A CT exam that is determined to have a radiation measurement at the 50th percentile of its peer group would be assigned a radiation grade of 3, in comparison to a CT exam whose radiation measurement is at the 90th; the data are inherently standardized, are derived from objective meta-data, provide an easy to understand numerical value, and can be recorded for longitudinal analysis.

In addition to providing a standardized numerical analysis of radiation dose for each individual exam and clinical context (ie, general radiation scores), the proposed system can also be modified to reflect radiation scores in accordance with specific patient, technology, or provider attributes (ie, modified radiation scores). The ability to perform radiation-dose analysis based on these exam modifiers becomes of critical importance when attempting to define "best practice" guidelines, which one would expect to differ in accordance with these modifying influences.

RADIATION DATA INFRASTRUCTURE

The proposed system would require creation of centralized radiation databases, the methodology of which has been recently described [12, 17]. This system would involve creation of an external infrastructure, platform, as well as software services for use by multiple parties in and outside of the enterprise. It would provide capabilities for data storage, processing, verification, security, analysis, and distribution. Making this patient centric and putting it in the "cloud" would provide the opportunity to improve data accessibility and real-time decision support and would facilitate medical research [18].

These cloud-based radiation databases could in turn lead to the creation of radiation-dose registries, which could expand ongoing efforts already under way by the ACR [19], the American College of Cardiology [20], and the FDA [21]. The commonalities for these radiation-dose registries are centralized data collection, creation of national diagnostic reference levels, and aggregation of publicly and freely available data.

The ability to create patient-centered data aggregation would in theory address an existing fundamental deficiency, in which radiation data collection and analysis is to a large extent limited to individual enterprise databases. As a patient migrates from one service provider to another, the corresponding radiation data are not consistently captured, resulting in incomplete and inaccurate radiation-dose records and analytics. The proposed infrastructure could also provide data compartmentalization