Seminars in NUCLEAR MEDICINE

Computer-Assisted Diagnosis in Renal Nuclear Medicine: Rationale, Methodology, and Interpretative Criteria for Diuretic Renography

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The goal of artificial intelligence, expert systems, decision support systems, and computer-assisted diagnosis (CAD) in imaging is the development and implementation of software to assist in the detection and evaluation of abnormalities, to alert physicians to cognitive biases, to reduce intraobserver and interobserver variability, and to facilitate the interpretation of studies at a faster rate and with a higher level of accuracy. These developments are needed to meet the challenges resulting from a rapid increase in the volume of diagnostic imaging studies coupled with a concurrent increase in the number and complexity of images in each patient data. The convergence of an expanding knowledge base and escalating time constraints increases the likelihood of physician errors. Errors are even more likely when physicians interpret low-volume studies such as technetium-99m-mercaptoacetyltriglycine diuretic scans where imagers may have had limited training or experience. Decision support systems include neural networks, case-based reasoning, expert systems, and statistical systems. iRENEX (renal expert) is an expert system for diuretic renography that uses a set of rules obtained from human experts to analyze a knowledge base of both clinical parameters and quantitative parameters derived from the renogram. Initial studies have shown that the interpretations provided by iRENEX are comparable to the interpretations of a panel of experts. iRENEX provides immediate patient-specific feedback at the time of scan interpretation, can be queried to provide the reasons for its conclusions, and can be used as an educational tool to teach trainees to better interpret renal scans. It also has the capacity to populate a structured reporting module and generate a clear and concise impression based on the elements contained in the report; adherence to the procedural and data entry components of the structured reporting module ensures and documents procedural competency. Finally, although the focus is CAD applied to diuretic renography, this review offers a window into the rationale, methodology, and broader applications of computer-assisted diagnosis in medical imaging.
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Nuclear medicine physicians and radiologists have the responsibility to monitor scan performance, analyze sequences of images, assimilate clinical information, assess quantitative data, formulate an interpretation, and generate a focused and coherent report. These processes are demanding and require knowledge of multiple disease processes as well as expertise in the performance and interpretation of a variety of imaging modalities; these processes can also be associated with multiple sources of error including a lack of procedural competency, cognitive bias, fatigue, insufficient training, and lack of expertise.

Lack of Training, Experience, or Expertise

The problems of insufficient training, limited experience, and lack of expertise simply reflect the inevitable convergence of a rapidly expanding knowledge base and escalating time

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constraints that characterize the training and practice of medicine; these problems are especially serious in the setting of low-volume studies where training is even more likely to have been limited. For example, radiology residents receive only 4 months of training to cover all of nuclear medicine including nuclear cardiology yet radiologists perform most noncardiac nuclear medicine studies. In contrast, the American Board of Nuclear Medicine has determined that competency in nuclear medicine requires 36 months of training to master the same material radiology residents attempt to assimilate in 4 months. Moreover, radiology residents are largely trained to interpret static or a series of static images that require a detailed knowledge of anatomy whereas interpretation of studies such as diuretic radionuclide renography depends much more on an understanding of renal physiology and technetium-99m-mercaptoacetyltriglycine (^{99m}Tc-MAG3) pharmacokinetics. Even so, interpretation of low-volume studies such as renal scintigraphy can be a challenge for fully trained nuclear medicine physicians as a large percentage of an estimated 590,000 renal scans performed annually in the United States are interpreted at sites that perform fewer than 3 studies per week.[1]

Because of differences in training and expertise, image interpretation is sometimes more dependent on which physician interprets the study rather than the presence or absence of underlying disease. Different specialists may disagree on the interpretation of the same study between 9% and 72% of the time.[2] In a recent study, Hunsche[3] showed that 25% of the diuretic renal scan interpretations (obstructed, equivocal, or not obstructed) depended on which experienced physician interpreted the study. This problem is not limited to nuclear medicine but also applies to other areas of imaging such as MRI of the lumbar spine and low-dose CT screening.[4,5]

Cognitive Bias

The 2 major components of clinical decision consist of making a diagnosis and devising a treatment plan based on that diagnosis; if the diagnosis is incorrect, there is a much greater likelihood that the treatment plan will also be incorrect or suboptimal. Although many factors contribute to diagnostic error, a principal cause consists of cognitive errors where the problem lies not in a lack of knowledge but with the clinician's thinking process.[6] Our minds are quite vulnerable to cognitive biases, logical fallacies, and false assumptions. Cognitive failures are best understood in the context of how our brains manage and process information. The 2 principal modes can be categorized as System 1 and System 2.[7] System 1 operates automatically, intuitively, and quickly, effortlessly originating impressions and feelings; whereas System 2 requires mental effort, focused concentration, and analysis. Cognitive errors are much more likely to occur when the scan, radiograph, or clinical problem is analyzed by System 1. Examples of System 1 errors consist of reports that are internally contradictory or reports where diuretic renal scan interpretations are primarily based on a simple heuristic rule governing the T1-2. (If the T1-2 is greater than 20 min, the kidney is obstructed.) The cognitive error rate may be even higher in areas where training, experience, or expertise is compromised.

Lack of Procedural Competency

Many regulatory and oversight groups require peer review processes to evaluate the interpretative competence of radiologists and nuclear medicine physicians on an ongoing basis but systems for evaluating *procedural competency* are not widely available.[8] Appropriate procedures are essential to a quality study and extensive procedure guidelines are provided by many professional organizations to facilitate procedural competency. To help standardize practice and guide interpretation of renal scans, for example, an international group of experts in renal nuclear medicine has published guidelines for renovascular hypertension,[9] suspected obstruction,[10] clearance measurements,[11] and quality control[12]; however, a recent survey showed that *less than 50% of full-time* British nuclear medicine practitioners were even aware that a clearance guideline existed.[13] The situation is undoubtedly worse in the United States where most renal scans are interpreted by *part-time* practitioners.[1] Moreover, there has been a proliferation of guidelines; the National Guideline clearinghouse (http://www.guideline.gov) contains more than 2373 clinical practice guidelines from 285 organizations. Too often, physicians lack the time or motivation to locate, read, assimilate, and implement the current and most appropriate guideline recommendations. Guidelines alone are not sufficient to ensure procedural competency; future research must focus on innovative intervention approaches that will help improve the translation of current knowledge into every day clinical practice.[14] Decision support systems that function in the reading room can overcome the limitation of guidelines by providing immediate patient-specific feedback at the time of scan interpretation and help to minimize interobserver variability by providing standardized, reproducible interpretative guidance.

Report Generation

Too often, renal nuclear medicine reports fail to contain the essential elements required to evaluate and interpret the study, fail to document the technical components of the study necessary for accountability, quality assurance, and reimbursement, or fail to communicate the results to the referring physician in a clear and unambiguous structured report.[15] Standardization of imaging reports represents an effort to counter this limitation.

Artificial Intelligence

Artificial intelligence (AI) has the capacity to address the problems of training, expertise, physician fatigue, cognitive bias, procedural competency, and report generation and represents a domain of science dealing with the processes of modeling and problem solving. AI is a broad field and encompasses artificial neural networks (ANNs), fuzzy logic, genetic algorithms, case-based reasoning, expert systems, and