

Focusing on the Issues

Scientific Method as a Framework for Critical Thinking in Diagnostic Medical Sonography

JIM BAUN, BS, RDMS, RVT, FSDMS

Critical Thinking

Critical thinking is a learned, scientific method of directing and using cognitive functions to achieve a well-defined goal or answer questions that require the use of judgment. It can also be defined as “active sustained cognitive effort directed at solving a complex problem.”¹ Critical thinking has the following characteristics. It

- entails purposeful, goal-directed thinking;
- aims to make judgments based on evidence (fact) rather than conjecture (guesswork);
- is based on principles of science and scientific method; and
- is pursued with an open mind and lack of prejudice.²

The purpose of critical thinking is to achieve understanding, evaluate viewpoints, and solve

problems. Because all three of these objectives involve asking questions, it can be postulated that critical thinking is the inquiry engaged in when seeking to understand, evaluate, or resolve. Critical thinking in general also involves

- distinguishing between fact and opinion,
- making detailed observations,
- uncovering assumptions and defining their terms,
- recognizing logical inconsistencies in a line of reasoning,
- making assertions based on sound logic and solid evidence.^{3,4}

The use of critical thinking is inherent, to some level, in virtually all decision-making processes. This is particularly true in settings where a great deal of complex information must be processed to find solutions for complex problems or formulate opinions on multifaceted issues.⁵ Rendering an interpretation, as is done in medical sonography, is a prime example of a decision-making process that requires a consistent, balanced, systematic method of analytical thinking to integrate complex information obtained from several different cognitive domains to answer a question about another person's health. The process through which this decision (interpretation) is reached, then, should be based in factual realities that are systematically filtered through the sonographer's logic and reason. The application of scientific methodology to the subjective and empirical data obtained through the physical examination, past medical history, lab results, sonographic findings, and other diagnostic testing provides the foundation for the formulation of practical, pertinent, and reproducible information generated by the sonographic examination process.

Scientific Method

A model for critical thinking in medical sonography should provide a structural framework in determining what to observe, how to organize the observations or data, and how to interpret the information. Once identified and defined, these components can be incorporated into a critical thinking schema that can form the framework for a consistent and reasoned approach to the sonographic examination process. This methodology can also be quantitatively formatted for use in teaching and evaluating critical thinking in sonography education.

The framework presented in this article is based on standard scientific method employed in many disciplines where deductive and inductive reasoning and empirical (objective) data are used to answer a question or formulate an opinion. This well-established approach to problem solving and question answering may be defined as “an objective, logical and systematic method of observation and analysis of phenomena, devised to permit the accumulation of reliable knowledge” (p 1).⁶ This method consists of the following:

- Observation
- Hypothesis (what to observe)
- Data collection (how to organize observations)
- Data analysis (how to interpret the information)
- Conclusion

Example of Scientific Method in Medical Investigation

Typically, prior to embarking on an investigation to answer a question, an *observation* is made. For example, an echocardiographer *observes* that a lot of pediatric patients that she has examined in the past two years are born with a particular type of minor congenital heart defect. And, it appears, subjectively (to her), that the mothers of all of these babies work at the same chemical company. In her experience, the rate of occurrence of this particular heart defect is higher than she would expect from the otherwise healthy population of patients that she cares for. This *observation* prompts her to think about what may be causing this unexpectedly high level of congenital defects.

Based on her education, training, experience, conversations with peers and epidemiologists, readings, and an initial investigation into this *observation*, she forms a *hypothesis* that working at this particular chemical company somehow is responsible for the high rate of cardiac defects she has observed. To validate her hypothesis and gain the support of other people who are concerned about this situation, she must embark on a course of study (*organized observations*) that will demonstrate objectively, using scientific data, that her hypothesis is tenable. To do this, she designs a study that will gather information (*data collection*). Designing such a study requires a great deal of work; in the real world, the collaboration of physicians, biostatisticians, epidemiologists, support staff, researchers, and others is necessary.

Once the type and quantity of data needed to reach a valid conclusion is determined and the data are acquired through an organized, repeatable study, the time comes for *data analysis*. In this example, the data show clustering of the occurrence of heart defects in patients who work in a particular part of the laboratory that produces xenon hypobromide. Further evaluation and study reveal that other researchers have reported in the literature an association between xenon hypobromide and congenital heart defects. A reasonable *conclusion*, then, is that xenon hypobromide exposure caused or significantly contributed to the observed congenital cardiac anomalies in this physician's patient population.

Scientific Method Applied to Medical Sonography

This scientific method can also be applied to the sonographic examination process. Some specific examples are included.

- *Observation*: patient complaints, clinical symptoms, patient input (cues)
- *Hypothesis*: reason for referral, working (tentative) diagnosis, indications for examination, ICD9 (*International Classification of Diseases, 9th edition*) code, rule out
- *Data collection*: subjective patient information, lab work, physical findings in the

sonography lab, sonographic findings, other imaging findings

- *Data analysis*: correlation of lab findings, clinical data, interpretation of sonographic images and other pertinent findings
- *Conclusion*: sonographic diagnosis, sonographer's impression, final report of U.S. examination

OBSERVATION (INDICATION FOR EXAMINATION)

In medical sonography, the indications for an examination are usually observations about the patient made by the referring physician that cannot be explained on the basis of the information present during his or her examination of the patient. These observations are sometimes called "cues," with *cue* being broadly defined as an external stimulus that induces an internal response in the examiner.⁷ Clinical cues can be further categorized as *observations*, which are data with no particular medical interpretation, and *findings*, which are observations that have clinical significance.⁸

Specifically, then, observations, physical signs and symptoms, abnormal lab results, and reports of abnormal imaging studies are frequent cues encountered during a patient examination or work-up that might form the foundation for a request for a sonographic examination. Other indications for sonography are not based on such cues but may still be considered as "observations" in this critical thinking schema. Such observations are wide and varied and, because sonography does not use any form of ionizing radiation, frequently include follow-up of known benign conditions (aortic aneurysms, uterine fibroids, carotid artery stenosis, etc.) and routine assessment or screening of selected cohorts of patients such as in obstetrics or in patients exposed to hepatitis B and C.

HYPOTHESIS (WORKING DIAGNOSIS)

In medical sonography, the hypothesis is a tentative explanation for a cue or a set of cues that can be used as a basis for further investigation and is sometimes called the *working diagnosis*. The ability to coordinate preliminary hypotheses with data collected is an essential component of the reasoning processes used in scientific and technological domains.⁹ This holds true in medical sonography.

The sonographer must possess the cognitive ability to understand the reason for patient referral so that the information provided by the sonogram will fit into the broader diagnostic reasoning process.

Frequently, in medical imaging settings, the hypothesis may correlate with the *ICD9* code⁹ that, in some clinical settings, may be found on the patient's medical referral form. Or it may correspond with the "rule-out" (R/O) request from the referring physician. A hypothesis may even be inferred in patients receiving follow-up sonographic study because of a benign condition or in obstetric patients undergoing routine prenatal screening sonography. For example, a patient with a known aortic aneurysm may present with the inferred hypothesis that "the aneurysm has grown" because of the well-documented natural history of aortic atherosclerotic disease. Or, in the uncomplicated obstetric patient, an inferred hypothesis for the performance of a sonogram may be that "this fetus is presumed to be anatomically normal" because of the overall low incidence of fetal anatomic anomalies in the general population.

DATA COLLECTION (PATIENT ASSESSMENT)

Patient assessment is the collection of data about the individual's state of health.¹⁰ In medical sonography, it involves applying the techniques of collecting and analyzing *subjective* data (what the person *says* about himself or herself during history taking) and *objective* data (what the sonographer *observes* by inspecting, percussing, palpating, and auscultating during the physical examination). Ideally, this level of clinical information is provided by the referring physician or clinical practitioner. However, in many real-life situations, the patient arrives in the sonography department devoid of any prerequisite clinical observations from the referring physician. Therefore, pertinent objective findings may need to be obtained by the sonographer when indicated by the subjective findings. This information is recorded and reported to the interpreting physician along with the other assessment data collected.

When integrated with the patient's medical history, laboratory results, and reports of other imaging studies, these objective observations are part of the elements that form the basis for the first infer-

ence, or determination, made by the sonographer—that is, what specific type and level of information is expected from this sonographic examination and how that information may affect the care and management of this patient. The application of critical thinking skills at this point in the sonographic examination process will ensure that the patient receives the appropriate type of examination (i.e., abdomen vs. pelvis) and the appropriate level of examination (i.e., full abdominal scan vs. limited scan).

The next application of critical thinking occurs during the real-time sonographic examination itself. The sonographer continuously acquires data in the form of 2D, sectional real-time images and, in many cases, hemodynamic information presented by various Doppler display techniques. For a successful sonographic examination, this information must be cognitively assessed by the sonographer, and a judgment must be made as to whether the information being obtained and recorded is of the appropriate type, level, and technical quality pertinent to this particular clinical scenario. If a determination is made that the information being obtained is not appropriate or adequate, alteration or tailoring of the imaging examination can be undertaken to remedy the inadequacies or improve the quality of information output.

DATA ANALYSIS (DIAGNOSTIC REASONING)

Data analysis in medical sonography is part and parcel of the broader cognitive process of diagnostic reasoning and/or making an interpretation. It requires a careful and systematic consideration of all the evidence gathered to answer the question posited in the hypothesis portion of this critical thinking schema.¹¹ Diagnostic reasoning is the cognitive process that relies on logic and experience to draw inferences about the health or condition of a patient from the data collected during the first three components of the critical thinking process applied to the sonographic examination. It is at this stage that meaning and value of the information obtained are evaluated in light of the critical thinking process.

Cognitive psychology research supports the notion that experts use mental frameworks or

“schemes,” both to organize knowledge in memory and to solve clinical problems.^{12,13} The cognitive (data analysis) process in medical sonography can begin with a restatement and consideration of the scientific method employed herein. This method of collecting and analyzing information is also the model of diagnostic reasoning in general medical practice. There are four major components:

1. Reviewing the available cues: these cues are typically symptoms or reasons for referral.
2. Formulating diagnostic hypotheses: in light of the symptoms present, a tentative diagnosis or technical impression is formulated.
3. Gathering data relative to the tentative hypotheses. These data are used in an attempt to discriminate between relevant hypotheses, eliminate incorrect hypotheses, and reinforce possibly correct ones.
4. Evaluating each hypothesis in light of new data collected. During this process of discrimination, a single impression, interpretation, or diagnostic hypothesis is isolated as the correct one.¹¹

Various authors have attempted to elucidate the specific cognitive processes involved in arriving at a diagnosis.¹⁴⁻¹⁷ To simplify several complex theories about this process, a study must involve inductive reasoning, deductive reasoning, and intuitive responses based on clinical experience. A full discussion of the theories of diagnostic reasoning is beyond the scope of this article.

There is a clear, positive correlation between clinical experience and diagnostic accuracy.¹⁸ The more experience an individual has in using systematic cognitive methods, the higher the probability that his or her interpretation or diagnosis will be correct.^{12,19} Of interest is recent work that identifies particular “aesthetics” and “sensibilities” found in experts practicing in the visual domains in medicine that enable them to take keen discrimination and judgment to the level of an art.²⁰ This psychologically intuitive or philosophically a priori ability on the part of a well-seasoned sonographer is frequently manifested in statements, such as “I just *knew* there was something wrong,” or “I had this *gut feeling* that something was abnormal.” This intuitive sensibility results from regular and conscious use of established thinking and practicing

patterns.²⁰ Many examples of this phenomenon exist in practical day-to-day sonography and can be found across credential-based specialties.

CONCLUSION (SONOGRAPHIC DIAGNOSIS)

Before defining a *sonographic diagnosis*, it is necessary to consider what the definition of *diagnosis* is in general terms. A simple encyclopedia definition of a medical diagnosis is the “determination of the nature of a disease or ailment” (p 174).¹⁴ Using the concepts of critical thinking methods employed in this schema, a more applicable definition of *diagnosis* may be the “process of converting evidence into the names of diseases” (p 502).²¹ This process involves the integration of many skills, and extracting diagnostic information from a sonographic examination is but one small component of the diagnostic process.²² The ultimate value in reporting the results of a sonographic examination as an interpretation or a “diagnosis” contributes to care and management of the patient by summarizing patient findings into a “coherent and functional unit that facilitates therapeutic and management decisions” (p 445).²³

A sonographic interpretation or diagnosis, then, is the conclusion reached or the judgment passed about a patient’s health or specific physical condition using various cognitive processes. These systematic thinking and observing patterns integrate (1) patient assessment data, (2) clinical findings (cues) observed by the referring physician and/or sonographer, and (3) a variety of types of sonographic and Doppler information. By applying this schema to specific clinical situations, a final diagnosis can be rendered in some cases (i.e., cholelithiasis), whereas in others, the information provided by the sonographic examination is one more piece of the broader diagnostic process being conducted by the referring physician.

Conclusion

Cognitive activity (thinking) that produces valid, reliable, and reproducible results is the sine qua non of efficacious diagnostic medical sonographic practice. Although this concept is bantered about in educational and peer review circles, few, if any, specific components of this practice are laid

out for the sonographer to contemplate while pursuing his or her lifelong learning process. Thinking about thinking, as it relates to arriving at a valid sonographic diagnosis, should be introduced to sonography students early in their studies, and it should be reintroduced to practicing sonographers as their experiential level increases. By adopting a cognitive schema, such as the scientific method, that is applicable specifically to medical sonography, sonographers can consciously work at improving and enhancing the critical thinking skills that are the foundation of the diagnostic reasoning process.

References

1. Grant GE: *Teaching Critical Thinking*. New York, Praeger, 1988.
2. Alfaro-LeFevre R: *Critical Thinking in Nursing: A Practical Approach*, 2nd ed. Philadelphia, W. B. Saunders, 1999.
3. Fowler B: *Critical Thinking Across the Curriculum Project*. Kansas City, MO, Longview Community College, 2001.
4. Duplass JA, Ziedler DL: Critical thinking and logical argument. *Soc Educ* 2002;66(5):1-5.
5. Halpern DF: *Critical Thinking Across the Curriculum: A Brief Edition of Thought and Knowledge*. Mahwah, NJ, Lawrence Erlbaum, 1997.
6. Lastrucci CL: *The Scientific Approach: Basic Principles of the Scientific Method*. Cambridge, UK, Schenkman, 1963.
7. McDonald FJ: *Educational Psychology*. San Francisco, Wadsworth, 1959.
8. Arocha JF, Patel VL: Novice diagnostic reasoning in medicine: Accounting for evidence. *J Learn Sci* 1995;4(4):357.
9. *International Classification of Diseases (ICD-9-CM), 9th Revision Clinical Modification*. Chicago, AMA Press, 2003.
10. Jarvis C: *Physical Examination and Health Assessment*. 3rd ed. Philadelphia, W. B. Saunders, 2000.
11. Wolff CR: Quantitative reasoning across a college curriculum. *College Teaching* 1993;41(1):5.
12. Coderre S, Mandin H, Harasym PH, Fick GH: Diagnostic reasoning strategies and diagnostic success. *Med Educ* 2003;37(8):695-703.
13. Hmelo CE: Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *J Learn Sci* 1998;7(2):174.
14. Patel VL, Arocha JF: Cognitive models of clinical reasoning and conceptual representation. *Methods Inf Med* 1995;34(1-2):47-56.
15. Patel VL, Arocha JF, Kaufman DR: A primer on aspects of cognition for medical informatics. *J Am Med Inform Assoc* 2001;8(4):324-343.

16. Patel VL, Kaufman DR, Arocha JF: Emerging paradigms of cognition in medical decision-making. *J Biomed Inform* 2002;35(1):52–75.
17. Gandjour A, Lauterbach KW: Inductive reasoning in medicine: Lessons from Carl Gustav Hempel's "inductive-statistical" model. *J Eval Clin Pract* 2003;9(2):161–169.
18. Ferrario CG: Experienced and less-experienced nurses' diagnostic reasoning: Implications for fostering students' critical thinking. *Int J Nurs Terminol Classif* 2003;14(2):41–52.
19. Distlehorst LH, Dunnington GL, Folse JR: *Teaching and Learning in Medical and Surgical Education: Lessons Learned for the 21st Century*. Mahwah, NJ, Lawrence Erlbaum, 2000.
20. Bleakley A, Farrow R, Gould D, Marshall R: Making sense of clinical reasoning: Judgment and the evidence of the senses. *Med Educ* 2003;37(6):544–552.
21. Fraser RC: *Clinical Method: A General Practice Approach*. London, Butterworth, 1987.
22. Norman GR, Brooks RL, Colle CL, Hatala RM: The benefit of diagnostic hypotheses in clinical reasoning: Experimental study of an instructional intervention for forward and backward reasoning. *Cogn Instr* 1999;17(4):445.
23. Arocha JF, Patel VL: Hypothesis generation and the coordination of theory and evidence in medical diagnostic reasoning, in *Proceedings of the 13th Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum, 1991, pp 623–628.

Correspondence: Jim Baun, Professional Ultrasound Services, 244 20th Avenue, San Francisco, CA 94212. E-mail: jimbaun@aol.com.