Appendix C Applications of Clinical Decision Support Systems[1]

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Clinical Decision Support Systems (CDSSs)—at least those whose effectiveness has been evaluated—perform one or more of the following functions: diagnosis, drug dose determination, preventive care reminders, and active (diagnostic or therapeutic) care advice.[1] These applications and some recent examples —including ones whose effectiveness has *not* been evaluated—are discussed in the following sections. With most of these systems, clinicians do not interact directly with the computer; rather, staff personnel input the needed data on the patient and provide the clinician with computer-printed reports.[2]

COMPUTER-AIDED DIAGNOSIS

These systems are designed to assist the clinician in determining the patient's exact diagnosis or the condition underlying his/her presenting health problem. The systems take as input the patient's signs and symptoms, physical findings, test results, and background information, and then report one or more possible diagnoses that match that combination of characteristics. The patient data must ordinarily be manually key-entered in a particular format required by the system. Rather than attempting to cover all diagnoses, most systems focus on specific health problems.

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[1] Johnston et al., op. cit., footnote 1. Connelly and Bennett propose a similar scheme for classifying the functions of knowledge-based systems that have clinical laboratory applications: classify (e.g., diagnosis), predict (e.g., adverse events), plan (i.e., recommend specific actions), monitor (including alerts, reminders, and process control/scheduling), facilitate (make a human task easier), and convey (present data, conclusions, etc.). D.P. Connelly and S.T. Bennett, "Expert Systems and the Clinical Laboratory Information System," *Clinics in Laboratory Medicine*, vol. 11, No. 1, March 1991, pp. 136-138.

[2] Johnston et al., op. cit., footnote 1, p. 137.

However, several systems, including Dxplain,[3] Iliad,[4] Meditel,[5] and QMR,[6] are designed to address the entire field of internal medicine. They employ either deterministic or probabilistic/adaptive algorithms to produce a list of possible diagnoses, ranked in order of likelihood.[7]

DRUG DOSE DETERMINATION

These systems are designed to assist the clinician in determining the proper dosage of a specific drug for a particular kind of patient.[8] Some evidence suggests that clinicians have a particularly difficult time calculating drug dosages.[9] Again, data on the patient is usually entered manually in a format required by the system. (The patient's diagnosis is usually assumed by the system, based on the drug being used.) The algorithms in the knowledge base then ascertain the proper dosage of the drug in question, either as an exact quantity or as a permissible range. One example of such a system generates estimates for dosing of aminophylline for acute asthma cases presenting in the emergency room.[10] Commercial programs have also been developed for dosing of selected drugs based on patient-specific characteristics and measured drug concentrations.[11]

PREVENTIVE CARE REMINDERS

These systems are designed to remind the clinician to administer a particular preventive service when the patient reaches a certain stage in the process of care for a given health problem (e.g., retinal examination for diabetics), or simply a certain stage of life (e.g., immunization). Unlike computer-aided diagnosis and drug-dose determination, which are usually designed to provide a single report in response to a specific set of data on a given patient, a preventive care reminder system requires repeated input of data on the patient over time. This includes not only the patient's diagnoses and other clinical characteristics, but also the treatments and tests administered and when they were administered. To the extent that the set of rules for generating reminders represents a model of the disease process for which a preventive service is to be administered, they constitute a type of formal clinical protocol.

The protocol specifies exactly what preventive treatments should be performed at each stage in the process of care for the health problem at hand, based either on the amount of time that has elapsed since the previous stage (e.g., a previous treatment or test) or on data values measuring the patient's

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[3] Massachusetts General Hospital, Boston, MA.

[4] Applied Informatics, Salt Lake City, UT.

[5] Meditel, Devon, PA.

[6] CAMDAT, Pittsburgh, PA.

[7] E.S. Berner et al., "Performance of Four Computer-Based Diagnostic Systems," *New England Journal of Medicine*, vol. 330, No. 25, June 23, 1994, pp. 1792-1796; R.A. Miller, "Medical Diagnostic Decision Support Systems—Past, Present, and Future," *Journal of the American Medical Informatics Association*, vol. 1, No. 1, January/February 1994, pp. 8-27.

[8] R.W. Jelliffe et al., "Adaptive Control of Drug Dosage Regimens: Basic Foundations, Relevant Issues, and Clinical Examples," *International Journal of Biomedical Computing*, vol. 36, No. 1-2, June 1994, pp. 1-23.

[9] S. Rolfe and N.J.N. Harper, "Ability of Hospital Doctors To Calculate Drug Doses," *British Medical Journal*, vol. 310, No. 6988, May 6, 1995, pp. 1173-1174.

[10] E.R. Gonzales et al., "Computer-Assisted Optimization of Aminophylline Therapy in the Emergency Department," *American Journal of Emergency Medicine*, vol. 7, No. 4, July 1989, pp. 395-401.

[11] Dasta et al., op. cit., footnote 1.

condition at that point in time. The Regenstrief Medical Record System at Indiana University[12] was apparently the first CDSS to develop a comprehensive set of preventive care reminders, for example, to administer influenza vaccinations.[13] More specialized examples include two systems that provide reminders to perform blood pressure measurement and cervical cancer screening, respectively.[14] The HealthQuiz program elicits background information and risk factors from patients, then compares their answers to detailed preventive care guidelines, flags problems, and recommends appropriate interventions.[15]

ACTIVE-CARE ADVICE

These systems are designed to assist the clinician in performing diagnostic or therapeutic procedures (including pharmaceutical treatments) when the patient reaches certain stages in the process of care for a given health problem, again often modeled in a formal clinical protocol. An active-care advisory system requires repeated input of data on the patient's health problems, tests, and treatments over time. The protocol specifies exactly what diagnostic and therapeutic procedures should be performed at each stage in the process of care for the health problem at hand. This type of computer-based clinical advice can take six basic forms:

1. *Treatment recommendations* (including pharmaceuticals) appropriate for the health problem at hand, for example, the MYCIN program that provides diagnostic and treatment advice for patients with meningitis,[16] and the *antibiotic consultant* component of the Health Evaluation through Logical Processing (HELP) system at LDS Hospital in Salt Lake City, Utah, that recommends appropriate antibiotics in light of the patient's characteristics and specific infection, drawn from an electronic medical record.[17]
2. *Reminders* to the clinician to perform specific diagnostic or therapeutic procedures at certain stages in the process of caring for the health problem at hand, such as adult respiratory distress syndrome in the HELP system.[18]
3. *Alerts* to the clinician regarding potential adverse events, for example, worsening of the patient's condition, based on feedback of abnormal test results.[19]
4. *Feedback* (including alerts) regarding orders that the clinician entered for the patient, including:

- possibly inappropriate treatments, given the patient's complicating health problems and/or

[12] C.J. McDonald et al., "The Regenstrief Medical Record System: 20 Years of Experience in Hospitals, Clinics, and Neighborhood Health Centers," *M.D. Computing*, vol. 9, No. 4, July/August 1992, pp. 206-217.

[13] C.J. McDonald, S.L. Hui, and W.M. Tierney, "Effects of Computer Reminders for Influenza Vaccinations on Morbidity During Influenza Epidemics." *MD Computing*, vol. 9, No. 5, September-October 1992, pp. 304-312.

[14] I. McDowell, C. Newell, and W. Rosser, "A Randomized Trial of Computerized Reminders for Blood Pressure Screening in Primary Care," *Medical Care*, vol. 27, No. 3, March 1989, pp. 297-305; I. McDowell, C. Newell, and W. Rosser, "Computerized Reminders To Encourage Cervical Screening in Family Practice," *Journal of Family Practice*, vol. 28, No. 4, April 1989, pp. 420-424.

[15] "'HealthQuiz' Makes Preventive Care Guidelines Easy To Apply," *Report on Medical Guidelines & Outcomes Research*, Jan. 26, 1995, pp. 5-6.

[16] E.H. Shortliffe, "Computer Programs To Support Clinical Decision Making," *Journal of the American Medical Association*, vol. 258, No. 1, July 3, 1987, pp. 61-66.

[17] R.S. Evans, D.C. Classen, and S.L. Pestotnik, "Improving Empiric Antibiotic Selection Using Computer Decision Support," *Archives of Internal Medicine*, vol. 154, No. 8, Apr. 25, 1994, pp. 878-884.

[18] A.H. Morris, "Protocol Management of Adult Respiratory Distress Syndrome," *New Horizons*, vol. 1, No. 4, November 1993, pp. 593-602.

[19] K.E. Tate, R.M. Gardner, and L.K. Weaver, "A Computerized Laboratory Alerting System," *M.D. Computing*, vol. 7, No. 5, September-October 1990, pp. 296-301; D.M. Rind et al., "Effect of Computer-Based Alerts on the Treatment and Outcomes of Hospitalized Patients," *Archives of Internal Medicine*, vol. 154, No. 13, July 11, 1994, pp. 1511-1517.

background characteristics (even if the treatment would otherwise be appropriate for the health problem at hand), for example, alerts regarding drug allergies in the order-entry system at Brigham and Women's Hospital in Boston;[20]

- possibly inappropriate treatments regardless of the patient's health problems or characteristics, for example, commercial programs to detect drug-drug and drug-nutrient interactions;[21]
- likely conflict or redundancy between a chosen test and others already ordered for the patient;[22]
- likely results of a test ordered for the patient; if the probability of an abnormal result is low, the clinician can reconsider whether the test is really worth performing;[23]
- results of previous tests on the patient that are like the one being ordered, so the clinician may reconsider whether the test really needs to be repeated;[24]
- the cost of a test or treatment ordered for the patient, so the clinician can reconsider whether it is really worth performing;[25] and
- tests or treatments that would be less costly than the one ordered, but equally effective in treating the health problem at hand.[26]

5. *Prompts* to the clinician for decisions regarding testing or treatment options, or for entry of information on the patient's health problems or background, as in the drug order-entry system at Brigham and Women's Hospital.[27]
6. *Prognoses* of intensive care unit patients based on such predictors as severity of illness (using vital signs and other physical measures) and physiological reserve (age and complicating health problems) in the Acute Physiology and Comprehensive Health Evaluation (APACHE) system.[28] APACHE is also used as a method of measuring severity of illness and risk-adjusting outcome measures.[29] An expanded prognostic model known as SUPPORT (Study to Understand Prognoses and Preferences for Outcomes and Risks of Treatments) is designed to predict survival to 180 days (rather than to discharge) and includes patients who are not severely ill.[30]

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[20] R. F. Gibson and B. Middleton, "Health Care Information Management Systems To Support CQI," *Clinical Practice Improvement: A New Technology for Developing Cost-Effective Quality Health Care,* S.D. Horn and D.S.P. Hopkins (eds.) (New York, NY: Faulkner & Gray, 1994), pp. 116-117.

[21] T.I. Poirer and R. Giudici, "Evaluation of Drug Interaction Microcomputer Software: Comparative Study," *Hospital Pharmacy*, vol. 26, No. 1, January 1991, pp. 30-37; T.I. Poirer and R. Giudici, "Evaluation of Drug-Food/Nutrient Interactions Microcomputer Software Programs," *Hospital Pharmacy*, vol. 26, No. 6, June 1991, pp. 533-540.

[22] Connelly and Bennett, op. cit., footnote 2.

[23] W.M. Tierney et al., "Computer Predictions of Abnormal Test Results: Effects on Outpatient Testing," *Journal of the American Medical Association*, vol. 259, No. 8, Feb. 26, 1988, pp. 1194-1198.

[24] W.M. Tierney et al., "Computerized Display of Past Test Results: Effect on Outpatient Testing," *Annals of Internal Medicine*, vol. 107, No. 4, October 1987, pp. 569-574.

[25] W.M. Tierney, M.E. Miller, and C.J. McDonald, "The Effect on Test Ordering of Informing Physicians of the Charges for Outpatient Diagnostic Tests," *New England Journal of Medicine*, vol. 322, No. 21, May 24, 1990, pp. 1499-1504.

[26] W.M. Tierney et al., "Physician Inpatient Order Writing on Microcomputer Workstations: Effects on Resource Utilization," *Journal of the American Medical Association*, vol. 269, No. 3, Jan. 20, 1993, pp. 379-383.

[27] Gibson and Middleton, op. cit., footnote 21.

[28] W.A. Knaus, D.P. Wagner, and J. Lynn, "Short-Term Mortality Predictions for Critically Ill Adults: Science and Ethics, *Science*, vol. 254, No. 5030, Oct. 18, 1991, pp. 389-394; J.E. Zimmerman, W.A. Knaus, and M. Seneff, "Outcome Prediction in Intensive Care," *Intensive Care Rounds*, No. 10125 (Abingdon, England: The Medicine Group (Education), Ltd., January 1993).

[29] L.I. Iezzoni, "Risk Adjustment for Medical Outcome Studies," *Medical Effectiveness Research Data Methods*, M.L. Grady and H.A. Schwartz (eds.), Agency for Health Care Policy and Research, AHCPR Pub. No. 92-0056 (Rockville, MD: July 1992), pp. 83-97.

[30] W.A. Knaus et al., "The SUPPORT Prognostic Model: Objective Estimates of Survival for Seriously Ill Hospitalized Adults," *Annals of Internal Medicine*, vol. 122, No. 3, Feb. 1, 1995, pp. 191-203.