1-1-2008

Automation, Decision Support, and Expert Systems in Nephrology

Sandeep Soman
Henry Ford Health, SSOMAN1@hfhs.org

Gerard Zasuwa
Henry Ford Health, gzasuwa1@hfhs.org

Jerry Yee
Henry Ford Health, JYEE1@hfhs.org

Recommended Citation

Soman S, Zasuwa G, Yee J. Automation, Decision Support, and Expert Systems in Nephrology. Advances in Chronic Kidney Disease 2008; 15(1):42-55.

Automation, Decision Support, and Expert Systems in Nephrology

Sandeep Soman, Gerard Zasuwa, and Jerry Yee

Increasing data suggest that errors in medicine occur frequently and result in substantial harm to the patient. The Institute of Medicine report described the magnitude of the problem, and public interest in this issue, which was already large, has grown. The traditional approach in medicine has been to identify the persons making the errors and recommend corrective strategies. However, it has become increasingly clear that it is more productive to focus on the systems and processes through which care is provided. If these systems are set up in ways that would both make errors less likely and identify those that do occur and, at the same time, improve efficiency, then safety and productivity would be substantially improved. Clinical decision support systems (CDSSs) are active knowledge systems that use 2 or more items of patient data to generate case specific recommendations. CDSSs are typically designed to integrate a medical knowledge base, patient data, and an inference engine to generate case specific advice. This article describes how automation, templating, and CDSS improve efficiency, patient care, and safety by reducing the frequency and consequences of medical errors in nephrology. We discuss practical applications of these in 3 settings: a computerized anemia-management program (CAMP©, Henry Ford Health System, Detroit, MI), vascular access surveillance systems, and monthly capitation notes in the hemodialysis unit.

Index Words: Anemia management; Clinical decision support system; Decision support; Expert systems; Electronic health records; Health information technology; Vascular access surveillance.

The Institute of Medicine report *To Err Is Human: Building a Safer Health System* has fostered an intense effort to use information technology as 1 means to reduce medical errors.[1] Physician practice patterns and corresponding treatment outcomes vary widely, and such variations can be associated with both suboptimal patient outcomes and increased treatment costs.[2] Observed differences in treatment outcomes across populations suggest that major opportunities for improvement exist, as clinicians, patients, payers, and the general public demand improved health care quality and more information about it.[3,4] Health care consumers seek to be better informed about their choices and expect to see provider-specific clinical outcomes data to confirm the promised benefits of medical treatments.[5] Payers require clinical outcome data to evaluate quality of care and cost-effectiveness.[6] This "outcomes movement" has been fueled by recent research that describes substantial geographical differences in hospital admissions and medical procedures, differences that cannot be explained solely by the severity of illness.[7] Such practice variations are driven by many factors, including patient population differences, lack of professional consensus, nonuniform access to care, differences in local or regional capabilities, and the overall quality of care practices. The great concern is that practice variability may lead to suboptimal treatment in a significant proportion of patients.[2,8,9]

Health care quality measurement is an elusive goal, and current quality of care measurement practices are relatively primitive.[10] There is a paucity of data to assess the implementation of treatment guidelines and related treatment outcomes.[11] In an effort to monitor and improve care, insurers and managed-care groups often apply utilization review, profiling, and other rudimentary methods.[4] Through the implementation of a robust health care quality information system, raw data can be transformed into useful codified information, leading to new knowledge that may improve patient care. These systems must support a particular form of knowledge

From the Division of Nephrology and Hypertension, Henry Ford Health System, Detroit, MI.

Address correspondence to Sandeep S. Soman, MD, Division of Nephrology and Hypertension, Henry Ford Health System, CFP-5, Detroit, MI 48202. E-mail: ssoman1@hfhs.org

1548-5595/08/1501-0009$34.00/0

doi:10.1053/j.ackd.2007.10.005

management, defined as "the process of creating, capturing, and using knowledge to enhance organizational performance."[12] This involves using automation, clinical decision support systems (CDSSs), and the development of large, sophisticated databases using medical information technology to support complex analyses integral to effective outcomes monitoring and management.[13,14]

Theory of Error

Although human error in health care systems has only recently received widespread attention, great attention has been accorded to human factors in error in the engineering and aviation fields.[15-17] It is easy and common to blame operators for accidents, but investigations often indicate that an operator "erred" because a system was poorly designed. The consensus among man-machine system engineers is that our control rooms, intensive care units, and operating rooms should be so designed that they are more "transparent" so that the operator can more easily "see through" the displays of the actual working system to "what is going on" behind the screens. Often the operator is locked into the dilemma of selecting and slavishly following one or another written procedure, each based on an anticipated causality. The operator may not be sure what procedure, if any, fits the current an imperfectly understood or anticipated situation.

Machines can also produce errors. It is commonly appreciated that humans and machines are different and that their combination has greater potential reliability than either alone, but how best to use this knowledge is unknown. Humans are erratic and err in surprising and unexpected ways; yet, they are also resourceful and inventive and can recover from their own and equipment-related errors in creative ways. In comparison, machines are more dependable, which means they can be dependably incorrect even when a minor corrective change in their output would prevent a failure in a neighboring component from propagating. The intelligent machine can be made to adjust to an identified variable whose importance and relation to other variables is sufficiently well understood. The intelligent human operator still remains useful, capable of responding to an "unknown unknown" (a variable that was never anticipated, so that there was never any basis for equations to predict it or computers and software to control it).

Finally, we seek to reduce the undesirable consequences of error, not simply the error itself. Senders and Moray[18] provide some relevant comments that relate to information technology: "The less often errors occur, the less likely we are to expect them, and the more we come to believe that they cannot happen" and "it is something of a paradox that the more errors we make, the better we will be able to deal with them." They comment further that "eliminating errors locally may not improve a system and might cause worse errors elsewhere."[18]

Systems Improvement and Error Prevention

Although the traditional approach in medicine has been to identify the persons making the errors and hold them responsible in some way, it has become increasingly clear that it is more productive to focus on the systems by which care is provided.[19] If these systems could be established in ways that would both make errors less likely and catch those that do occur, safety might be substantially improved. A system analysis of a large series of serious medication errors (those that either might have or did cause harm) identified 16 major types of system failures associated with these errors.[19] Of these system failures, all of the top 8 could have been addressed by the better use of medical information technology.

Currently, the clinical information systems in routine use in health care in the United States leave a great deal to be desired. The health care industry spends less on information technology than do most other information-intensive industries. As a result, in part, the dream of system integration has been realized in few organizations. For example, laboratory systems do not communicate directly with pharmacy systems. Even within medication systems, electronic links between parts of the system including prescribing, dispensing,

and administering typically do not exist today. Nonetheless, real and difficult issues are present in the implementation of information technology in health care, and simply funding a large project does not guarantee that an organization will necessarily get an outstanding information system, as many organizations have learned to their chagrin.

Evaluation is also an important issue because data on the effects of information technology on error and adverse event rates are remarkably sparse, and many more studies are needed to address this issue. Although such evaluations are challenging, tools that assess the frequency of errors and adverse events in a number of domains are now available.[20-22] Errors are much more frequent than actual adverse events (for medication errors, the ratio in 1 study was 100:1). As a result, it is attractive from the sample size perspective to track error rates, although it is important to recognize that errors vary substantially in their likelihood of causing injury.[23,24]

The Role of Automation, Clinical Decision Support, and Expert Systems

Although many errors can be detected and corrected through use of human knowledge and inspection, these modalities represent weak error reduction strategies. In 1995, Leape et al[19] showed that almost half of all medication errors were intimately linked with insufficient information about the patient and drug. Similarly, people routinely miss errors when they are asked to detect them by inspection.[25]

DSS can be thought of as "active knowledge systems which use two or more items of patient data to generate case-specific advice."[26] CDSS are typically designed to integrate a medical knowledge base, patient data, and an inference engine to generate case specific advice.[26]

CDSS provides clinicians, staff, patients, or other individuals with intelligently filtered knowledge and person-specific information at appropriate times to enhance health and health care, especially at the point care.[27] CDSSs encompass a variety of tools and interventions including computerized alerts and reminders, clinical guidelines, order sets, patient data reports and dashboards, documentation templates, diagnostic support, and clinical workflow tools. CDS has been effective in improving outcomes at some health care institutions and practice sites by making needed medical knowledge readily available to knowledge users at point of care. Yet, at many other sites, CDS has been problematic, stalled during the planning stages, or not even attempted. Consequently, relevant medical knowledge is not readily available or used for many health care decisions in this country. This is an important contributor to the well-documented problems and suboptimal performance of our health care system. Furthermore, growing consumerism throughout US society and efforts to shift the costs of care to patients and expand patient participation in health care decisions are driving increasing patient and consumer demand for access to reliable medical information. Achieving desirable levels of patient safety, care quality, patient centeredness, and cost-effectiveness requires that health systems optimize their performance via consistent, systematic, and comprehensive application of available health-related knowledge through CDS.[27]

Computerized physician order entry systems that incorporate CDS have substantially reduced medication error rates and improved the quality and efficiency of medication use. In 1998, Bates and colleagues[23] determined that computerized physician order entry systems produced a 55% reduction in serious medication errors. In another time series study, the same group found an 83% reduction in the overall medication error rate with the introduction of a simple system.[28] CDS has also improved antibiotic-associated adverse drug events and decreased costs.[28]

Another class of CDS is computerized alerting systems, which can notify physicians about problems that occur asynchronously. A growing body of evidence suggests that such systems may decrease error rates and improve therapy, thereby improving outcomes, including survival, the length of time patients are exposed to dangerous conditions, hospital length of stay, and costs.[29,30] Although an increasing number of clinical information systems contain data worthy of generating an alert message, delivering the message to

caregivers in a timely way that can be acted on expediently has been problematic. For example, Kuperman and coworkers[31] documented significant delays in treatment even when critical laboratory results were phoned to caregivers. Various new forms of alerting mechanisms such as computer-generated terminal messages, e-mail, and even flashing lights on hospital wards have been devised and are being tested to improve the delivery process.[31-33] It is now possible to integrate laboratory, medication, and physiologic data alerts into a comprehensive real-time wireless alerting system.

Alerts are a crucial part of a CDS, and their value has been shown in controlled trials.[30] In 1 study, physicians alerted via e-mail to elevations in serum creatinine of patients receiving nephrotoxic medications or renally excreted drugs, adjusted or discontinued drugs an average of 21.6 hours earlier than they would have had no alerts been sent. In another study, when clinicians who were paged about "panic" laboratory values, time to therapy decreased by 11% and the mean time to resolution of abnormalities was shortened by 29%.[30] As more and different kinds of clinical data become available electronically, the ability to perform more sophisticated alerts and other types of decision support will grow. Most sophisticated systems include a combination of these tools.

The Value Proposition

For information technology to be implemented more globally, returns on investment must be sufficient, but far too few data exist regarding this point in health care, and there are stories in which huge investments in information technology have, distressingly, come to naught.

Positive examples relate to computer order entry. At 1 large academic hospital, the savings were estimated to be $5 to $10 million annually on a $500 million budget.[34] In addition, in a randomized controlled trial, order entry was found to result in a 12.7% decrease in total charges and a 0.9 day decrease in length of stay.[35] Even without full computerization of ordering, substantial savings can be realized; data from Latter Day Saints Hospital showed that a program that assisted with antibiotic management resulted in a 5-fold decrease in the frequency of excess drug dosages and a 10-fold reduction in antibiotic-susceptibility mismatches, with substantially lower total costs and lengths of stay.[28]

Factors Determining Successful Implementation of CDS

Bates and others describe the "Ten Commandments" for effective CDS, which are noted below[36]: (1) speed is everything; (2) anticipate needs and deliver in real time; (3) fit into the users workflow; (4) little things can make a big difference; (5) recognize that physicians will strongly resist stopping existing practices; (6) changing direction is easier than stopping; (7) simple interventions work best; (8) ask for additional information only when you really need it; (9) monitor impact, get feedback, and respond; and (10) manage and maintain your knowledge-based systems.

Barriers

Despite demonstrated benefits, only a handful of organizations have successfully implemented CDSS. A number of barriers have prevented implementation. Among these are the tendency of health care organizations to invest in administrative rather than clinical systems; the issue of "silo accounting" so that benefits that accrue across a system do not show up in 1 budget and thus do not get credit; the current financial crisis in health care (exacerbated by the Balanced Budget Amendment, which has made financial investment in CDSS difficult); the relative lack of leaders and standardization in medical information technology; and a paucity of expertise in implementing systems.

One of the greatest barriers to providing outstanding decision support has been the requirement for an extensive electronic medical record system infrastructure. Although much of the data required to implement significant clinical decision support is available in digital formats at many institutions, the data are either inaccessible or not interfaced with CDS. Presently, existing and evolving standards for exchange of information (Health Level 7) and coding

of these data are simplifying this task. The approaches to choosing the information that should be coded and the mechanisms of aggregating purposefully a mixture of structured coded information and unstructured text remain to be developed and perfected.

Some organizations have proceeded before global adoption of standards with tangible benefits. Henry Ford Health System (HFHS) is currently in the process of developing a state-of-the-art electronic medical record that incorporates queryable Web-based databases and computerized provider order entry.

A second major hurdle involves the choice of appropriate rules or guidelines for implementation. Many organizations have not developed processes for developing and implementing consensus choices in their physician groups. Once the focus has been determined, the organization must determine exactly what should be done about the selected problem. Regulatory and legal issues have also prevented vendors from providing this type of content. Finally, despite good precedents for delivering feedback to clinicians for simple decision support, changing provider behavior for more complex aspects of care remains challenging.[17]

Automation, CDSS, and Expert Systems in Nephrology

The application of these principles to nephrology practice is discussed in 3 settings: (1) computerized anemia-management program (CAMP©, Henry Ford Health System, Detroit, MI), (2) vascular access surveillance system, and (3) ESRD note documentation.

CAMP

Background

Despite nearly 2 decades of experience regarding the treatment of the anemia of chronic kidney disease (CKD) with erythropoietin, there is inconsistency in outcomes and management of this issue. The initial hemoglobin at the outset of renal replacement therapy remains at less than 10 g/dL in a significant number of patients for various reasons.[37] Patient-related factors such as inflammation may preclude an adequate response to erythropoietic-stimulating agents (ESAs) and/or iron therapy, or there may be inadequate dosing of these agents, singly or in combination, by the health care provider.[37] In addition, logistical factors may hamper optimal dosing strategies. For instance, a patient who receives weekly subcutaneous ESA dosing may miss doses for whichever reason or may encounter insurance snafus, the consequence of which is delayed or missed ESA dosing.

Anemia management represents a major portion of the HFHS's comprehensive CKD clinic and more than 1,000 patients have been or are being treated for anemia associated with CKD in this clinic. The large volume of patients requiring chart review before drug administration and the time to deliver the ESAs and/or intravenous iron represented a large proportion of nursing time daily. Time allocation was aggravated by the requirement to obtain authorization from the prescribing health care provider before ESA injection, which was prolonged by inevitable conversations regarding a review of the case. Before implementation of a quality improvement and CDSS for the anemia of CKD, multiple heterogeneous strategies were used. ESAs used were divided between epoetin alfa and darbepoetin alfa in a ratio of 1:4 and timing of administration varied from as much as twice weekly to once monthly. Each regimen was provider specific and patterns of iron administration displayed heterogeneity equal to that of ESAs. Iron was administered as several common iron preparations and, typically, no consistent time of delivery was specified, resulting in patients taking their iron quite often with food, thereby impairing its absorption. The utilization of intravenous iron was highly provider specific and only triggered when several months of an inadequate response to ESAs in association with oral iron intake was appreciated.

The Task

To reduce nursing time to deliver ESAs and intravenous iron and optimization of target hemoglobin in CKD patients, we created a CDSS, incorporating automation, templating, and alerts that were available at the point of care. All anemic CKD patients were placed into this CDSS, CAMP©.

System Description

CAMP© was specifically comprised of 2 parallel algorithms derived from the evidence-based literature and published and empiric observations regarding ESA treatment using darbepoetin alpha at extended intervals (defined as dosing no less than once every 2 weeks) and outpatient intravenous iron as low–molecular-weight dextran iron at doses from 250 to 1,000 mg at infusion rates of 333 to 500 mg/h. One algorithm applied monthly darbepoetin alfa dosing based on entry hemoglobin. The more anemic the patient, the greater the initial dose of darbepoetin alfa. Notably, although dosing according to bodyweight is commonly done, this logic was dispelled by the observation that no such equivalent dose is based on weight but rather on the patient's hemoglobin response to therapy. Iron therapy was based on KDOQI guidelines, and oral therapy was attempted first when iron deficiency was mild or absent. Therefore, iron-sufficient patients who entered the CAMP© program would be prophylactically treated with iron to provide for the erythropoietic demands imposed by the ESA. Parenteral iron therapy was first administered to patients with clear-cut iron deficiency based on transferrin saturation and serum ferritin. CAMP© logic and treatment parameters were visualized by the administering agent, a nurse or medical assistant, through a simple Web-based interface, acting as a front end to a relational database. Appropriate linkages with the health system's central laboratory (Fig 1) were made such that the most recent information regarding the last darbepoetin alfa dose, hemoglobin, and ferrokinetic parameters was onscreen. Trend analysis by CAMP© led to a specific prescription of iron and ESA, of which the default was to accept the dose, unless written documentation was presented to override CAMP©. In addition, the program facilely allowed the end user to rapidly click on menus that specified drug(s) and their site (right/left arm) and type (subcutaneous or

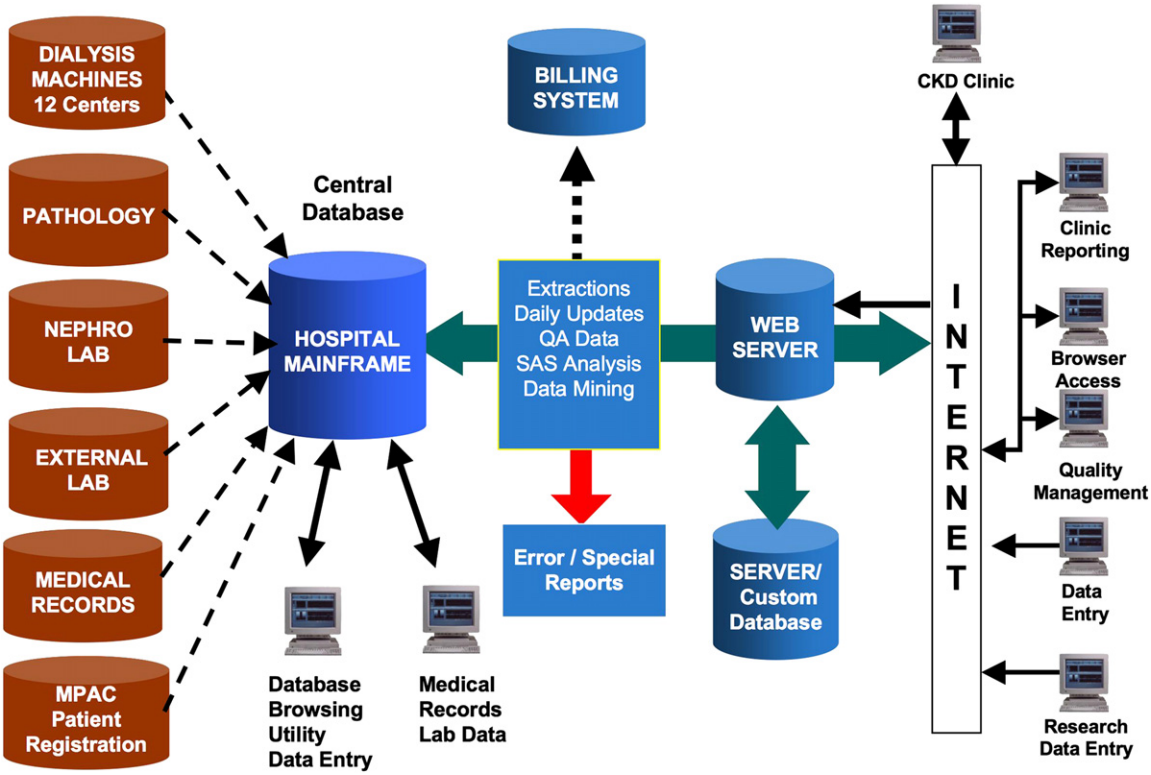


Figure 1. Schema of the flow of information and data extraction within the GHS and HFHS computer system. HFHS, Henry Ford Health System; CKD; chronic kidney disease; GHS, Greenfield Health System; QA, quality assurance; SAS, SAS software.

intravenous) of administration. All of this information was concatenated into a documentation template for real-time entry into the health system's electronic health record, satisfying the need for accurate and medicolegal documentation. In addition, CAMP© immediately notified the patient's health care provider electronically of procedures completed or suboptimal or unanticipated erythropoietic responses.

Organizational and Implementation Challenges

Because CAMP© has a database, clinical outcomes are easily monitored and utilization of iron and ESAs is handily compiled. The database can be queried for hemoglobin, serum iron, transferrin saturation, ferritin, and ESA dose at a single point time or longitudinally. Reports with informative graphs were developed and are used for continuous quality improvement initiatives. Because darbepoetin dosing was only at amounts that corresponded to either drug vial sizes or that of manufacturer-specified prefilled syringes (Aranesp Singleject; Amgen Corp, Thousand Oaks, CA), the most frequently used doses were readily determined, thereby facilitating drug ordering and supply chain management. In addition, patients who required very high doses of ESA could be determined rapidly. Given its user friendliness, time-saving features, ability to override the output, and positive outcomes, CAMP© was readily adapted by our nephrology group at HFHS.

Status Report

CAMP© resulted in the establishment of a homogeneous prescribing pattern for the treatment of anemia, which balances iron and ESA therapy from the outset, eliminating the possibility that true or functional iron deficiency will occur. Changes (overrides) to CAMP© by various providers were nearly absent after the program had been in use for 6 months. Average ESA administration times declined from nearly 60 minutes per patient per month, at 4.3 weekly doses per month, to 7 minutes per patient per month, a 90% monthly time reduction. In addition, clinical outcomes significantly improved during CAMP© utilization. Sixty percent of patients who had received at least 3 consecutive doses of darbepoetin and had undergone treatment for a mean of 60 days maintained hemoglobin levels of 11 to 13 g/dL. This compared to approximately 40% of patients having achieved the target hemoglobin of 12 ± 1 g/dL before CAMP© implementation and only a few patients who exceeded 13 g/dL. Lastly, the average monthly darbepoetin dose varied considerably from 0 to 300 μg per month, with 300 μg representing the maximal allowable dose under CAMP©.

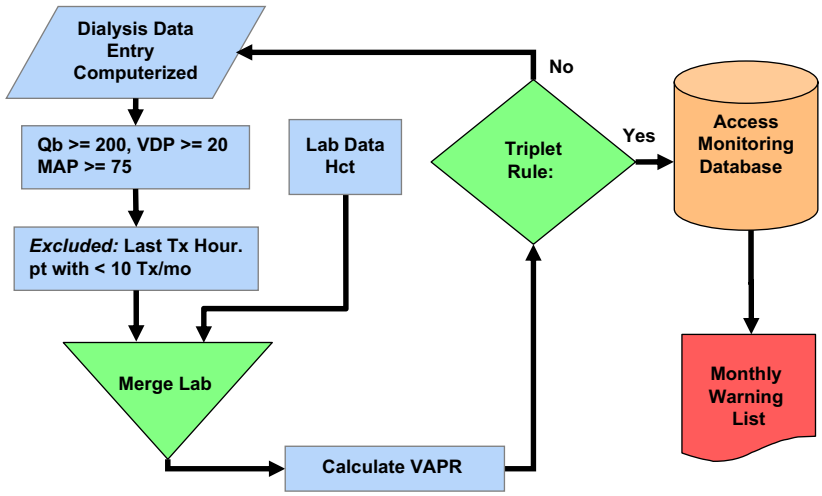


Figure 2. Vascular access surveillance logic. Hct, hematocrit; pt, patient; Qb, dialysis blood flow (mL/min); Tx, treatment; VDP, venous drip pressure; MAP, mean arterial pressure; VAPR, vascular access pressure ratio.

A

OPD Vasc-Alert MONTHLY REVIEW

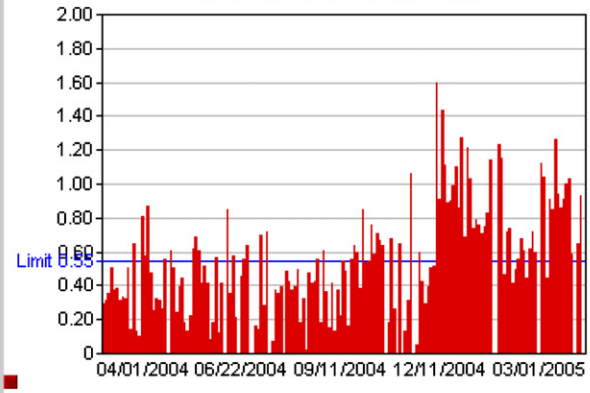
Date: 5/11/2005
Vascular Access Monitoring Report

PATIENT:
MRN:

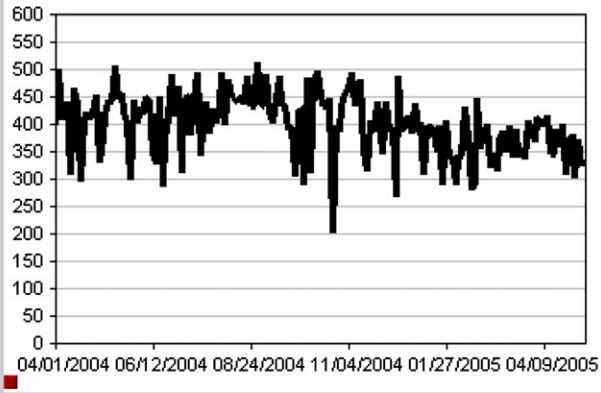
PLOTS

Graph Output: (under construction)

Venous Access Pressure Ratio



Blood Flow mL/min



ESRD TREATMENT

Last Date: **05/07/05**
Mean QB: **325** ORDER:**400** mL/min
Dialyzer: **F80**
Actual Time: **162** -ORDER:**165** min.

Access:
Current Access: **FISTULA**
Last Warning: **04/05/2005**

Vascular Access Pressure Ratio:

05/07/05 **0.93**
05/05/05 **0.65**
05/03/05 **0**
04/30/05 **0.59**
04/28/05 **1.03**
04/26/05 **1**
04/23/05 **0.91**
04/21/05 **0.86**
04/19/05 **0.94**
04/16/05 **1.26**
04/14/05 **0.85**
04/12/05 **0.91**
04/09/05 **0.44**
04/07/05 **1.04**
04/05/05 **1.12**
04/02/05 **0**
03/31/05 **0.6**
03/29/05 **0.72**
03/26/05 **0.62**
03/24/05 **0.44**
03/22/05 **0.61**
03/19/05 **0.68**
03/17/05 **0.56**
03/15/05 **0.49**
03/12/05 **0.41**
03/10/05 **0.74**
03/08/05 **0.72**
03/05/05 **0.46**
03/03/05 **1.15**

OBJECTIVE:

Access Changes:

Consultation:

Assessment/Plan:

0.55 is the Alarm Set point. Three consecutive alarms constitute a warning. Examine the plot for trends indicative of rising pressure.

Signature:/Title/Dr.: _____ Date: _____

Figure 3. (A, B) Sample report of vascular access surveillance. ESRD, end-stage renal disease.

B

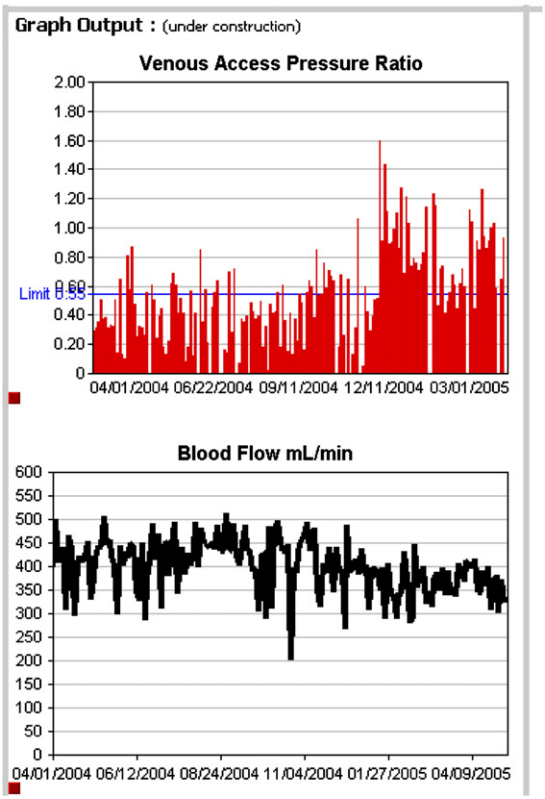


Figure 3. *(Cont'd)*

Vascular Alert System

Background

Arteriovenous grafts (AVGs) remain prevalent in the United States hemodialysis population, and clotting of these grafts represents a significant problem.[38] The cost associated with graft dysfunction is significant and represents the cumulative sum of the costs of hospitalization, in-center facility revenue loss and procedures performed for graft salvage or replacement. Compounding this problem is inconsistent and heterogeneous care of AVGs. Prophylactic inspection and physical examination of AVGs are performed inconsistently and nonuniformly. Consequently, elevated intra-access pressures, detected during the dialytic procedure, often represent the sentinel event of impending AVG thrombosis.[39] However, in many cases, vascular pathobiology has likely been present for an extended period, possibly beginning shortly after construction of the biosynthetic conduit. Nearly 75% of hemodialysis patients are hospitalized for a vascular access-related problem within 2 years.[40,41] Vascular access complications account for about 30% of hospital admissions in chronic hemodialysis programs. Hospitalization costs for vascular access problems exceed $1 billion per year or around 10% of Medicare ESRD expenditures.[40,41] The major risk is with AVGs, whose risk of thrombosis is 6-fold higher than arteriovenous fistulas (AVFs). The risk of AVG thrombosis increases up to 4-fold as stenosis approaches more than 50%. Lastly, graft patency is much better after elective angioplasty than after thrombectomy.[42]

Recently, to prevent AVG and AVF thrombosis, there has been a reemphasis of using proper techniques to evaluate for access dysfunction. Accompanying this resurgence have been several methodologies that promote vascular access surveillance.[39,43-45] An inexpensive method using a vascular access pressure ratio (VAPR) has been devised to prospectively detect and monitor for AVG and AVF thrombosis.[46,47]

The Task

At HFHS, we have determined that vascular access surveillance was only feasible for a relatively small number of patients. Static vascular access pressure measurements can be used to determine graft patency vis-à-vis risk for thrombosis. However, performing this procedure on large numbers of dialysis patients requires great expertise and a high degree of fidelity, with highly operator-dependent results. Individuals with expertise in direct measurement of static access pressures are few, and, consequently, ultrasound-based technology has supplanted static pressure measurement. Nonetheless, given a 100-patient census in a hemodialysis unit with an AVG and AVF prevalence of 60%, an operator who requires 30 minutes per patient for ultrasonic measurements and documentation is limited to approximately 340 evaluations monthly. Therefore, under the best of circumstances, deployment of skilled personnel at 2.0 Full-time equivalent translates to access surveillance only 72% to 80% of the number of times dialyzed. This scenario is a costly proposition, with equipment and personnel costs amounting to greater than $140,000 annually.

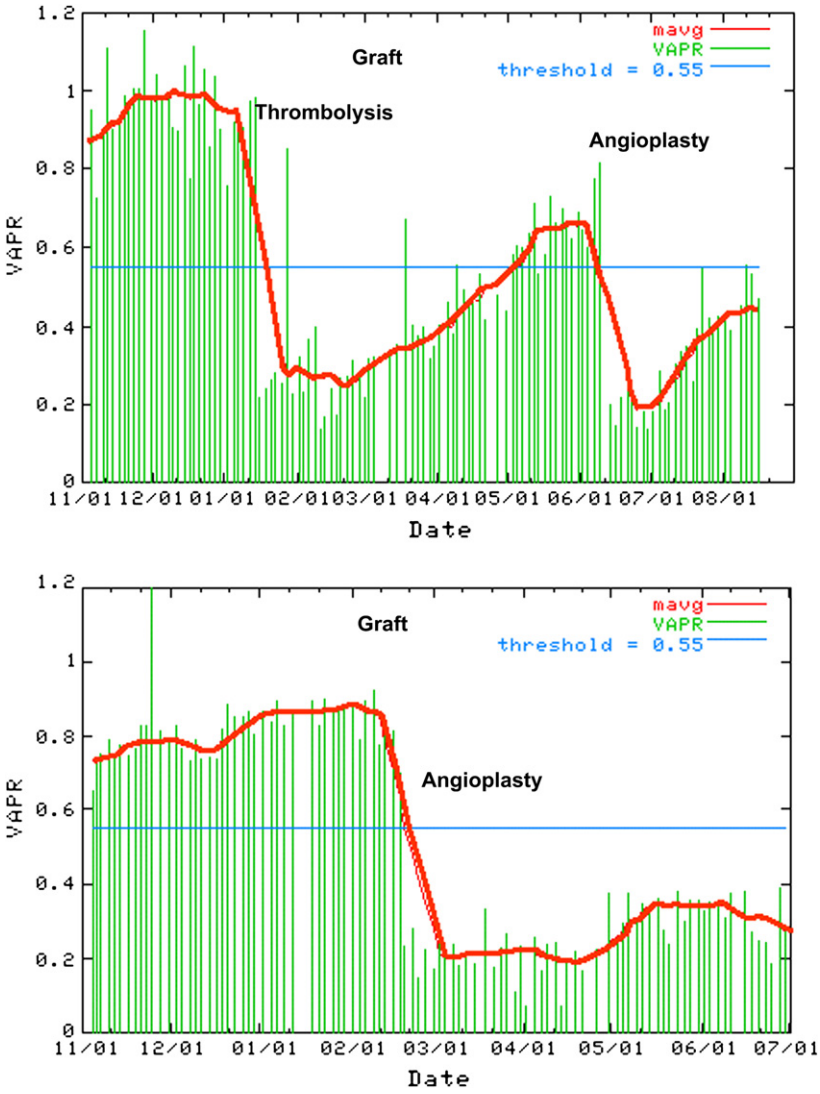


Figure 4. Implications of and further management after an alert from the vascular access surveillance system. VAPR, vascular access pressure ratio.

System Description

The vascular access surveillance system at HFHS uses routinely collected dialysis data to calculate VAPRs. Data from the dialysis machines are transmitted to a central hospital server and then to a dedicated Web server as seen in Figure 1. A proprietary Web-based algorithm on the nephrology server houses the various "rules" for this system (Fig 2) and streams outputs to monthly progress notes and enables users to make queries regarding any warnings concerning the vascular access of patients (Fig 3A and B). Three sequential VAPRs of greater than 0.55 indicate possible access stenosis and create an alert for the provider on the monthly progress note so that further workup can be done to try and prevent access thrombosis (Fig 4). In addition, a report can be run to identify all those patients at higher risk for access stenosis.

Organizational and Implementation Challenges

Nearly all conventionally used hemodialysis machines have the capability to record the variables needed to compute VAPR, which can readily be transmitted electronically to a dedicated database for further data collation and refinement. These parameters yield a family of curves that encompass an ability to determine

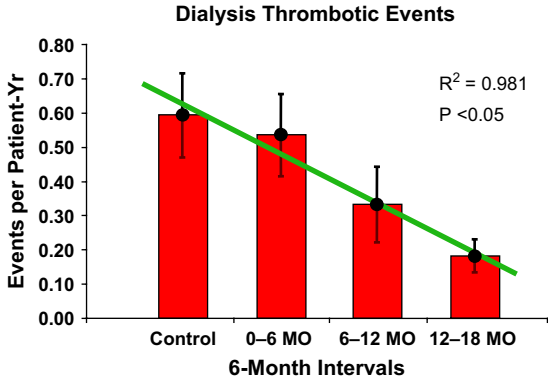


Figure 5. Thrombotic dialysis events decrease using Vasc-Alert™ technology during 3 consecutive 6-month intervals.

intra-access pressure within the access site. From this family of curves, we derived the vascular access pressure ratio test.[39] Ratios exceeding 0.55 were determined predictive of access thrombosis/stenosis.[39] With this instrument and appropriate electronic outfitting of hemodialysis machines, access surveillance became much more efficient and widely implementable, with little requirement for human intervention. Hence, a complex mathematical set of relationships was simplified into a convenient decision support system.

To extend the usability of the system, customized health care provider-specific reports were developed, with serial pictorial representations of continual patient-specific data. These "easy-to-read reports" could be "eyeballed" for anomalous pressure readings (eg, needle reversal with high-pressure profile, arterial-end stenosis of the access [highly negative pressure at the prepump arterial pressure transducer], unsuccessful access revision/repair/angioplasty, and results that clearly delineated whether VAPRs were in suprathreshold "danger zones" when access clotting probabilities greatly increased).

Such reports are sent to the hemodialysis unit director as a package or individually after a patient's dialysis session. Alternatively, by using a secure Health Insurance Portability and Accountability Act–compliant Web server, reports could be examined and downloaded at any time by health care providers, permitting utilization of our vascular access surveillance system by everyone involved in the care of the access. Notably, the total cost of software purchase for database initialization, front-end programming, report generation, and hemodialysis machine preparation was less than $30,000.

Status Report

After the implementation of the vascular access surveillance system at HFHS, there was a significant decline in the vascular access thrombosis rates (Fig 5). The vascular access protocol that we presently use continues to evolve, as those working with vascular access issues develop a better understanding of its practical application. Vascular access surveillance reports prioritize those patients most at risk for access failure. Currently, we conduct careful physical inspections of vascular accesses and complete an Access Information Sheet monthly for each patient in addition to the monthly Vascular Access Warning Report, which triages patients with vascular access pressure ratio tests that exceed 0.55. Depending on the analysis of key parameters, the attending physician determines if the patient requires interventional evaluation.

Presently, the HFHS vascular surveillance system is being marketed and sold, external to HFHS, as a patent-pending commercial product, by Vasc-Alert LLC (West Lafayette, IN). This company provides service and technical support for vascular access pressure surveillance for AVGs and AVFs. To date, 5,000 patients external to HFHS are undergoing dynamic pressure surveillance through Vasc-Alert.

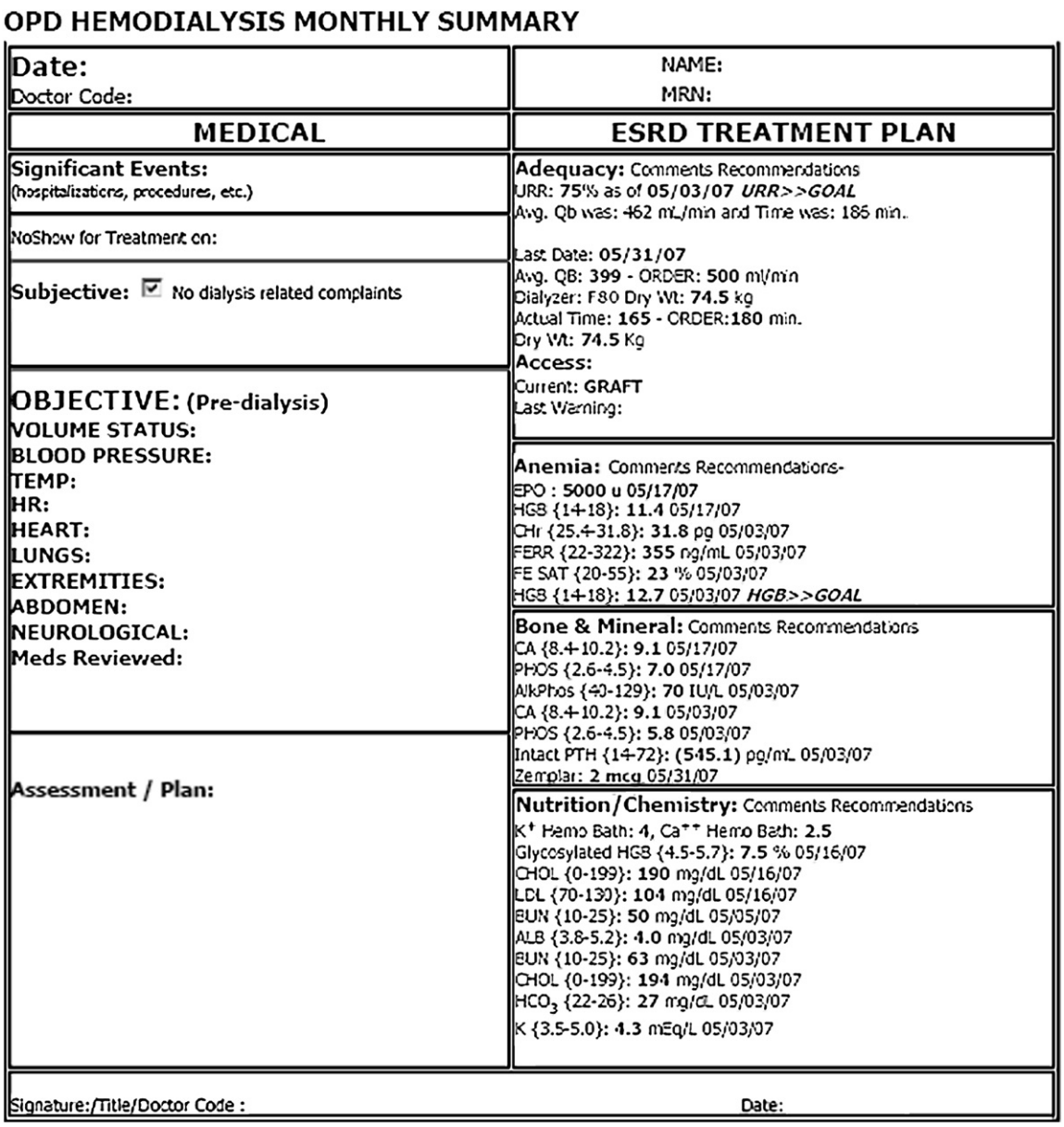
ESRD Monthly Documentation

Background

Greenfield Health System (GHS) is an independent provider for renal replacement therapies with dialysis units in Michigan and Ohio. Together, they provide long-term renal replacement therapy for nearly 2,000 patients. Currently, Medicare requires 4 documented notes per month by the provider for maximum reimbursement. One of these is the "monthly capitation progress (MCP) note," which is a requisite for reimbursement.

The Task

The task is to be able to provide the dialysis providers with a tool that generates automated



OPD HEMODIALYSIS MONTHLY SUMMARY

Date:
Doctor Code:

NAME:
MRN:

MEDICAL

Significant Events:
(hospitalizations, procedures, etc.)

NoShow for Treatment on:

Subjective: ☑ No dialysis related complaints

OBJECTIVE: (Pre-dialysis)
VOLUME STATUS:
BLOOD PRESSURE:
TEMP:
HR:
HEART:
LUNGS:
EXTREMITIES:
ABDOMEN:
NEUROLOGICAL:
Meds Reviewed:

Assessment / Plan:

ESRD TREATMENT PLAN

Adequacy: Comments Recommendations
URR: **75**% as of **05/03/07** ***URR>>GOAL***
Avg. Qb was: 462 mL/min and Time was: 186 min.

Last Date: **05/31/07**
Avg. QB: **399** - ORDER: **500** ml/min
Dialyzer: F80 Dry Wt: **74.5** kg
Actual Time: **165** - ORDER:**180** min.
Dry Wt: **74.5** Kg
Access:
Current: **GRAFT**
Last Warning:

Anemia: Comments Recommendations-
EPO : **5000 u 05/17/07**
HGB {14-18}: **11.4** 05/17/07
CHr {25.4-31.8}: **31.8** pg 05/03/07
FERR {22-322}: **355** ng/mL 05/03/07
FE SAT {20-55}: **23** % 05/03/07
HGB {14-18}: **12.7** 05/03/07 ***HGB>>GOAL***

Bone & Mineral: Comments Recommendations
CA {8.4-10.2}: **9.1** 05/17/07
PHOS {2.6-4.5}: **7.0** 05/17/07
AlkPhos {40-129}: **70** IU/L 05/03/07
CA {8.4-10.2}: **9.1** 05/03/07
PHOS {2.6-4.5}: **5.8** 05/03/07
Intact PTH {14-72}: **(545.1)** pg/mL 05/03/07
Zemplar: **2 mcg** 05/31/07

Nutrition/Chemistry: Comments Recommendations
K^+ Hemo Bath: **4**, Ca^{++} Hemo Bath: **2.5**
Glycosylated HGB {4.5-5.7}: **7.5** % 05/16/07
CHOL {0-199}: **190** mg/dL 05/16/07
LDL {70-130}: **104** mg/dL 05/16/07
BUN {10-25}: **50** mg/dL 05/05/07
ALB {3.8-5.2}: **4.0** mg/dL 05/03/07
BUN {10-25}: **63** mg/dL 05/03/07
CHOL {0-199}: **194** mg/dL 05/03/07
HCO_3 {22-26}: **27** mg/dL 05/03/07
K {3.5-5.0}: **4.3** mEq/L 05/03/07

Signature:/Title/Doctor Code :

Date:

Figure 6. Screen capture of sample ESRD monthly capitation note. ESRD, end-stage renal disease.

reports on the patient's laboratory values, urea kinetics, and other parameters, which are required for providing services during clinical rounds. Given GHS' geographic area, the systematic goal was to provide an instrument that facilitated global review of all the monthly blood test results and identified patients with vascular access issues (discussed previously).

System Description

As mentioned earlier, GHS provides long-term renal replacement therapy to about 2,000 patients. Patients' monthly and midmonthly blood tests are delivered to a central laboratory for processing. Test results are downloaded to the central hospital server daily. From here, extractions are performed daily, with export to the hospital medical records and its billing system, which tracks the tests obtained. From the hospital server, a nephrology server extracts data and communicates with a local server that hosts a Web-based database. Output is then targeted to providers at point of care. These include outputs to CKD

clinic at the HFHS, ESRD MCP note, and others. Thus, providers can run queries on their patient's data, and this is done over a secure environment (Fig 1). An illustrative MCP note is presented in Figure 6 as a screen shot.

Organizational and Implementation Challenges

One of the initial challenges was to identify the need for such a system. However, once the potential benefits to providers were presented, including the ease for billing through such a system, there was consensus support from administrative and medical sides of the issue. The major implementation challenges were to be able to ensure secure transmission of data. This was enabled by using currently available secure socket technology.

Status Report

The majority of the GHS and HFHS providers now use the automated MCP note for their documentation. This has resulted in significant time savings for the providers who no longer review reams of printed data from different sources and enter them in their notes. This note covers the entire requirement for billing purposes. In addition, the billing team is able to capture documentation during the revenue cycle to facilitate and ease billing efficiency and improve organizational efficiency.

Conclusions

It is important to implement automation, templating, and clinical decision support judiciously and consider consequent actions when designing and implementing systems. Appropriate increases in the use of information technology in health care, especially the introduction of clinical decision support and better linkages in and among systems has resulted in process simplification with substantial improvement in efficiency, and patient safety. As we have shown in this article, there is a tremendous need and scope for implementing CDS in nephrology, given the increasing demands from patients and payers on the providers.

References

1. Kohn LT, Donaldson MS (eds): To Err Is Human: Building a Safer Health System. Washington, DC, National Academies Press, 2000
2. Hammond JJ: Protocols and guidelines in critical care: Development and implementation. Curr Opin Crit Care 7:464-468, 2001
3. Craft PS, Zhang Y, Brogan J, et al: Implementing clinical practice guidelines: A community-based audit of breast cancer treatment. Australian Capital Territory and South Eastern New South Wales Breast Cancer Treatment Group. Med J Aust 172:213-216, 2000
4. Brook RH, McGlynn EA, Cleary PD: Quality of health care. Part 2: Measuring quality of care. N Engl J Med 335:966-970, 1996
5. Simmons BP, Swiontkowski MF, Evans RW, Amadio PC, Cats-Baril W: Outcomes assessment in the information age: Available instruments, data collection, and utilization of data. Instr Course Lect 48: 667-685, 1999
6. Ritter MA, Albohm MJ: Overview: Maintaining outcomes for total hip arthroplasty. The past, present, and future. Clin Orthop Relat Res 344:81-87, 1997
7. White AW: The outcomes movement and the role of health information managers. Top Health Inf Manage 18:1-12, 1998
8. Smith TJ, Hillner BE: Ensuring quality cancer care by the use of clinical practice guidelines and critical pathways. J Clin Oncol 19:2886-2897, 2001
9. Hillner BE, Smith TJ, Desch CE: Hospital and physician volume or specialization and outcomes in cancer treatment: Importance in quality of cancer care. J Clin Oncol 18:2327-2340, 2000
10. Bates DW, Pappius E, Kuperman GJ, et al: Using information systems to measure and improve quality. Int J Med Inform 53:115-124, 1999
11. Pilote L, Tager IB: Outcomes research in the development and evaluation of practice guidelines. BMC Health Serv Res 2:7, 2002
12. Malone SM: Knowledge management: White knight or white elephant? Top Health Inf Manage 21:33-43, 2001
13. Petryshen P, Pallas LL, Shamian J: Outcomes monitoring: Adjusting for risk factors, severity of illness, and complexity of care. J Am Med Inform Assoc 2:243-249, 1995
14. Bond S, Thomas LH: Issues in measuring outcomes of nursing. J Adv Nurs 16:1492-1502, 1991
15. Rasmussen J: Human errors: A taxonomy for describing human malfunction in industrial installations. J Occup Accid 4:311-333, 1982
16. Reason J (ed): Human Error. Cambridge, Cambridge University Press, 1990
17. Bates DW, Cohen M, Leape LL, et al: Reducing the frequency of errors in medicine using information technology. J Am Med Inform Assoc 8:299-308, 2001
18. Senders JMN: Human Error: Cause, Prediction and Reduction. Mahwah, NJ, Lawrence Erlbaum, 1991
19. Leape LL, Bates DW, Cullen DJ, et al: Systems analysis of adverse drug events. ADE Prevention Study Group. JAMA 274:35-43, 1995

20. Brennan TA, Leape LL, Laird NM, et al: Incidence of adverse events and negligence in hospitalized patients. Results of the Harvard Medical Practice Study I. N Engl J Med 324:370-376, 1991
21. Jha AK, Kuperman GJ, Teich JM, et al: Identifying adverse drug events: Development of a computer-based monitor and comparison with chart review and stimulated voluntary report. J Am Med Inform Assoc 5: 305-314, 1998
22. Classen DC, Pestotnik SL, Evans RS, et al: Computerized surveillance of adverse drug events in hospital patients. JAMA 266:2847-2851, 1991
23. Bates DW, Leape LL, Cullen DJ, et al: Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA 280:1311-1316, 1998
24. Gurwitz JH, Field TS, Avorn J, et al: Incidence and preventability of adverse drug events in nursing homes. Am J Med 109:87-94, 2000
25. Bates DW, Miller EB, Cullen DJ, et al: Patient risk factors for adverse drug events in hospitalized patients. ADE Prevention Study Group. Arch Intern Med 159: 2553-2560, 1999
26. Wyatt J, Spiegelhalter D: Field trials of medical decision-aids: Potential problems and solutions. Proc Annu Symp Comput Appl Med Care 3-7, 1991
27. Osheroff JA, Teich JM, Middleton B, et al: A roadmap for national action on clinical decision support. J Am Med Inform Assoc 14:141-145, 2007
28. Evans RS, Pestotnik SL, Classen DC, et al: A computer-assisted management program for antibiotics and other antiinfective agents. N Engl J Med 338: 232-238, 1998
29. Tate KE, Gardner RM, Weaver LK: A computerized laboratory alerting system. MD Comput 7:296-301, 1990
30. Rind DM, Safran C, Phillips RS, et al: Effect of computer-based alerts on the treatment and outcomes of hospitalized patients. Arch Intern Medicine 154: 1511-1517, 1994
31. Kuperman GJ, Boyle D, Jha A, et al: How promptly are inpatients treated for critical laboratory results? J Am Med Inform Assoc 5:112-119, 1998
32. Shabot MM, LoBue M, Leyerle BJ, et al: Decision support alerts for clinical laboratory and blood gas data. Int J Clin Monit Comput 7:27-31, 1990
33. Shabot MM, LoBue M: Real-time wireless decision support alerts on a Palmtop PDA. Proc Annu Symp Comput Appl Med Care 174-177, 1995
34. Glaser J TJ, Kuperman G. Impact of information events on medical care. Proceedings of the 1996 Healthcare Information and Management Systems Society (HIMSS) Annual Meeting, Atlanta, GA, March 6, 1996
35. Tierney WM, Miller ME, Overhage JM, et al: Physician inpatient order writing on microcomputer workstations. Effects on resource utilization. JAMA 269: 379-383, 1993
36. Bates DW, Kuperman GJ, Wang S, et al: Ten commandments for effective clinical decision support: Making the practice of evidence-based medicine a reality. J Am Med Inform Assoc 10:523-530, 2003
37. Jaureguy M, Choukroun G: [Factors affecting the response to erythropoiesis-stimulating agents]. Nephrol Ther 2:S274-S282, 2006 (suppl 4)
38. Stehman-Breen CO, Sherrard DJ, Gillen D, et al: Determinants of type and timing of initial permanent hemodialysis vascular access. Kidney Int 57:639-645, 2000
39. Frinak S, Zasuwa G, Dunfee T, et al: Dynamic venous access pressure ratio test for hemodialysis access monitoring. Am J Kidney Dis 40:760-768, 2002
40. Feldman HI, Held PJ, Hutchinson JT, et al: Hemodialysis vascular access morbidity in the United States. Kidney Int 43:1091-1096, 1993
41. Feldman HI, Kobrin S, Wasserstein A: Hemodialysis vascular access morbidity. J Am Soc Nephrol 7: 523-535, 1996
42. Maya ID, Oser R, Saddekni S, et al: Vascular access stenosis: comparison of arteriovenous grafts and fistulas. Am J Kidney Dis 44:859-865, 2004
43. Schwab SJ, Oliver MJ, Suhocki P, et al: Hemodialysis arteriovenous access: Detection of stenosis and response to treatment by vascular access blood flow. Kidney Int 59:358-362, 2001
44. Besarab A: Preventing vascular access dysfunction: Which policy to follow. Blood Purif 20:26-35, 2002
45. Besarab A: Access monitoring is worthwhile and valuable. Blood Purif 24:77-89, 2006
46. Besarab A: Intervention for intra-access stenosis. Semin Dial 14:401-402, 2001
47. Besarab A: Vascular access: issues and management. Contrib Nephrol 142:29-46, 2004