Design and implementation of the Indianapolis Network for Patient Care and Research*†

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We are creating a health care information network that will link a large community medical record system to three hospital emergency departments, fifty community pharmacies, ten clinics, four health-maintenance organization (HMO) offices, and twelve homeless care sites in Indianapolis, Indiana. This project will test the feasibility of linking care providers across organizational boundaries and measure the benefits of such a network. The network will supply three kinds of information services: a "mini-medical library," patient medical record information, and a citywide prescription database incorporating a computer-based prescription-writing system. The use of medical resources, the cost of care, provider time spent giving care, and providers' opinions of the services will be used as outcomes in randomized clinical trials. Through this project, we hope to expand the information base available to the target care sites; reduce unnecessary testing and increase the efficiency of care in emergency departments; improve emergency department, office, and clinic prescribing patterns; enlarge the consortium of health care providers connected by the network; and develop strategies for successfully implementing a comprehensive city medical record resource.

INTRODUCTION

Communitywide electronic patient medical records (CEPR) may have the potential to enhance the quality of health care and control costs [1–3]. Few firm data exist to evaluate this hypothesis. To prove the value of a CEPR, we are building the Indianapolis Network for Patient Care and Research (INPCR). This network will consist of clinician workstations linked to a central clinical data repository, which will provide interorganizational access to information resources, data retrieval, order entry, and other services that are currently available at a single hospital system. We will study the effect of providing these services on the process and cost of care in formal randomized clinical trials, analyzing use of medical resources, cost of care, provider time spent giving care, and providers' opinions of the services. This paper describes the rational, technical approach and experimental design that we will employ. We expect these studies to prove the value of communitywide medical information systems and to stimulate greater participation in the network as the first step toward a truly comprehensive community computer-based medical record.

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DESIGN

Overview

The INPCR project requires creation of the technologic infrastructure and evaluation of the value gained from availability of the CEPR. Technologic tasks include development and installation of the communications systems, deployment of workstations, and establishment of interinstitution electronic data interchange. Three studies will be performed to evaluate the value of a CEPR, including physician use of electronically accessible full-text medical references, impact on testing in the emergency department (ED), and effect on cost and quality of prescription writing.

Setting and subjects

The patient population includes inner-city residents who are uninsured or underinsured and who receive care at sites throughout the city, as well as fully covered health-maintenance organization (HMO) patients. The network will link thirty-one sites controlled by five different institutions: three hospital emergency departments, ten community health clinics, twelve homeless care sites, four HMO practice centers, and two pharmacy systems, scattered over an area twelve miles in diameter. Table 1 shows the patient volume and number of providers at each of the clustered sites.

The care sites fall into four categories.

- Emergency departments. Care is least likely to be provided by a physician familiar with the patient. The provided drug profile and patient medical record information should be of the greatest value at these sites.
- Community health clinics. At the community clinics, assigned physicians provide care using a paper medical record for reference. These patients will obtain much of their acute and hospital care from an unrelated site; information related to this care will not be available in the paper medical record. Also, there is some migration from one community clinic to another, resulting in care fragmentation.
- Homeless care sites. Four physicians from the Homeless Initiative Program visit twelve homeless care sites per week to treat approximately two thousand patients who make about five thousand visits per year. Most patients have no insurance. This patient population is more likely to seek sporadic ED and hospital clinic care than those at the community clinics.

Table 1
INPCR care sites

Care organization	No. of sites	Type of site	Visits/ year	No. of M.D.'s
Wishard Health Services	1	ED	100,000	160
	5	office	42,500	
IU Healthcare	4	HMO	18,500	20
Methodist Hospital	1	ED	85,000	58
HealthNet	3	clinic	42,000	12
Community Hospital	1	ED	46,000	17
Citizens Health Center	1	clinic	15,000	5
People's Health Center	1	clinic	26,000	4
Homeless care	12	clinic	5,000	

- HMO office practice sites. Here, the patients have private insurance and are generally middle and upper-middle class. Patients are assigned to one physician, and all care is coordinated by the HMO. Continuity is probably greatest in this setting. However, because patients can receive care at four sites, their assigned physician may not always be available. Acute care is provided through the Wishard ED.

Network

The INPCR is a wide-area network (WAN). Most of the care sites will be linked over a private cable television system using Digital Equipment Corporation's ChannelWorks modems, which provide demonstrated throughput of ten megabits per second. A few sites, which are farther from the cable loop, will use T-1 links (dedicated 56-megabit-per-second data connections supplied by telephone companies). The homeless care site will be linked via dedicated telephone lines, high-speed (28,000-baud) modems, and Symantec's Norton pcANYWHERE.

Communications protocols will include transmission-control protocol/Internet protocol (TCP/IP) and Novell's Internetwork Packet Exchange. Message structure standards will include HL7/ASTM E-1238 for clinical observations, laboratory results, and admission/discharge/transfer (ADT) information [4–5] and DICOM for radiologic images [6].

Clinical data repository

For twenty years, the investigators from the Regenstrief Institute have pursued the goal of improving patient care with computer technology [7]. Specifically, we dedicated computers to capture, organize, sort, and analyze patient data. Using computers in this way frees up physician time for more complex, subtle, human functions. Toward this end, we created the Regenstrief Medical Record System (RMRS), a computer-stored medical record that not only stores patient data but also monitors trends in a patient's data; compares a patient's findings to medical treat-

ment guidelines; and provides warnings, reminders, and suggestions for alternative treatments.

In a series of randomized clinical trials, Regenstrief Institute researchers have demonstrated that the reminders the RMRS provides improve the care process [8–12]. Other investigators have shown similar results [13–25].

The INPCR will be based on the RMRS as the clinical data repository for the network. RMRS data include demographics, clinical findings, outpatient visits, hospitalizations, reports, summaries, impressions, physician orders, diagnostic test results, diagnoses, procedures, medications, and charges. Data, including 100 million observations, 600,000 text reports, and 120,000 electrocardiogram tracings from more than 800,000 patients, are already stored in the RMRS. The system is accessed more than 400,000 times per month by 1,000 physicians and medical students and 2,000 nursing personnel.

Clinician's workstation

In addition to establishing the centralized clinical data repository described above, the Regenstrief Institute has developed and studied a computerized order-entry system that helps physicians improve drug, test, and nursing orders [26–31]. Physicians have used the system to order all diagnostic tests since it was installed in 1987. It was installed in the inpatient medicine service in 1989, and physicians have written all inpatient orders on it since then. All outpatient prescriptions in our large, hospital-based, general medicine practice are written using the workstation. Medicine faculty and house staff write 50,000 inpatient orders and 40,000 outpatient prescriptions directly into the computer each month. This practical experience has allowed us to refine the workstation and increase its usefulness over the last seven years. The Medical Gopher workstation will be used to implement all aspects of the upcoming project. Clinicians participating in the INPCR will use this workstation to access information resources, retrieve data, and enter orders.

The Medical Gopher software is written in Revelation, C, and Assembler code for the Novell network system and runs on 486 PCs with eight megabytes of RAM. Response times range from 0.05 to 0.3 seconds on a thirty-three-megahertz 486 PC. The workstations operate on a Novell network and can run under DOS, Windows, or OS/2. Programs; screen definitions; report definitions; and nonvolatile files, such as the drug and test dictionary that control the program's action, are stored on the workstations' local hard disks, reducing network traffic and minimizing workstation response time. An efficient means to distribute updates of these files to all of the workstations is in place.

Volatile information, such as orders and patient registry information for "active" patients, is stored on a file server. Patients are considered "active" for approximately one year after any clinical encounter. The file server links through Ethernet to the central clinical data repository on a cluster of VAX computers where archival information is stored. Information is transferred between the file server and the VAX repository through HL7 messages. When a patient first becomes active on the network, the RMRS registry data and a subset of the medical record data is transferred to the file server. While a patient remains active, the two systems inform each other about all new patient information (such as new orders, new lab results, or changes in registry data). All patient information is available in the clinical repository and can be downloaded from there to the server whenever it is needed.

The Medical Gopher provides

- access to medical reference texts
- flow sheets of patients' data whose contents are dynamically defined by the clinician
- display of medication profiles
- problem list maintenance
- allergy list maintenance
- order entry and prescripting writing
- dosage calculations
- reminders about patient states that need attention
- consequent orders triggered by entering another order
- blocking rules that evaluate data stored in the repository, remind the clinician about potential problems, and suggest alternatives
- electronic mail

The workstation actively assists prescribing by alerting the clinician to drug allergies, drug interactions, and patient diagnoses that contraindicate certain drugs based on local refinements of standard references and the literature. The workstation software improves patient care by offering menus of drugs and order instructions specific to the patient's medical problem, academic detailing messages (directed at countering the promotional activities of pharmaceutical company sales representatives), price information, and other advisories. In addition, the system provides instruction templates for each drug with submenus of dosages and durations. The system also provides guidance for adjusting doses according to age, renal function, and co-morbidity.

Data sources

Most of the data sources required for this study are already linked to the RMRS, as described in the section on the clinical data repository. However, this project will add two sources of information. We will capture prescription records from two pharmacy

chains. The first is a large Indianapolis chain that fills almost 40% of the retail prescriptions in Indianapolis and which has twenty-four-hour pharmacies located near each of the three EDs. The second is a small pharmacy that is the sole provider of prescriptions to the three HealthNet community clinics. In addition, we will capture outpatient visit and prescription information from twenty-three sites that have not in the past contributed that information to the RMRS. It is possible that we may obtain additional clinical information, such as the dictated ED visit reports, from some of the participating sites.

The volume of pharmacy prescription data will be very large. We will only tie prescription records from this new source into the RMRS for patients registered in the RMRS database. We will use all available "registration" information, such as birth date, sex, name, insurance number, and telephone number, to create these linkages. The pharmacy sources use the Food and Drug Administration's National Drug Codes (NDC) to identify drugs. We will use Medi-Span's *Master Drug Database* to link these drugs to our pharmacy dictionary.

Many of the study sites, including the HMOs, the homeless sites, and most of the community health clinics, already use the RMRS to register their patients. Methodist will provide an ADT message for each registered ED patient to trigger the study intervention. The outcome variables, such as hospital admissions or ED costs, will come from billing tapes of the respective hospitals.

EVALUATION

Osheroff and his colleagues describe three categories of information needs: those that could be fulfilled by a medical record, by textbook or literature retrieval, or by a synthesis of the two [32]. An overall goal of this proposal is to provide these three categories of information. We will give clinicians online access to medical text books and published papers and to patient medical record information. We will synthesize the two by having the computer coordinate guidelines available in the literature with the patient's specific circumstances.

Information delivery (minilibrary)

The advantages of online computer access to the medical literature can be measured by the usage rate [33–34], the effect on the process of care [35], and the degree to which patient outcomes are changed [36]. Computers access the medical literature hundreds of thousands of times each year at some institutions. Forty-seven percent of the retrievals changed the process of care in one study. Text and reference books are common sources of information for care providers [37], but the value of electronic versions of these is less well documented.

Study participants will have electronic access to full-text versions of the *New England Journal of Medicine*, *Annals of Internal Medicine*, and the *Journal of the American Medical Association*; abstracted literature, such as *ACP Journal Club* and Mosby's *Year Book of Medicine*; selected electronic reference texts, such as the AHFS Formulary System Monographs; and literature searching through GRATEFUL MED. Access to these materials will be through three mechanisms: keyword look-up, table-of-contents browsing, and context-sensitive links to reference material from clinical content such as reminders and comments.

We will study the effects of access to a minilibrary by observing its use for six months. We will assess the value of minilibrary access by maintaining usage logs; asking clinicians to provide a subjective 5-point Likert scale evaluation after each use; and conducting a formal user survey, which will evaluate their knowledge, attitudes, and beliefs about electronic reference materials.

Emergency department testing

Available evidence suggests that test usage in EDs is profligate compared to office care; patient information is unavailable, and care is fragmented. In a controlled trial, tests were ordered more than twice as often in the fragmented care group compared to the continuous care group [38]. Similarly, consultants ordered ten times as many tests for patients about whom they had little information compared to those about whom they had much information [39].

In EDs, all relevant medical records are usually unavailable. Emergency services are rarely sought at the patient's regular place of care. For the homeless, uninsured, underinsured, and Medicaid patients, the problem is compounded, because such patients often do not have a regular source of care. Due to disability or educational limitations, these patients may be the least able to supply details of their medical histories. We have shown that providing clinical data to ED physicians in a flow-sheet format decreased the number of tests ordered by 15% [40]. As a result, we hypothesize that providers perform tests and initiate treatments that could be avoided if all of a patient's records were available.

To study the impact of clinical information availability on ED testing, patients with "significant" data in the clinical repository will be studied. This represents approximately 80% of patients cared for in the Wishard ED and 10% to 20% of patients cared for in the Methodist ED. These patients will be randomly assigned to intervention and control groups.

The study will be a twelve-month, randomized, controlled trial. When patients register in the ED, the

Figure 1
Clinical abstract

PATIENT,EXAMPLE #0xxxxxx-x AGE:60 SEX:F RACE:B PHONE:xxx-xxxx

MEDICAL CLINICAL ABSTRACT

HISTORY & PHYSICAL
HISTORY FORM
(no data found)

DX & COMPLAINTS 11-JAN-94
bronchitis
osteoarthritis
sinusitis
asthma
rhinitis allergic
ear abn othr
scoliosis
periodic GYN exam
postmenopausal bleeding
hematuria
arthritis other
tenosynovitis
surgery follow-up
stress incontinence female
breast pain /R
med refill
screening mammogram
pain /L THUMB

HOSP ABS
10 days 24-APR-93

E.R. DIAGNOSIS 29-MAY-93
bronchitis

VITALS			01-JUL-78
TEMP	98.4	DEG F	10-MAR-94
PULSE	76	/MIN	
RR	16	/MIN	08-JUL-86
WEIGHT LBS	138	LBS	10-MAR-94
SYS BP SITTING	106	MM HG	
DIAS BP SITTING	62	MM HG	
SYS BP STANDING	108	MM HG	01-JUL-78
DIAS BP STANDING	70	MM HG	
PULSE STANDING	84	/MIN	
SYS BP RECUMBENT	80*L	MM HG	
DIAS BP RECUMBNT	60	MM HG	
PULSE RECUMBENT	70	/MIN	

PREVENTIVE
HEMOCCULT(0-4) 01-JUN-85
HEMOCCULT(0-4) 0 0-4

MAMMOGRAM 12-OCT-93
bilateral
no evidence for mass/malignancy

TSH BASELINE 05-JUL-90
TSH BASELINE 1.15 uIU/ML

CHEMISTRY
CHEM 12 05-JUL-90

BUN	5*L	MG/DL	18-OCT-91
GLUCOSE	115*H	MG/DL	
CREATININE	1.0	MG/DL	
CALCIUM	9.5	MG/DL	05-JUL-90

CHEMISTRY (continued)

CHEM 12			05-JUL-90
PHOSPHORUS	4.7	MG/DL	
URIC ACID	5.5	MG/DL	
CHOLESTEROL	248	MG/DL	
PROTEIN-TOTAL	6.1*L	G/DL	
ALBUMIN	3.6	G/DL	
BILIRUBIN TOTAL	0.5	MG/DL	14-OCT-91
ALK PHOS	75	UNITS	05-JUL-90
SGOT (AST)	20*L	UNITS	

ELECTROLYTE PRFL			18-OCT-91
SODIUM	134*L	mmol/l	
POTASSIUM	4.2	mmol/l	
CHLORIDE	94*L	mmol/l	
CO2-TOT	30*H	mmol/l	

BLD GAS PANEL 1			20-OCT-91
HGB	11.5*L	G/DL	

AMYLASE			14-OCT-91
AMYLASE	122*H	UNITS	

HEMATOLOGY

BLOOD CELL PROFILE			20-OCT-91
WBC	8.6	THOU/CU MM	
RBC	3.7	MILL/CU MM	
HGB	11.5*L	G/DL	
HCT	33*L	%	
MCV	90	fl	
MCH	31	PG	
MCHC	34	%	
RDW	13.6	%	

DIFFERENTIAL			20-OCT-91
LYMPHS	21	%	
MONO	2	%	
PLT EST	adeq		

ROUTINE COAG			14-OCT-91
PT CONTROL	12.0	SEC	26-JUL-82
P.T.	12.1	SEC	14-OCT-91
APTT PATIENT	25	SEC	

ROUTINE URINALYSIS			12-JUL-90
COLOR:UA	yellow		
TURBID URN	sl cldy		
GLUCOSE-UA	neg		
BILIRUBIN-UA	neg		
KETONES-UA	neg		
SP GRAV-UA	1.015		
HGB-UA	trace		
PH-UA	7.0		
PROTEIN-UA	neg		
WBC-UA	rare	#/HPF	
RBC-UA	2-5	#/HPF	
EPITH CELLS-UA	rare		
BACTERIA-UA	several		

RADIOLOGY
CHEST PA & LATERAL 14-OCT-91
RLL, interstitial fibrosis, scoliosis

RADIOLOGY (continued)
ABDOMEN XRAY
(no data found)

EKG 03-DEC-76
normal

TEXT REPORTS
Operative reports (3) 01-MAY-93
History & Physicals(1) 01-JUN-93

MEDICATION SUMMARY			04-MAY-94
ACETAMINOPHEN	3900	MG	
ACTIFED EQV	4	TABS	
AQUAPHOR	1	JAR	
ARTIFICIAL TEARS	1	ML	
CIMETIDINE	300	MG	
DIMETAP ELIX EQV	40	ML	
DIPIVEFRIN	2	DROPs	
FLUOCINONIDE CR	1	APPLIC	
LAC-HYDRIN LOT	2	APPLIC	
MAALOX TC	90	CC	
PILOCARPINE 4%	4	DROPS	
PROPOXYN/ACET 100/	4	TABS	

ALLERGIES
Penicillins
Sulfa Containing Drugs
ACE Inhibitors

#0xxxxxx-x

PATIENT,EXAMPLE
Printed 02-JUN-94

admission message will trigger a search of the clinical repository for data. If the patient has been assigned to the intervention group, a clinical abstract (Figure 1) will be printed in the ED. Clinicians treating intervention-group patients will also have full access to the data in the clinical repository via workstations. Clinicians treating control-group patients will not have access to these information sources.

The effect of the intervention will be evaluated by comparing the frequency of test ordering, ED-visit charges, ED-visit duration, the proportion of immediate and thirty-day hospital admissions per ED visit, and ED return visits within thirty days of intervention- and control-group patients. In addition, a survey of clinicians' perceptions of the system will also be conducted.

Analysis of these data presents substantial challenges because of the complex hierarchical structure and repeated measures involved. The "atomic" unit of interest is the cost of one ED visit by one patient. We wish to estimate the effect of our intervention on this outcome measure. However, attributes of the patient, the care provider, and the ED are likely to influence the outcome measure and must be taken into account. Further complicating the analysis, patients may visit an ED more than once, or they may visit more than one ED. Worse, different providers are likely to see patients at different encounters. One way to deal with these complexities is to discard the data for repeat visits. Such an approach would satisfy most of the independence assumptions of traditional analytic techniques. However, eliminating these data would waste information and might produce misleading results, as would be the case if the greatest savings opportunities occurred among patients with repeated visits in one year.

We will use a generalized linear model with a hierarchical structure to accommodate the complexity of our study [41–42]. In addition to telling us whether the study intervention had a significant effect on the outcome variable, it also will tell us which patient, provider, and care site characteristics are independent predictors of the outcome of interest. The approach described by Liang [43] has the additional advantage of not requiring assumptions about the statistical distribution of the outcome variables or the predictor variables. Thus, the same method can be applied to all of our outcome variables. This method only requires information about the mean and standard deviation of the distribution and is robust with respect to the variance. Finally, this method can take into account the correlation within clusters of repeated measures within hierarchies, so we do not have to discard any study data.

Pharmaceutical prescribing

A number of observations suggest the need for computer-based drug profiles. Physicians cannot depend upon patients to accurately report the drugs they are taking. Less than 10% of elderly patients could report the names of all of the drugs they were taking, let alone the dose [44]. The provider who assumes the care of these patients could not know the correct medication regimen without access to the original prescription records. Lack of such information can lead to duplicate prescribing, overdosing, adverse effects due to drug interactions, and undertreatment.

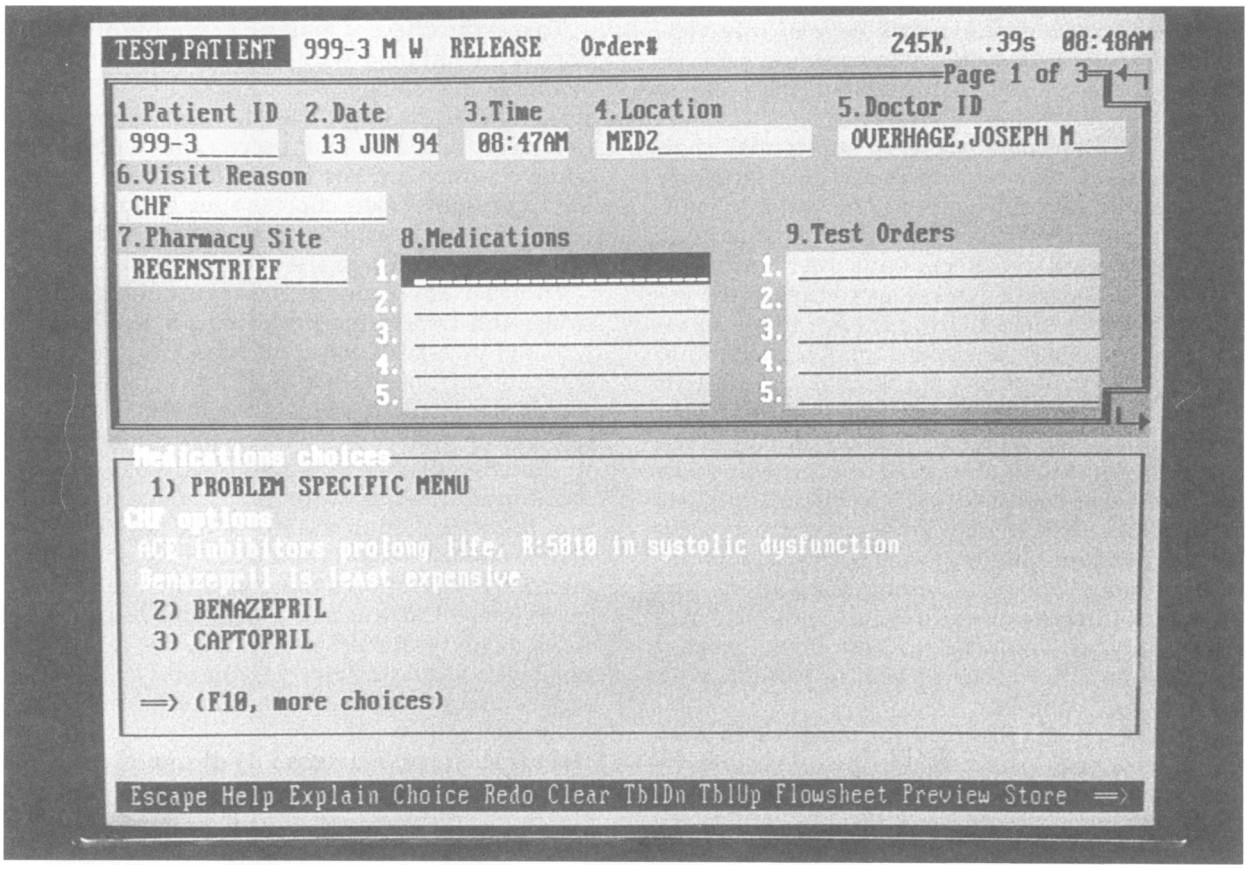
To test the effect of making a communitywide drug database combined with a "smart" ordering system available, physicians will be asked to write all their prescriptions through the Medical Gopher workstation described earlier. Prescriptions will be entered using a screen similar to that shown in Figure 2. A menu presents drug choices specific to the patient's problem. The computer also displays the patient's active drug profile in the same menu.

To order any drug on the menu, including active drugs and treatments preferred for the index problem, the prescriber types the menu number or selects the choice from the menu. If the drug of interest is not on the menu, the prescriber must enter all or part of the drug's name. In this case, the partial-name lookup function of the workstation will display all drugs that contain that character string. Once a drug is chosen, the workstation examines the patient's computerized medical record for allergies, drug interactions, and patient diagnoses that make the use of this drug inadvisable and warns the provider of contraindications. If no reminders are issued, the computer next displays a window depicting the cost of the drug and any available information, including how long the drug has been on the market. The user can type in the instructions or select a fill-in-the-blank template from the menu, filling in all variables such as dose, frequency of treatment, and indications for PRN orders. If there are other orders that should be initiated as a result of the index order, the computer offers a reminder.

We expect this approach to influence prescribing in a number of ways. By providing more information about the patient's medical history and drug usage, the workstation should reduce duplicate prescribing, reduce the chance of adverse effects from drug interactions and drug-diagnosis conflicts, make it easier to write prescriptions, and produce more economical and appropriate prescribing.

All care sites will be included in a twelve-month, randomized, controlled clinical trial of prescription writing. Clinicians will be randomly assigned to intervention or control status. Intervention physicians will have access to a composite medication profile constructed from the RMRS database, the commercial pharmacy chain databases, academic detailing messages [45], problem-specific menus, online formulary lists, blocking rules, reminders, and consequent orders [46]. To assess the impact of the intervention, we will compare physician prescription-writing time, drug charges, proportion of patients with polypharmacy, and proportion of patients experiencing adverse drug reactions sufficiently severe to lead to ED

Figure 2
Prescription order menu



visits or hospitalization between intervention and control physicians.

BARRIERS AND CHALLENGES

Privacy and security

All data passing through the network using TCP/IP protocols will be encrypted using a private key Data Encryption Standard (DES) algorithm. In addition, data passing over the cable system-based WAN will be transformed into analog signals that are virtually undecipherable without intimate knowledge of the CableWorks technology. The encryption feature of pcANYWHERE will protect data transferred over telephone lines when using this program to access the system. The encryption software and keys will be installed on the workstations by project personnel.

Each clinician provided with access to the INPCR system will be issued a password only after executing a witnessed confidentiality agreement. We are establishing cross-institutional enforcement agreements. Users will be issued a permanent, unique, user identifier and private password, both of which are used to confirm identity when retrieving or entering data. Passwords must be changed every six months or when a user suspects that his or her password is no longer secure. All data access will be logged and analyzed for patterns of access to identify inappropriate use.

Patient identifiers

Each patient in the clinical repository is assigned a unique medical-record number that includes a check digit to avoid entry errors. We anticipate that clinicians looking for patient data in the study will use a few characters of the surname and the last four digits of the Social Security number, because this produces a manageable list of possible patients. The list of pos-

sible matches consisting of preferred name, date of birth, gender, race, and mother's name will be displayed. Aliases and alternative identifiers such as name and medical-record number are supported.

We will have to match patient-identifying information to merge data from multiple sources. We will rely on a hierarchical approach in which an insurance ID and other identifying numbers are matched. The system will compare the candidate matches using an algorithm that combines a match value computed for the name, date of birth, gender, and mother's name. For patients with aliases or alternative names such as maiden names, multiple match values will be computed [47]. We will only merge data into the RMRS when those data can be linked to a known patient with a high degree of certainty.

Standards

We will use *ICD-9-CM* codes [48] to represent diagnoses and the WHO drug codes [49], along with the Anatomic Therapeutic Classifications, to identify drugs and to group drugs for analysis. Unfortunately, laboratory test names lack a comprehensive coding scheme, so we will map laboratory results to our existing laboratory code dictionary. This effort will build on a current cross-organizational effort to extend the EUCLIDES coding system [50].

Physician time

Clinician acceptance will be a significant determinant of success for the INPCR. Many aspects of the system should save the physician time, including renewing maintenance medications (which is much more common than writing a new prescription) and searching for and verifying information about the patient. Writing a new prescription should not take much longer than writing a paper prescription in longhand, given the structured instructions for most drug/indication pairs. We will minimize the time costs of using the system by optimizing the software; using sufficiently powerful personal computers for the workstations; providing shortcuts for common orders, defaults, order sets, and problem-specific menus; and attempting to anticipate the physician's needs.

CONCLUSIONS

Many have argued for the potential efficiency and health care benefits that will come from communitywide electronic medical records systems. We have an opportunity to prove these hypotheses with the system and planned studies. If our hypotheses are proved valid, the care system we have discussed can be economically and medically justified.

REFERENCES

1. Dick RS, Steen EB, eds. The computer based patient record: an essential technology for health care. Washington, DC: National Academy Press, 1991.
2. U.S. General Accounting Office. Medical ADP systems: automated medical records hold promise to improve patient care. Washington, DC: The Office, 1991. Report No.: GAO/IMTEC-91-5.
3. McDonald CJ, Tierney WM. Computer-stored medical records: their future role in medical practice. JAMA 1988 Jun 17;259(23):3433-40.
4. American Society for Testing and Materials. ASTM E1238-94: standard specification for transferring clinical observations between independent computer systems. Philadelphia: The Society, 1994.
5. Health Level Seven. An application protocol for electronic data exchange in healthcare environments. Version 2.1. Ann Arbor, MI: Health Level Seven, 1990.
6. American College of Radiology. Digital imaging and communications 1988. Washington, DC: ACR/NEMA, 1988. (Standard publication, no. 300-1985).
7. McDonald CJ, Tierney WM, Overhage JM, Martin DK et al. The Regenstrief medical record system: 20 years of experience in hospitals, clinics, and neighborhood health centers. MD Comput 1992 Jul/Aug;9(4):206-17.
8. McDonald CJ. Protocol-based computer reminders: the quality of care and the nonperfectibility of man. N Engl J Med 1976 Dec 9;295(24):1351-5.
9. McDonald CJ. Use of a computer to detect and respond to clinical events: its effect on clinical behavior. Ann Intern Med 1976;84:162-7.
10. McDonald CJ, Wilson GA, McCabe GP Jr. Physician response to computer reminders. JAMA 1980 Oct 3;244(14):1579-81.
11. McDonald CJ. Action-oriented decisions in ambulatory medicine. Chicago: Year Book Medical Publishers, 1981.
12. McDonald CJ, Hui SL, Smith DM, Tierney WM et al. Reminders to physicians from an introspective computer medical record: a two-year randomized trial. Ann Intern Med 1984 Jan;100(1):130-8.
13. Barnett GO. The application of computer-based medical record systems in ambulatory practice. N Engl J Med 1984 Jun 21;310(25):1643-50.
14. Barnett GO, Winickoff RN, Morgan MM, Zielstorff RD. A computer-based monitoring system for follow-up of elevated blood pressure. Med Care 1983 Apr;21(4):400-9.
15. Barnett GO, Winickoff R, Dorsey JL, Morgan MM et al. Quality assurance through automated monitoring and concurrent feedback using a computer-based medical information system. Med Care 1978 Nov;16(11):1962-70.
16. Bleich HL, Beckley RF, Horowitz GL, Jackson JD et al. Clinical computing in a teaching hospital. N Engl J Med 1985 Mar 21;312(12):756-64.
17. Classen DC, Pestotnik SL, Evans RS, Burke JP. Computerized surveillance of adverse drug events in hospital patients. JAMA 1991 Nov 27;266(20):2847-51.
18. Cummings KM, Frisof KB, Long MJ, Hrynkiewich G. The effects of price information on physicians' test ordering behavior: ordering of diagnostic tests. Med Care 1982 Mar;20(3):293-301.
19. Gardner RM, Clemmer TP, Larsen KG, Johnson DS.

Computerized alert system used in clinical medicine. In: Proceedings of the Thirty-Second Annual Conference on Engineering in Medicine and Biology, 1979.
20. Larsen RA, Evans RS, Burke JP, Pestotnik SL et al. Improved perioperative antibiotic use and reduced surgical wound infections through use of computer decision analysis. Infect Control Hosp Epidemiol 1989 Jul;10(7):316–20.
21. McPhee SJ, Bird JA, Fordham D, Rodnick JE et al. Promoting cancer prevention activities by primary care physicians: results of a randomized, controlled trial. JAMA 1991 Jul 24–31;266(4):538–44.
22. Safran C, Slack WV, Bleich HL. Role of computing in patient care in two hospitals. MD Comput 1989 May/Jun; 6(3):141–8.
23. Stead WW, Hammond WE. Computerized medical records: a new resource for clinical decision making. J Med Syst 1983 Jun;7(3):213–20.
24. Whiting-O'Keefe QE, Simborg DW, Epstein WV, Warger A. A computerized summary medical record system can provide more information than the standard medical record. JAMA 1985 Sep 6;254(9):1185–92.
25. Wirtschafter D, Carpenter JT, Mesel E. A consultant-extender system for breast cancer adjuvant chemotherapy. Ann Intern Med 1979 Mar;90(3):396–401.
26. Tierney WM, Hui SL, McDonald CJ. Delayed feedback of physician performance versus immediate reminders to perform preventive care: effects on physician compliance. Med Care 1986 Aug;24(8):659–66.
27. Tierney WM, McDonald CJ, Martin DK, Rogers MP. Computerized display of past test results: effect on outpatient testing. Ann Intern Med 1987 Oct;107(4):569–74.
28. Tierney WM, McDonald CJ, Hui SL, Martin DK. Computer predictions of abnormal test results: effects on outpatient testing. JAMA 1988 Feb 26;259(8):1194–8.
29. Tierney WM, Miller ME, McDonald CJ. The effect on test ordering of informing physicians of the charges for outpatient diagnostic tests. N Engl J Med 1990 May 24; 322(21):1499–504.
30. Tierney WM, Miller ME, Overhage JM, McDonald CJ. Physician inpatient order writing on microcomputer workstations: effects on resource utilization. JAMA 1993 Jan 20; 269(3):379–83.
31. McDonald CJ, Tierney WM. The Medical Gopher: a microcomputer system to help find, organize and decide about patient data. West J Med 1986 Dec;145(6):823–9.
32. Osheroff JA, Forsythe DE, Buchanan BG, Bankowitz RA et al. Physicians' information needs: analysis of questions posed during clinical teaching. Ann Intern Med 1991 Apr;114(7):576–81.
33. Bleich, op. cit.
34. Haynes RB, McKibbon KA, Walker CJ, Ryan N et al. Online access to MEDLINE in clinical settings: a study of use and usefulness. Ann Intern Med 1990 Jan 1;112(1):78–84.
35. Ibid.
36. Lindberg DAB, Siegel ER, Rapp BA, Wallingford KT et al. Use of MEDLINE by physicians for clinical problem solving. JAMA 1993 Jan 23–30;269(24):3124–9.
37. Hjortdahl P, Borchgrevink CF. Continuity of care: influence of general practitioners' knowledge about their patients on use of resources in consultations. BMJ 1991 Nov 9;303(6811):1181–4.
38. Heagarty MC, Robertson LS, Kosa J, Alpert JJ. Some comparative costs in comprehensive versus fragmented pediatric care. Pediatrics 1970 Oct;46(4):596–603.
39. Hjortdahl, op. cit.
40. Wilson GA, McDonald CJ, McCabe GP Jr. The effect of immediate access to a computerized medical record on physician test ordering: a controlled clinical trial in the emergency room. Am J Public Health 1982 Jul;72(7):698–702.
41. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. Biometrics 1986;73:13–22.
42. McCullagh P, Nelder JA. Generalized linear models. 2d ed. London, New York: Chapman and Hall, 1989.
43. Liang, op. cit.
44. al Mahdy H, Seymour DG. How much can elderly patients tell us about their medications? Postgrad Med J 1990 Feb;66(772):116–21.
45. Soumerai SB, Avorn J. Principles of educational outreach ('academic detailing') to improve clinical decision making. JAMA 1990 Jan 26;263(4):549–56.
46. Overhage JM, Tierney WM, McDonald CJ. Computer-assisted order-writing improves compliance with ordering guidelines. Clin Res 1993;41:716A.
47. Friedman C, Sideli R. Tolerating spelling errors during patient validation. Comput Biomed Research 1992 Oct;25(5): 486–509.
48. United States Health Care Financing Administration. The international classification of diseases: 9th revision, clinical modification: ICD-9-CM. 4th ed. Washington, DC: The Administration, 1991.
49. World Health Organization Collaborating Centre for International Drug Monitoring. WHO drug dictionary. Version 2. Uppsala, Sweden: The Centre, 1992.
50. Euclides Foundation International. EUCLIDES coding system. Version 3.10. Gent, Belgium: Euclides Foundation, 1992.

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