Over the past 20 years, there has been an explosion in the availability of practice guidelines. Currently, the National Guideline Clearinghouse (http://www.guideline.gov) alone has almost 1000 publicly accessible guidelines. There are innumerable unpublished private and institutional guidelines as well. Ironically, even though many guidelines have been developed, most receive little use for a variety of reasons. Some of the barriers to use arise at the time of content development. First, there are gaps and inconsistencies in the medical literature supporting one practice versus another. There are also differences in the biases and perspectives of guideline authors, who may be specialists or generalists, payers or providers, marketers, or public health officials. The result is guidelines of variable quality and conflicting recommendations.

Once the content has been decided, the next set of barriers involves acceptance of the guideline by both clinicians and patients. Physician disagreement\(^2\),\(^3\) the inertia associated with traditional practice behaviors\(^4\) and the lack of incentives (or even disincentives) to change\(^5\) can cause a guideline to be ignored. Patient-specific and community-wide factors can also impact adherence; this so-called “patient noncompliance” may be related to lack of patient education, misinformation, or the cost or side effects of proposed treatments.

Even when acceptable to both providers and patients, guideline content must be easily accessible
at precisely the right time—while delivering care. If a relevant guideline is not frankly overlooked during a patient’s already short and intervention-laden visit, tracking it down and looking up its recommendations may be too time-consuming. Even if the guideline were accessed later, the opportunity to act has been lost once the patient has left the office.

**Automated Guidelines**

Not withstanding the above obstacles, the promise of guidelines, especially automated ones, to reduce practice variability and improve outcomes is great. Previous work has shown that computer-generated, patient-specific reminders can positively influence practice. As computers become standard tools of clinical practice, computer-based guidelines increasingly can be integrated into routine workflow, delivering “just-in-time” information pertinent to the current clinical situation. Links to related resources, such as patient handouts and references to the medical literature, can promote patient and physician acceptance, respectively. Furthermore, as electronic medical records (EMRs) become more prevalent and robust, there is more potential to specifically tailor a guideline’s recommendations to individual patients by taking into account their medications, symptoms and comorbid conditions.

Four years ago, one of the authors (RDZ) described the state of the art for electronic guidelines and tried to anticipate advancements in the field. One difficulty noted was the lack of a definition of “computerized.” At a first level, this term signifies access to a digital but still narrative-text version of a printed document. Such access now can be made widely available to an entire practice or institution via an intranet or more globally on the Internet. An example is the National Guideline Clearinghouse, which is conveniently indexed and searchable. However, simply displaying guidelines on a computer monitor does not necessarily increase adherence.

The next level of automation occurs when the computer is able to make use of the patient’s clinical data, follow its own algorithm internally, and present only the information relevant to the current state. An obstacle to achieving this goal is the ambiguous language with which most text-based guidelines are composed. Eligibility criteria and severity of disease or symptoms are often not explicitly defined. When they are, the definitions may not map to computable data within an EMR. The process of translating ambiguous guideline statements into equivalent ones that use available coded data is not only arduous but also carries the risk of distorting the intent and spirit of the original guideline.

Models and tools for extracting and organizing knowledge, representation models for publishing and sharing guidelines, and computational models for implementing guidelines have been developed to help overcome these problems (Arden, GEM, Protégé, GLIF, EON, Prodigy). Few guidelines have been successfully translated using these systems and implemented into real clinical settings. Instead, most working implementations have been relatively simple “if–then” rules triggered off EMR data. The resultant messages can be synchronous and interactive, such as alerts linked to computer-based physician charting or order entry, or asynchronous, such as alphanumeric pages or phone calls. The messages are usually reminders or recommendations, but they may also be performance reviews or feedback. They may be directed at nurses, pharmacists, clerical staff, or patients in addition to physicians. In general, the beneficial effect of these systems has been on the order of 10–20% absolute improvement in process measures, and most studies have not evaluated patient outcomes.

There is little published experience with automating EMR-integrated complex multistep algorithmic guidelines for the management of chronic diseases over extended periods. At Brigham and Women’s Hospital, where we have an extensive history of implementing single-step guidelines and reminders, we began in 1996 to work on more complicated types of alerts and decision support. This article examines the progress made toward this goal at our institution and attempts to distill lessons that may guide future work in this field.

**Setting**

The project took place at Brigham and Women’s Hospital (BWH), a 700-bed tertiary care academic medical center in Boston. The BWH environment has several features that can support the implementation of computer-based guidelines. Primary care physicians at BWH use an EMR that, in addition to coded laboratory and visit data, contains physician-maintained allergy, medication, and coded problem lists. BWH also has an inpatient physician order entry application with built-in drug-dosing calculators and synchronous, interactive alerts and reminders about drug-allergy and drug-drug interactions. In addition, an event monitor, coupled with an active provider coverage database, automatically can noti-
fy clinicians asynchronously based on data added to
the clinical data repository. Finally, an ambulatory
reminders application can compute short messages
using if–then rules and print them on the bottom of
encounter sheets produced for every scheduled out-
patient visit.48 These elements (coded electronic data,
event monitoring, synchronous and asynchronous
messaging capability, and order entry) form a robust
platform on which to implement complex automated
practice guidelines.

Design Objectives

There were three major objectives of the project. First
was the development of a knowledge model that
incorporated data input, logic and processing, and
notification and effector mechanisms necessary to
implement automated practice guidelines in both
inpatient and outpatient settings. Second was the
construction of editing tools to allow nonprogram-
er analyst and/or medical domain experts to
implement guideline specifications using this knowl-
dge model; these high-level specifications would
then be automatically translated into working com-
puter code. Third was the implementation and eval-
uation of EMR-based automated guidelines within
real clinical workflow environments.

System Description

Choice of Guideline

For our first attempt at automating a multistep prac-
tice guideline, we chose the National Cholesterol
Education Program (NCEP)49 guideline for the man-
agement of hypercholesterolemia, specifically the
portion dealing with secondary prevention. The
NCEP guideline has several features conducive to
successful automation.50,51 First, it addresses a com-
mon and clinically important problem52 and is sup-
ported by strong scientific evidence, particularly for
secondary prevention.53–55 Second, the guideline is
straightforward and uses data frequently found in a
coded form in an EMR. Third, despite familiarity and
acceptance by clinicians, compliance is unacceptably
low.56,57 At our institution in particular, 69% of
patients with atherosclerotic vascular disease fail to
meet the NCEP goals by not having a recently
checked lipid level, not being on a statin drug when
indicated, or not having the dose of statin properly
adjusted to meet target LDLs.58 There also is signifi-
cant overuse of statins as well as inappropriate mon-
toring.59 These factors suggested that a computer-

Guideline Content

Following Lobach’s model of adapting clinical guide-
dines for electronic implementation,60 we met iter-
atively with relevant specialists (a cardiologist and an
endocrinologist) to forge agreement about the rela-
tively small portions of the printed guidelines that
were vague or controversial. For instance, we needed
to determine whether to include diabetes as an eligi-
bility criterion for secondary prevention rather than
just a risk factor for primary prevention; and how fre-
quently and which lipid levels to monitor. Once this
small group reached consensus, it was then possible
to get sign-off from their respective clinical depart-
ment chiefs.

Guideline Representation

Concurrently, we worked on the knowledge model for
representing and executing guidelines. In an attempt to
use existing “standards” whenever possible, we decid-
ed to start with GLIF2,17 which models guidelines as
directed graphs of decision and action steps. Of course,
the model had to be extended to make the guideline
executable within our EMR. First, the Decision Step
object was extended to render the logic computable
with data from the EMR. Second, the Action Step
object was substantially extended to provide hooks to
various reporting and ordering programs (such as
order entry) as well as to allow time and event-
dependent actions (such as a Wait Step). An Eligibility
Step specified whether a guideline was appropriate for
a given patient and designated who, if anyone, must
approve enrollment onto the guideline. A new
Notification object was added to specify parameters for
various types of messaging, including e-mail, text pag-
ing, and online messaging. Finally, Questionnaire Steps
were implemented to allow the clinician to provide
data not obtainable from the EMR itself. Figure 1 pres-
ents an abbreviated object model of the resulting
knowledge model for our guideline system.

Guideline Authoring

Based on the above knowledge model for represent-
ing practice guidelines, we next developed an appli-
cation for authoring them called Partners
Computerized Algorithm Processor and Editor
(PCAPE).61 PCAPE (Figure 2) is intended to be used
by a trained analyst or domain expert (such as a
physician or nurse) to enter the parameters of an
algorithm from a high-level flowchart specification (as in Figure 3). These parameters consist of triggers and eligibility criteria, instructions for obtaining permission to enroll a patient onto a guideline, provider notification rules, and action and decision steps and their relationships (Figure 4).

Data and logic-building templates facilitate design of an algorithm without programming. For example, PCAPE includes a dialog editor to construct questionnaires. The dialog editor calls on a database of reusable and modifiable questions, and assembles them into an online survey instrument. Multiple question/response types are supported (text box/line; radio buttons; multi- or single select check boxes, drop down lists, or list box), as are response validation and branching logic (Figure 5). On execution, the survey populates an array of user-defined variables with values that are numerical functions of the scored responses. The variables can be used in decision steps just like any coded element of the EMR, such as lab results, allergies, or medications.

**Guideline Execution**

PCAPE automatically compiles the entered parameters into MUMPS code and data structures. These, in turn, are used by the Navigator and Notifier (see Figure 2), which are modified components of the event-monitoring system that powers the BWH alerting system. The Navigator processes the steps of the guideline and logs all transactions. Events that can initiate transitions from one state of the algorithm to another include new lab results, medication orders, admissions, procedures, clinician log-on, or passage of a prespecified amount of time. Actions may take the form of messages presented to the user, perhaps requiring a response, or triggers that call the event engine to activate rules governing further actions. The Notifier sends messages to a patient's covering clinician, seeking data or presenting recommendations and order sets that can be processed by the system. The notification of a message's presence may be via synchronous (interactive) on-screen alerts or asynchronously via e-mail, alphanumeric page, or printed notices.

**Workflow**

We considered a number of ways to notify clinicians of the current recommendations and data needs at any given step of the guideline. Alphanumeric pages were abandoned because they were felt to be inappropriate-
ly interruptive for the level of urgency required for cholesterol management. E-mail was also rejected by clinicians because such notification was not actionable unless received and read during a patient’s visit.

The method that was most widely accepted is an extension of the current system of printing reminders at the bottom of an encounter sheet. The encounter sheet is printed before every non-urgent patient visit, and lists the patient’s medications, allergies, and active problems (Figure 6). Information about the current guideline step is printed on the encounter sheet, which is routinely reviewed by most clinicians at the actual time of the patient visit. Unfortunately, because of space constraints on the printed page, guideline messages are limited to two lines of text.

Although the encounter sheet gives good static information, it does not allow physicians to enter information interactively through dialogs. Therefore, to allow more extensive messaging and data collection, the ability to interact synchronously with the guideline was incorporated into the navigation engine as well. For example, a patient’s enrollment on a clinical guideline is indicated on the main screen of the outpatient EMR. Much as one would look up a lab result or radiology report, the clinician can access the guideline, exchange information via online dialog boxes, traverse decision nodes of the algorithm, receive computed alerts and messages, and (at least on the inpatient side) initiate order sessions. For the outpatient setting, where the NCEP guideline presumably is most frequently utilized, such order sessions really are secondary dialog screens intended to capture acknowledgement and intent of the clinician; they do not generate actual orders because outpatient order entry has not yet been implemented. Finally, throughout the interaction described above, the clinician can follow links to relevant citations, supplementary resources, and patient handouts.

Status Report

The final automated NCEP secondary prevention guideline has 9 decision steps and 9 action steps. We use Visio for the intermediary flowchart specification of the guideline (see Figure 3—online data supplement), from which the PCAPE specification was entered. The full PCAPE specification, although human-readable, is in comparison cryptic and lengthy (9 pages). For example, compare Steps 11a and 14 in Figure 3 with their corresponding PCAPE representations in Figures 7 and 8.
To evaluate the impact of the computer-based guideline on compliance with the NCEP recommendations for secondary prevention patients, we are carrying out a prospective randomized controlled trial. One-half of the primary care physicians at BWH have been randomized to receive the reminders at the bottom of their patients’ encounter sheets. In the first year of the evaluation, 2,258 reminders were printed for 690 patients. Reminders were generated for 65% of the visits by secondary prevention patients of intervention group physicians. Reminders generated thus far have been to check LDL (979), start or consider a statin (554), or optimize therapy (725). Proportional numbers and types of reminders were generated but not displayed for control patients. Notably, only 20 times (0.8% of 2610 visit opportunities) has a clinician opted to interact directly with the guideline using the computer. The final evaluation will assess the impact of the reminders on overall compliance with the NCEP goals as well as on the frequency of executed recommendations.

**Figure 4.** PCAPE Guideline Editor screenshot, showing one screen of the cholesterol algorithm within the Editor. Here one can enter all the parameters of a guideline as specified in the guideline object model (see Figure 1).

**Figure 5.** PCAPE Dialog Editor screenshot, showing the construction of an interactive questionnaire that queries a user about a patient’s cardiac risk factors.
Discussion

Our experience with this project has confirmed our belief that implementing automated guidelines is still extremely difficult—despite having started with a state-of-the-art clinical information system, garnering significant institutional commitment from the outset, employing a powerful underlying knowledge model, and starting with as ideal a guideline as possible. A number of lessons have been learned at each step of the process.

Choice of Guideline

We limited the scope of the guideline to secondary prevention to minimize complexity and to maximize consensus. First, this subset of the NCEP guidelines enjoyed significant backing by scientific evidence as well as wide acceptance by clinicians and addressed an important clinical problem. Second, data required to compute and navigate the guideline were all contained in the EMR (cholesterol levels, problem lists, and medications); in other words, interactive dialogs

<table>
<thead>
<tr>
<th>Vital Signs</th>
<th>04/14/00</th>
<th>BP 121/73</th>
<th>BP SITTING</th>
<th>P 80</th>
<th>R ++</th>
<th>WT 141</th>
<th>T --</th>
</tr>
</thead>
</table>

- Entered Problems (*=not coded)
  1. 5/94 HYPOTHYROIDISM
  2. 5/94 S/P TAH-BSO
  3. 7/99 H/O DUODENAL ULCER *
  4. 10/02 CHF
  5. 10/02 CAD> CAVB 4/95, PTCA 10/02

- # Start Changed Medications (*=not coded)
  1. 11/04 09/11/91 COZAAR 100MG PO QD (disp #90 11/15/02)
  2. 11/04 12/29/96 LASIX 80MG PO 1/2 QD (disp #90 08/09/02)
  3. 02/94 11/11/94 PREMARIN 0.625MG PO QD (disp #30 08/01/04)
  4. 07/90 11/06/99 ECGOTRIN 1 PO QD
  5. 05/91 11/11/99 LEVOTHER 50MG PO QD

- # Allergies
  1. I.V. STATIN G1 upset
  2. PCN, HIVES

- Health Maintenance Items
  Breast exam
  Mamagram 03/22/00: Done elsewhere w/o @ MT AUBURN HOSPITAL.
  Pap smear 10/15/98: Deferred N/A
  Pap TAH-BSO
  Cholesterol test 10/11/01: 245 (HDL: 44) (cLDL: 177)
  Stool guaiac
  Flu shot 12/1/00;
  Pneumovax
  Ophthalm exam
  Advance directive
  EKG 02/08/01: 12A Final
  Hep B vaccine
  PPD Control
  1st booster 09/08/05: L. DL VISL/0978460 8/28/00 NC
  Smoking status 10/15/04: FORMER SMOKER
  Flex sig 10/15/08: *See Report
  Colonoscopy

- Reminders
  1. Patient is overdue for Mamagram (rec: q 1 year)

- # Algorithms: To access, select CLINICAL ALGORITHMS from the Patient Summary.
  CHOLESTEROL: Start statin if not allergic; log-in for details.

Figure 6. Sample outpatient encounter summary printed for the clinician to review during a patient's visit. Guideline messages appear at the bottom. Data do not correspond to any real patient.
with the clinician to collect these data were not required. Third, the secondary prevention portion of the guideline was relatively easy to translate because the decision logic and recommendations were explicit and measurable (check cholesterol level, start drug therapy, or adjust drug therapy). In comparison, the primary prevention portion of the NCEP guidelines had less scientific support, less acceptance by clinicians, and vague logic and recommendations.

**Guideline Content**

It became clear that even simple and relatively straightforward guidelines can be interpreted in different ways, depending on one’s perspective or specialty. Much effort was spent trying to achieve agreement among our experts about details of the guideline. Although initial efforts tried to put too much corrective action into the algorithm’s recommendations, the experts ultimately focused on a more pragmatic goal. This goal was simply to ensure that the basic and most important recommendations of the NCEP guidelines were being followed, not to pre-
specify every medical decision related to the management of hypercholesterolemia or to replace the clinician or substitute for his or her medical education. For example, rather than recommend one particular drug (or drug class) over another (which entails factoring in highly nuanced patient-specific data that is not stored in or easily accessible from the EMR), we decided to implement the more general reminder that the patient simply qualified for pharmacologic treatment. Then, by linking to background reference information about the mechanism, effectiveness, costs, and side effects of various lipid-lowering medications, the autonomy of the clinician to make the best decision for the patient was preserved.

Guideline Representation

We were pleasantly surprised to learn that our knowledge model was not the project’s limiting step. Indeed, GLIF was easily extended, even to deal with execution modalities that were not anticipated at the start of the process, notably the ability to support different notifications and actions from the same step, depending on whether the user was currently interacting with the guideline. Others have also successfully extended GLIF in similar ways.62

One noticeable but surmountable obstacle that had as much to do with the original guideline as with the knowledge model used to encode it was conflicting or borderline data. For example, the NCEP guideline does not specify what to do if more than a single recent LDL is available. For any specific patient, a human can quickly integrate the levels over time and judge whether it is reasonable to use the lowest, highest, most recent, median, or mean value. The computer is limited to an analyst’s best a priori guess, which must then be applied to every subsequent patient.

Although our guideline model allows different recommendations for different test results, it does not flexibly handle borderline labs, such as an LDL of 102 mg/dl. The NCEP guideline itself is precise enough about this point, but clinicians in practice might violate the strict guidelines for such a close result, rightly or wrongly.

Guideline Authoring

We used Visio to represent the sequence of decisions and actions at a highly conceptual level, as a flowchart. This version was passed back and forth among the experts and "debugged" by hand. Because PCAPE cannot read Visio data, the flowchart representation had to be re-entered step by step into the editor, which, though powerful, was not particularly user-friendly. A simple change in the Visio flowchart, such as the insertion of a new decision step, could mean a 15-minute interaction with PCAPE.

Guideline Execution

Others have developed integrated tools that link graphically based authoring and editing of guidelines with execution engines of one kind or another.63–65 Such tools that directly translate the flowchart specification of a guideline into executable code not only would speed development of computer-based guidelines but also would help ensure the fidelity of the translations. Without it, the PCAPE version had to be debugged independently of the expert-verified flowchart. Even after extensive testing in a "live" test environment and then again in a real-world pilot clinic, some important bugs slipped by our scrutiny. These were most commonly related to issues with modeling the passage of time or with supporting synchronous interaction between clinician and computer.

Workflow Integration

Clinicians who use our EMR are quite familiar with encounter sheet-based reminders. Other encounter sheet reminders at our institution are followed 5–60% of the time (the wide variation is due to differences among the reminders that we have implemented).48 Based on how physicians interact with our EMR in the inpatient arena, we hypothesized that direct synchronous interaction with an electronic guideline would have added value in the outpatient setting as well. However, despite incentives to do so, such as access to more detailed recommendations and background information, citations of supporting references, links to patient handouts, and facilitated documentation, clinicians almost never opted to interact in real time with the guideline. Instead, they relied only on the brief reminders printed at the bottom of patient encounter sheets. This finding is consistent with McDonald et al. that physicians do not take advantage of ancillary features that require extra time and effort.66

Whether the lack of online interaction with the cholesterol algorithm reflected obstacles in using the guideline application itself or the EMR in general or whether it was a characteristic of the problem domain is not clear. The end result was that the guideline’s ability to collect data and to disseminate in-depth recommendations was limited. Indeed, without synchronous or interactive forms of messaging, it is difficult to deter-
mine whether a recommendation has been read, let alone accepted or rejected, except by using proxies such as new LDL results or changes in the medication list (which do, in fairness, reflect the intended goal).

Our implementation of automated guidelines also may have been more effective if used in conjunction with an outpatient physician order entry system. Unlike inpatient alerts and warnings, which have been so successful at our institution, there was no way to facilitate the actual implementation of recommended outpatient actions, such as ordering a lipid level or prescribing a statin, because we did not have outpatient order entry. Outpatient order entry with rule-based decision support (as opposed to multistep and persistent algorithms such as ours) has been successfully implemented at other centers. Of course, order entry does not guarantee compliance with guidelines. For example, a recent study by Dexter et al. documented that one user interface model in an order entry system did not increase compliance with guidelines, whereas another user interface model did.25

We also envision additional data that can be included to make the guideline’s recommendation more meaningful. For instance, knowing details of the context of the visit (urgent, general check-up, health maintenance) can help determine the most appropriate mode of messaging. Also, additional data elements not commonly found in EMRs, such as information about modifiable risk factors (e.g., diet and exercise), may allow finer tuning of decisions and recommendations. This information could be captured with user dialogs, but, as noted above, getting physicians to provide such data is difficult. Interestingly, in our inpatient order entry system, there are many situations in which physicians enter supplemental data reliably and frequently. It may be that because entering orders is a necessary and regular part of clinical workflow in the hospital, greater interaction and user data entry have become acceptable. On the other hand, investigating a clinical algorithm—especially when the basic answer is already revealed—may be perceived as peripheral to the clinical workflow in the office, making extra interaction unnecessary and/or unacceptable.

Conclusions

Even with a robust EMR, an advanced event-monitoring system, and a rich set of messaging options, the successful implementation of complex computer-based clinical practice guidelines remains a difficult task. First, guideline development is always arduous because it demands making choices about what will and will not be automated based on degree of national and local expert consensus and the sophistication of available computer resources.

The next obstacle is guideline representation. Although this obstacle has occupied the bulk of the theoretical and published discussion on this topic, it fortunately was not the limiting factor in our effort. Nevertheless, more sophisticated development tools to translate high-level guideline specifications directly into executable code would be welcome.

Instead, the biggest obstacle to implementing complex automated guidelines that we encountered was with presentation and integration into the clinical workflow. Clinicians rarely interacted with the online version of the guideline. Other methods to integrate into the workflow are required. Until these methods are developed, including outpatient order entry and more sophisticated messaging modalities, such as synchronous methods acceptable to physicians for use during a patient’s visit, the marginal benefit of automating complicated algorithmic guidelines over simple rule-based reminders generated on demand is small.

References

10. Zielstorff RD. Online practice guidelines: issues, obstacles, and


