

Towards a Representation Format for Sharable Clinical Guidelines

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Running title

Representation of sharable guidelines

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Abstract

Clinical guidelines are being developed for the purpose of reducing medical errors and unjustified variations in medical practice, and for basing medical practice on evidence. Encoding guidelines in a computer-interpretable format and integrating them with the electronic medical record can enable delivery of patient-specific recommendations when and where needed.

Since great effort must be expended in developing high quality guidelines, and in making them computer-interpretable, it is highly desirable to be able to share computer-interpretable guidelines (CIGs) among institutions. Adoption of a common format for representing computer-interpretable guidelines (CIGs) is one approach to sharing. Factors that need to be considered in creating a format for sharable CIGs include (1) the scope of guidelines and their intended applications; (2) the method of delivery of the recommendations; and (3) the environment, consisting of the practice setting and the information system in which the guidelines will be applied. Several investigators have proposed solutions that improve the sharability of CIGs and, more generally, of medical knowledge. These approaches can be useful in the development of a format for sharable CIGs.

Challenges in sharing CIGs also include the need to extend the traditional framework for disseminating guidelines to enable them to be integrated into practice. These extensions include processes for (1) local adaptation of recommendations encoded in shared generic guidelines and (2) integration of guidelines into the institutional information systems.

Key words

Clinical guidelines, knowledge representation, knowledge sharing, decision support, computer-interpretable guidelines, local adaptation, functional requirements, standards

1. Introduction

Recent trends in health care delivery have led to an increased emphasis on the development of guidelines for prevention, diagnostic work-up, treatment, and patient-management. The flurry of development is motivated by concerns about marked variations in clinical practice and evidence of a surprisingly high incidence of medical errors and sub-optimal care [1]. Much work goes into the development of a high quality guideline, in reviewing literature and evaluating alternative strategies, with the aim of making the guideline as evidence-based as possible [2]. A guideline thus developed is intended to help provide a common standard of care both within a health care organization and among different organizations.

Guidelines have been disseminated in many forms, by publishing them in magazines and journals, textbooks, CD-ROMs, and on the Web. While electronic dissemination has broadened the availability of guidelines, and enables guidelines to be retrieved even in clinical settings, most guidelines have typically been specified in non-computer-interpretable narrative text or non-executable flowchart formats. These non-computable formats limit the usability of the guideline since the knowledge contained in the guideline may not be easily accessible during the patient encounter. Further, extracting recommendations from a non-computable document and determining their relevance for a specific patient require additional effort from the care provider. These usability issues have been identified as factors impeding compliance with guidelines [3].

For better integration of guidelines into the clinical workflow and to provide point-of-care patient-specific recommendations, guidelines are increasingly being implemented using computer-based systems [4, 5]. Yet a major obstacle to the large scale implementation of guidelines in computer-based decision support systems is the additional effort, beyond creating

the guidelines, required for structured, computer-interpretable representation. Further, even guidelines that are encoded often cannot be shared across institutions or even across different types of applications, because of differences in formatting or encoding conventions. Sharing encoded guidelines could potentially reduce the cost of implementing guidelines in large-scale computer-based decision-support systems. The lack of a standard representation format for guidelines causes developers to encode CIGs in proprietary or institution-specific formats. Other barriers to sharing include the frequent need for local adaptation and modification of guidelines due to institution-specific needs, and the requirement for adaptation to varying kinds of technical applications (such as results-reporting or order-entry) and systems environments in which guidelines will be used.

In this paper, we discuss important requirements of a representation format for sharable CIGs, such as those described in the previous paragraph. We intentionally focus on those requirements that affect sharability and do not address the broader knowledge representation requirements of guidelines [6]. We look at solutions provided by existing CIG representation schemes from the perspective of the sharability requirements. However, this paper is not intended to be a comprehensive review of current CIG representation schemes. Instead, we intend to provide a foundation for the development of standard representation for sharable CIGs.

In the next section, we describe the current model for guideline development and dissemination, and factors that must be considered in developing solutions for sharing guidelines. We then discuss the critical role of a common guideline-representation format to support sharing of the knowledge in guidelines across institutional, national, and medical domain boundaries [7]. We identify usage requirements for CIGs, and accordingly identify the features that must be

represented. We also present requirements for a dissemination framework that facilitates implementation.

2. Background

Sharing of CIGs needs to be founded on an approach to both dissemination and integration into practice that recognizes not only the wide variation of guidelines and their applications, but also the multiplicity of practice settings and information systems environments within which guidelines are to be used.

2.1 Development and dissemination of clinical guidelines

Figure 1 depicts in general terms the current process for the development and dissemination of narrative guidelines [8]. Note that the model illustrates the process of creating guidelines at national or regional levels. We recognize that guidelines are often created within local healthcare institutions. However, since the focus of this paper is on sharing of guidelines, we limit our discussion to guidelines that are developed with the intention of dissemination or sharing. When guideline authors create a guideline, they must identify the clinical problem, review the literature, develop recommendations, and typically then seek consensus-based approval of the guideline. The guideline is then disseminated via publication in the scientific literature, a monograph, or even via the Internet. At this stage, techniques such as group education and academic detailing have been used for enhancing physicians' awareness and knowledge of the guideline [9-11]. Assumptions underlying this model of development and dissemination are that practitioners will internalize the knowledge contained within the guideline, and subsequently recall and apply this knowledge at relevant times during clinical practice.

The interest in CIGs is partly based on evidence that the current model for guideline dissemination has not been very effective [12-16]. Results of several trials, on the other hand, suggest that computer-based decision-support systems have substantial influence on patient care decisions [17]. For CIGs, the expected usage model is different from that of non-computable guidelines. Rather than being passively read and later remembered, CIGs can adapt to clinical context and known patient data to make context-specific, patient-specific recommendations at the point of care. How guidelines are integrated with care can vary enormously, and is subject to much experimentation, in terms of interface, platform, and kinds of applications. But for all of these, the common element is the need to go beyond the development of non-computable guidelines, by encoding the guidelines into a structured format.

Structured CIGs can then be distributed via the Internet by making them available on the publishers' Web sites (or from on-line compendia such as the National Guideline Clearinghouse at <http://www.guidelines.gov>). Local organizations will download selected guidelines from these servers for integration and use within their settings. However, the problem of disseminating CIGs is more complicated. In order to use a CIG locally, a clinical practice must take care to reconcile the variability that exists in scope and focus of the guideline in relation to its own care processes, the methods for local delivery of guideline knowledge, and the setting in which it will be used. A model for dissemination and local integration of sharable CIGs is discussed in a later section.

2.2 Aspects of CIG use that must be considered

A shared guideline representation format must take into account the breadth of contextual and application-specific factors that affect the use of guidelines. These factors include:

1. *Variability of scope and focus:* Guidelines are created for a variety of medical domains and for various stages (screening, prevention, diagnosis, treatment, etc.) of problems in a domain [18]. Representations for such guidelines may differ, for example, with the decision-making models used in these guidelines. Additionally, the implementation of these guidelines may require different types of interactions and involve different workflow issues (e.g., urgent alerts for acute care guidelines versus an e-mail reminder for mammography screening). Guidelines may also be used for different applications. For example, guidelines may be used primarily as knowledge sources for clinical decision support. Alternatively, guidelines may be used for driving utilization or quality-review and critiquing functions [19-21]. In an educational context, they may be used to provide tutorials or, more actively, to drive problem-based simulations.
2. *Delivery method:* Depending on their intended use, guideline recommendations can be delivered in a variety of ways. For clinical decision support, guidelines have been implemented as the basis for automated reminders and alert systems, as consultation tools for appropriateness determination of intended clinical actions [22] , and as interactive disease management tools that deliver advice specific to applicable clinical states of a patient [4, 23, 24]. Unlike guidelines that recommend but do not prescribe specific interventions, the delivery of clinical-trial protocols requires strict adherence to the experimental protocols for controlled intervention and for data collection; nevertheless such protocols share much in common with clinical practice guidelines [25] and thus representation methods for CIGs may generalize for use in representing arms of clinical-trial protocols. CIGs can also be used as inputs to resource management and in workflow facilitation tools [26].

3. *Practice setting*: In developing a shared format for guidelines, one must also consider the contextual and setting-specific factors that affect the use of guidelines. Such factors include the anticipated delivery platform (e.g., workstation vs. handheld device), the sophistication and mode of user interaction of the clinical information system, the experience of users with computer systems, and the practice environment (e.g., hospital, office, home, or via telephone). Besides the delivery methods and application environments, other local factors may require that a sharable guideline be modified. These factors include differences in local experience resulting in a preference for an alternative approach to one that is recommended by a guideline, lack of availability of a specific resource (such as an analytic or therapeutic procedure), and differences in the physical environment (e.g., tropical Florida versus arctic Alaska) or differences in the patient population (e.g., veterans versus children) leading to different prevalence of diseases.

3. Sharing guidelines

From the above discussion, one can recognize many different goals for sharing CIGs. For example, a CIG may be shared among many institutions with different practice environments, integrated with different types of clinical information systems on different operating platforms, or used in different types of applications such as decision support and quality assurance.

Sharing of CIGs can be accomplished in several different ways:

1. Institutions use proprietary formats and translate CIGs distributed by publishers in other formats into their own format.
2. CIGs are not shared as files but as decision-support services provided through standard application programming interfaces (APIs) adopted by all systems.

3. All institutions adopt a common format for CIGs. Guideline publishers encode and distribute CIGs in this common format, and system-specific programs interpret the CIGs.

The first approach has limitations in that it may not be possible to translate from one format to another because of syntactic and semantic incompatibilities among formats. Current guideline-modeling formats differ significantly in this respect, partly because of differing functional goals or application intentions. Furthermore, translators are costly to build and maintain. It may not be feasible to have translators that translate among several different formats. The DARPA Knowledge Sharing Effort in the early 1990s took a translation approach to knowledge sharing [27]. Even though that effort generated many insights into the problems of knowledge sharing, the translation approach has not been widely adopted.

The PRODIGY project [23] in the United Kingdom has successfully pursued the second approach--that of providing guideline recommendations via external decision-support services. The developers of PRODIGY have defined a set of APIs that specify the mutual obligations between a common guideline execution engine and a host environment. Alternative host systems use the API to obtain decision-support services from the shared guideline execution engine. Conversely, the execution engine uses the shared API to obtain EMR and order-entry services from alternative host systems. In principle, guidelines encoded in alternative formats can be used as long as their execution engines support these APIs. However, currently the CIGs in the PRODIGY system are encoded in a single format at a central site. It is unclear whether the APIs defined by the PRODIGY group are robust enough to support encoding and execution of CIGs in alternative formats.

A common format for CIGs allows sharing them across different platforms and institutions and flexibility in how guideline knowledge is reused in different applications. CIGs developed at

different organizations in a common format can be more easily brought together and integrated into a clinical information system than CIGs developed in different formats. Medical logic modules (MLMs) written in the Arden Syntax [28] are examples of sharing via a common knowledge representation format. However, there has been limited sharing of MLMs among institutions due in part to the lack of, both, a common representation for medical record queries and a common vocabulary [29, 30]. Nonetheless, the size and complexity of MLMs is usually much less than that of CIGs. MLMs can therefore be encoded and implemented with relative ease without a significant need for sharing MLM files. In the case of CIGs that manage medical interventions over time, the complexity of their logic, predecessor-successor ordering of guideline steps, temporal relationships, and control flow make their encoding more difficult and sharing more critical. Implementers have attempted to use Arden Syntax as a representation for temporally complex care plans by having MLMs call one another [31, 32]. However, using a rule-based knowledge-representation model to encode the complex temporal and flow-control relationship among steps of guidelines leads to problems in knowledge authoring and maintenance, and difficulties in managing the sequence of firing of rules. More recent efforts at modeling guidelines seek to address these problems by explicitly modeling such temporal and flow-control relationships in their models. These representation formats are perhaps more effective in modeling multi-step guidelines.

4. Requirements of a format for sharable guidelines

As a first step toward creating a common representation format for sharable computer-interpretable guidelines, requirements should be elicited that define the functionalities that the common format needs to support. In this section, we identify requirements based on the factors

discussed in earlier sections and examine solutions for these problems proposed by various investigators.

4.1 Representation of different types of guidelines

As we discussed in Section 2.1, guidelines are developed for a variety of conditions and applications. Representation formats that are suitable for one type or application of guidelines may often be less optimal for other applications. For example, representations of patient state are not needed in simple alert and reminder applications, such as those that use Arden Syntax MLMs. However, representations for state are important for implementing care plans that are more complex and of longer duration [32], thereby limiting the use of Arden Syntax in these types of applications. As another example, consider a clinical-trial protocol that could be modeled as a graph, the nodes of which represent visits for screening, treatment, and follow-up. Each node could contain information on time-schedule, patient-care actions, and administrative actions for that visit [33]. The model would also contain concepts for representing adverse events and their management. If such a model were to contain application-specific constructs, it would find less reusability, or it would impose more demands for details by guideline authors when used in representing many other types of guidelines.

An approach based on using different formats for different types of guidelines has several limitations that affect sharability: software tools and components (such as authoring tools and decision-support engines) that are created for applications of one type of guideline cannot be reused in other contexts. Furthermore, knowledge engineers would need to gain expertise in multiple representation schemes.

To overcome this problem, several representation schemes are being developed that aim to allow modeling of many different types of guidelines [34-36]. Generally, these representations provide components that are low-level or primitive abstractions of concepts required for describing decisions, recommended actions, and clinical states of patients. However, authoring of guidelines using such primitives can be more cumbersome and time-consuming than if the guideline were encoded in an application-specific model such as the representation for clinical-trial protocols mentioned earlier [37]. Furthermore, encoding guidelines using low-level primitives produces flowcharts that may be visually complex. Approaches to managing such complexity that have been proposed include (1) specializing a general model to compose guideline models that match requirements of different classes of guidelines [38] and (2) building high-level constructs specific to each type of guideline that can be mapped to a procedural pattern of the knowledge representation primitives [39].

4.2 Local adaptation of guidelines

Due to variations in health care settings, guidelines developed by national organizations, medical specialty organizations, or under other broad aegis, often need to be modified before practitioners find them suitable for local use [12, 14, 40]. Reasons for local adaptation include variations among settings due to the type of institution (e.g., hospital vs. office), location (e.g., urban vs. rural), differential availability of equipment and medications, dissimilarity of patient population (e.g., as reflected in prevalence of the disease), and local policies and workflow patterns. Contextually adapted guidelines may enhance acceptance of evidence-based guidelines by making the guidelines more consistent with local practice and population variations. Moreover, the process of local adaptation may lead to a feeling of ownership by local practitioners, an important factor in acceptance of guidelines [2, 41-43].

A representation format for sharable guidelines must provide the ability to adapt knowledge contained in guidelines, and track and document modifications to the guideline. Such a methodology would maintain the integrity of the setting-independent guidelines during adaptation, i.e., preserve the intentional objectives. Studies such as [44-46] provide examples of the types of modifications made to guidelines during local implementation. The Decision Systems Group at Brigham and Women's Hospital has also undertaken a study to examine modifications made to guidelines during computer-based implementations [47].

Several approaches have been explored for making CIGs adaptable. One approach is to represent guidelines in a nested manner where plans are defined in greater detail at successive levels of nesting. At the most abstract level, the plans represent the "big picture" or the intentions of the steps of the guideline. Through successive levels of nesting, the high-level plans are refined to atomic plans, which serve as recommendations (Figure 2). Thus, modification of details of guideline recommendations can be made at deeper levels of the specification while preserving the intentions of the recommendations (Figure 3). This approach of specification of the guideline by successive refinement is exemplified by Asbru [48]. Fridsma et al have developed an approach that explicitly models the capabilities and limitations of an organization that wishes to adapt a "generic" guideline. A program known as CAMINO assists users to adapt generic guidelines for local use [49]. The CAMINO program provides a series of operators (e.g., addition, deletion, refinement, and substitution) that are applied to a guideline step to adapt it. The program maintains the links between the corresponding steps of the generic guideline and the locally adapted guideline. Miller et al have described a third approach based on parameterization for successfully maintaining multiple versions of a childhood immunization guideline [50]. This approach disassociates decision rules from parameters of the rules (e.g., the

parameter *age* at which the DPT vaccine is due). Parameterization of decision rules provides a simple method for adapting guidelines but has limitations when more complex modification of knowledge is required. A combination of the above methods may provide a more comprehensive solution for adapting guidelines to local contexts.

4.3 Integration with institutional systems

In order for guidelines to be more acceptable for clinical use, they should be integrated into the workflow. The goal is to trigger CIGs in appropriate patient-specific contexts, to respond to and utilize already known patient data values, to utilize the multiple sources of information available (patient, physician, nurse, others), and to optimize the conduct of various actions (e.g., pre-visit testing, preparations, and information provision), the organization of subsequent actions, and the dispatch of relevant information to those responsible for the actions [51]. To achieve this, guidelines must be integrated with clinical information systems, such as electronic medical record systems (EMRs), physician order-entry systems (POEs), and communication systems (e-mail, paging) for notifying and alerting care providers. That is, patient data items (such as demographics, results of laboratory tests, and problems) that are referred to in guidelines must be mapped to entries in the EMR and recommendations of guidelines (such as for medication and laboratory tests) must be mapped to actions in the POE system, notifications, or other procedures.

In order to enhance sharability of guidelines, the effort required in integrating them with institutional clinical information systems needs to be minimized. However, the inadequacy of existing standards in EMRs and POE systems, in interfaces to these systems, and in adopting medical vocabularies [52], makes it challenging to map to individual systems the patient data and recommendations in a portable, sharable guideline.

One approach to reducing the integration effort is to separate the system-dependent data references from the medical knowledge (Figure 4a). This approach is exemplified in the MLMs of Arden Syntax. In Arden Syntax MLMs, institution-specific mappings to patient data are separated into what is known as the data section. Within this section, the mapping of each data reference to an entry in the local EMR system is enclosed in a pair of curly braces. Significant effort is required for the mapping of data items and testing of these mappings at each institution. Furthermore, because this mapping must be performed manually at every institution, the approach is error-prone due to the possibility of misinterpretation of data items needed [53]. The problems are further compounded when mappings must be performed for guidelines which typically contain references to many more data items and recommendations than are contained in individual MLMs.

In contrast, the PRODIGY and EON systems [54] use an approach that defines a shared schema of the EMR (Figure 4b). This shared schema is referred to as the *virtual EMR*. Mappings are created from the virtual EMR to actual EMR systems. Queries for patient data in the guideline are written against the virtual EMR schema. At execution time, the references to patient data in the virtual EMR are resolved to entries in the physical EMR. This approach allows sharing to occur at a higher level since mappings between the virtual EMR and the guideline are performed once for each system and can then be used for all guidelines in a system. The PRODIGY system has implemented several primary-care guidelines using this approach in at least two different clinical information systems. In contrast, the approach used by the Arden Syntax-based MLMs requires mappings to be performed for each MLM.

Standards are evolving that would support portable mapping of patient data references in guidelines and MLMs to the electronic medical record. Efforts at HL7 are focusing on creation

of a reference information model (RIM) for patient data [55, 56]. The RIM is intended to be used as the underlying data model for all HL7 standards. It attempts to build a shared information model for the EMR and decision-support systems [57]. The RIM contains classes for medical data (e.g., Observation, Medication), attributes of these classes, and relationships among the classes. It may be possible to use the RIM as the basis for developing a standard interface to EMR systems [58], similar to the virtual EMR interface described above.

While the RIM provides the data structures for patient data, there also need to be complementary standards for the terminologies that form the content of these structures [59]. However, currently, most clinical information systems do not share vocabularies even for the same applications. In implementing guidelines containing terms from standard vocabularies, a mapping will need to be created to terms in the locally used vocabularies [60, 61].

4.4 Use of an explicit medical concept model

Clinical guidelines often describe patient conditions and possible interventions in abstract terms. A hypertension guideline may state that *ACE inhibitors are indicated* when a patient has the additional diagnosis of *diabetes mellitus*. The term ACE inhibitor is an abstraction that represents a class of specific drugs such as Captopril. The term diabetes mellitus is also an abstraction for a set of diagnoses in the ICD-9 vocabulary. These abstractions and their relationships (Captopril *is-a* ACE inhibitor) should be made explicit through a *medical concept model*. A medical concept model provides a framework for describing entities or concepts in the medical domain and the relationships among these concepts. This model consists of definitions of concepts and related facts such as indications and contraindications of drugs, causes and symptoms of diseases, and mechanisms of tests and procedures. The concept model provides a means for

expressing the abstractions contained in guideline criteria, in terms of the patient data available in the EMR [62]. Such abstractions, for example, can consist of the following:

1. Classifications (e.g., whether a patient has ischemic heart disease, which must be derived from entries in a problem list)
2. Temporal inferencing (e.g., if patient has a chronic cough, to be concluded from episodic encounter data)
3. Deriving categorical values from numerical data (e.g., if patient has *abnormally elevated* serum cholesterol, to be derived from a numeric result obtained from a laboratory test)

The concept model allows expression of such abstractions without necessarily specifying how these expressions must be resolved. The guideline-execution engine, for instance, may evaluate criteria by calling external knowledge bases and by using classification axes in standard vocabulary systems. Limitations have been found, however, in coding systems such as the National Drug Codes (NDC) for use in decision-support applications [63]. NDC codes have redundancies, are not permanent, are reused over time, and importantly map to brands and packages of drugs and not to classes of drugs.

4.5 Multiple modes of use

Computer-interpretable guidelines can potentially be used in different modes. Guidelines can be used interactively for patient-specific decision support and workflow support. Quality assurance applications would use guidelines as benchmarks of quality care, perhaps in a batch-processing mode [21]. Guidelines may be used to drive simulations in educational applications and this may be dependent on the level of expertise of the user. Users may read or browse guidelines as educational and reference resources. The representation format must enable various uses of a

guideline by structuring the knowledge in a way that will support its retrieval for all those likely modes of use [64]. For any of these, the interaction format and interface may differ depending on the application.

Only a few guideline systems have tried to use the same encoding scheme for different purposes. The Careflow approach developed at the University of Pavia [26] is one example of such a system. In this approach, a high-level guideline encoding supports simulation of guideline-based patient management for educational purpose. The high-level guideline encoding is combined with an organizational model and translated into a Petri net for the purpose of simulating implementation of a guideline in the organization. Finally, a workflow management system implements the guideline in actual clinics to remind clinicians of tasks and decisions that should be performed.

More typically, guideline models are explicitly designed for a specific set of uses. In GLIF3, we have proposed the use of a multi-layer representation for guidelines [34]. The top layer structures the guideline as a “human-readable” flowchart. The steps of the guideline, and the associated objects such as recommendations and decision criteria have names and descriptions in narrative text. Additionally, supplemental material objects can be added to each step. The supplemental materials can be used for a variety of purposes including providing rationale for recommendations, and details of tasks such as linking to drug reference sources. Deeper layers of representation of guidelines in GLIF3 are intended to support machine interpretation, execution, local adaptation and host system mapping.

The EON system conceptualizes the decision-support functionality provided by a clinical guideline as a set of abstract tasks -- goal setting, decision making, action sequencing, data abstraction, and action refinement -- and organizes the guideline model in terms of different

methods for performing these tasks. The segmentation of the guideline knowledge into this set of abstract tasks may allow reuse of the knowledge in different situations where these specific tasks are relevant. Thus, specification of goals for a section of the guideline allows one to use the guideline for automatically measuring compliance.

4.6 Revision management of guidelines

Guidelines are occasionally revised by organizations that developed them in response to new biomedical knowledge and experience obtained from using the guidelines. For example, a guideline for treatment of HIV infections was recently revised [65] to recommend "... patients with fewer than 350 CD4⁺ T cells/mm³ should be offered therapy..." whereas previous versions of the guideline [66] had recommended "... treatment should be offered to individuals with fewer than 500 CD4⁺ T cells/mm³...." When revised guidelines are disseminated, they must be reintegrated into the local clinical settings. The revisions must be synchronized with the changes previously made to the guideline for local adaptation and integration. In order to facilitate synchronization of revised guidelines with local adaptations of earlier versions of the guideline, the changes in the revised guideline should be identified in detail. The revision markup must identify the type of modification made in the revised components of the guideline (such as whether a recommendation was modified, deleted or added), and the reason why the change was made. In addition, other components that are affected or *jeopardized* by the changes must also be identified [67]. Current guideline representations do not provide sufficiently fine-grained representation for completely identifying the revisions in a guideline. The Guideline Elements Model (GEM) [68] developed at Yale University is designed to provide standards for characterizing the nature of a guideline, rather than formally encoding its logic. Among the standards it proposes are elements for identifying whether a guideline has been revised and

adapted. GEM could be enhanced by adding components that identify the specific elements that have been revised, state the reason for the change, and explain the revision.

4.7 Summary of requirements

In the previous sections, we presented requirements for a format for sharable guidelines. We illustrated these requirements with examples from clinical guidelines and their applications and reviewed some of the approaches that have been implemented to meet these requirements. A direction for future work in this area would be to integrate these solutions into a common representation format that would enable easier sharing of guidelines.

5. A model for dissemination and integration of sharable guidelines

A model for dissemination and integration of sharable clinical guidelines should explicitly describe processes for local adaptation after downloading a guideline (Section 4.2), for integrating with institutional information systems (Section 4.3) including EMR system, POE system, notification system, for mapping abstractions used in guidelines to methods that resolve those abstractions (Section 4.4), for integrating guidelines into various applications (Section 4.5), or for re-integrating a revision of a guideline into the local system (Section 4.6). We propose an augmented dissemination model to accommodate these requirements. In the augmented model (Figure 5), the guideline is downloaded, its content is adapted to local practice preferences, and then it is integrated with an institutional clinical information system. When revisions of the guideline are published, the revised guideline is downloaded, unmodified sections of the revised guideline are automatically synchronized with the previous local version of the guideline, and the modified sections are then manually adapted and integrated.

6. Discussion

The goal of enhancing quality of health care is a primary motivation for development of clinical guidelines. Yet there is no evidence that the large investment in guideline development has achieved this goal to date. The reasons for limited success may be considered along the following dimensions:

- (1) guideline-related factors, such as vagueness of recommendations, conflicting recommendations from different guidelines, and sometimes even internal inconsistency within a single guideline;
- (2) provider-related factors, such as lack of acceptance of guidelines; and
- (3) environmental factors, such as poor integration of guidelines into the clinical workflow, reimbursement issues, or non-availability of resources to carry out recommendations [3].

Many problems with guideline adherence can be addressed by computer-based implementation of guidelines. A number of systems for delivering guidelines and guideline-based advice to clinicians have been developed [24, 26, 34-36, 48, 68-73]. A huge corpus of guidelines has been developed as well, but only a few of these have been encoded in computer-based format other than for simple dissemination as CD-ROM or Web documents. As a result, most have not had a significant impact on practice at the point of care and are, rather, simply consulted occasionally as references.

The effort required to create medically valid, evidence-based, robust guidelines is enormous, as attested to by the experience of various study groups and professional organizations that have undertaken the task. Considerable further effort is required to encode guidelines in computer-based form using any of the existing guideline-authoring environments. Still additional effort is

required to maintain the guidelines over time as medical knowledge evolves, to adapt the guidelines to local constraints, preferences, and idiosyncrasies, and to integrate guidelines into actual applications that practitioners will find useful and desirable. The best way to maintain, adapt, and integrate CIGs remains to be found, and will perhaps require experimentation both by academic researchers and by healthcare information systems providers.

Little experience exists to determine which modes of guideline use have the largest potential benefit in terms of enhancing quality of patient care, lowering costs, and improving adoption of best practices. The adoption of approaches described here will facilitate the development and testing of more applications so that CIGs can be evaluated for effectiveness. This will in turn identify the particular functional requirements of those applications that are successful, helping us to ascertain those capabilities that need to be supported by a sharable representation, or where support needs to be improved. Thus we expect that a sharable representation will evolve over time to incorporate or enhance support of those features that are identified as most important.

Our focus on functional requirements of a representation format for sharable guidelines is aimed primarily at enabling applications to be developed and explored. Our goal, in turn, is ultimately to be able to deliver on the promise of guidelines by integrating them into practice in ways that can be demonstrated to enhance quality. While computer-based representations are required, sharability is also essential if the best guidelines are to be able to be used soon in multiple experimental and test-bed systems, and eventually routinely throughout the healthcare environment. A common format for representation and sharing of guidelines must have the ability to operate in diverse settings for a variety of applications.

Our own work on development of the GLIF has been motivated by the desire to create a sharable format for guidelines that can be used as a basis for adaptation and integration into disparate

systems. The project has been a collaboration of informatics groups at Harvard, Columbia, and Stanford universities, known as InterMed, with the American College of Physicians-American Society of Internal Medicine, and funded by the National Library of Medicine, the US Army, and the Agency for Healthcare Quality and Research. Version 2 of GLIF(GLIF2) was published in 1998 [74] and provided a specification for a level of exchange that supported browsing and limited interpretation, but did not address computability. Version 3 of GLIF, currently in draft form [34], enables computability by providing more detailed and structured representation of decision criteria, recommendations, and patient data contained in CIGs.

In developing GLIF, we realized that because of the differing application goals of various models, it was not feasible to develop a single true interchange format that captured all of the features of the various models. In March 2000, the InterMed Collaboratory hosted a Workshop “Toward a Sharable Guideline Representation”, sponsored by the National Library of Medicine, the United States Army, the Agency for Healthcare Research and Quality, and the Centers for Disease Control and Prevention, aimed at identifying functional requirements as a basis for determining the optimal knowledge representation. A primary outcome of this meeting was a recognition of the need for a life cycle process based on identification of successful approaches to CIG implementation, incorporation of features to support those approaches, facilitation of further experiments, and iteration of the process as additional successful approaches are identified. In follow up of the workshop, the InterMed group approached the HL7 organization about hosting a guideline standardization effort. In response, HL7 created a Decision Support Technical Committee (DSTC). The Arden Syntax standardization in HL7 was moved into an Arden Syntax Special Interest Group (SIG) under the DSTC, and a Clinical Guidelines SIG was

also established. The HL7 TC now has broad participation by several guideline modeling groups, as well as a number of vendors.

Requirements for sharable guidelines raise several challenges in trying to develop a representation format. We have reviewed solutions that have been investigated for many of these problems and identified those that should be considered in the development of a standard representation format for sharable guidelines. We believe that a standard representation will result in rapid progress in the computer-based representation of clinical guidelines, development of applications that integrate them into practice, and demonstration of improved quality of care in such settings.

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References

1. Kohn LT, Corrigan JM, Donaldson MS. To err is human: building a safer health system. Institute of Medicine. National Academy Press, Washington, D.C.; 1999.
2. Grol R. Development of guidelines for general practice care. *Br J Gen Pract.* 1993;43:146-51.
3. Cabana MD, Rand CS, Powe NR, et al. Why don't physicians follow clinical practice guidelines? A framework for improvement. *JAMA.* 1999;282:1458-65.
4. Lobach DF, Hammond WE. Computerized decision support based on a clinical practice guideline improves compliance with care standards. *Am J Med.* 1997;102:89-98.
5. Zielstorff RD, Teich JM, Paterno MD, et al. P-CAPE: a high-level tool for entering and processing clinical practice guidelines. Partners Computerized Algorithm and Editor. *Proc AMIA Symp.* 1998:478-82.
6. Peleg M, Boxwala AA, Tu S, Greenes RA, Shortliffe EH, Patel VL. Handling expressiveness and comprehensibility requirements in GLIF3. *Medinfo.* 2001:In press.
7. Greenes RA, Peleg M, Boxwala AA, Tu S, Patel V, Shortliffe EH. Sharable computer-based clinical practice guidelines: rationale, obstacles, approaches, and prospects. *Medinfo.* 2001:In press.
8. Woolf SH. Practice guidelines, a new reality in medicine. II. Methods of developing guidelines. *Arch Intern Med.* 1992;152:946-52.
9. Lin EH, Katon WJ, Simon GE, et al. Achieving guidelines for the treatment of depression in primary care: is physician education enough? *Med Care.* 1997;35:831-42.

10. Goldberg HI, Wagner EH, Fihn SD, et al. A randomized controlled trial of CQI teams and academic detailing: can they alter compliance with guidelines? *Jt Comm J Qual Improv.* 1998;24:130-42.
11. Brown JB, Shye D, McFarland BH, Nichols GA, Mullooly JP, Johnson RE. Controlled trials of CQI and academic detailing to implement a clinical practice guideline for depression. *Jt Comm J Qual Improv.* 2000;26:39-54.
12. Weingarten S, Stone E, Hayward R, et al. The adoption of preventive care practice guidelines by primary care physicians: do actions match intentions? *J Gen Intern Med.* 1995;10:138-44.
13. Wolff M, Bower DJ, Marbella AM, Casanova JE. US family physicians' experiences with practice guidelines. *Fam Med.* 1998;30:117-21.
14. Hayward RS, Guyatt GH, Moore KA, McKibbon KA, Carter AO. Canadian physicians' attitudes about and preferences regarding clinical practice guidelines. *CMAJ.* 1997;156:1715-23.
15. Taylor DM, Auble TE, Calhoun WJ, Mosesso VN, Jr. Current outpatient management of asthma shows poor compliance with International Consensus Guidelines. *Chest.* 1999;116:1638-45.
16. Davis DA, Thomson MA, Oxman AD, Haynes RB. Changing physician performance. A systematic review of the effect of continuing medical education strategies. *JAMA.* 1995;274:700-5.
17. Johnston ME, Langton KB, Haynes RB, Mathieu A. Effects of computer-based clinical decision support systems on clinician performance and patient outcome. A critical appraisal of research. *Ann Intern Med.* 1994;120:135-42.
18. Bernstam E, Ash N, Peleg M, et al. Guideline classification to assist modeling, authoring, implementation and retrieval. *Proc AMIA Symp.* 2000:66-70.

19. James PA, Cowan TM, Graham RP, Majeroni BA, Fox CH, Jaen CR. Using a clinical practice guideline to measure physician practice: translating a guideline for the management of heart failure. *J Am Board Fam Pract.* 1997;10:206-12.
20. Bell D, Layton AJ, Gabbay J. Use of a guideline based questionnaire to audit hospital care of acute asthma. *BMJ.* 1991;302:1440-3.
21. Advani A, Lo K, Shahar Y. Intention-based critiquing of guideline-oriented medical care. *Proc AMIA Symp.* 1998:483-7.
22. American College of Radiology ACR Appropriateness Criteria 2000. *Radiology.* 2000;215 Suppl:1-1511.
23. Johnson PD, Tu S, Booth N, Sugden B, Purves IN. Using scenarios in chronic disease management guidelines for primary care. *Proc AMIA Symp.* 2000:389-93.
24. Goldstein MK, Hoffman BB, Coleman RW, et al. Implementing clinical practice guidelines while taking account of changing evidence: ATHENA DSS, an easily modifiable decision-support system for managing hypertension in primary care. *Proc AMIA Symp.* 2000:300-4.
25. Greenes RA, Tu S, Boxwala AA, Peleg M, Shortliffe EH. Toward a shared representation of clinical trial protocols: Application of the GLIF guideline modeling framework. In: Silva JS BM, Chute C, Langlotz C, Hiland JC SW, Douglas JV, eds. *Cancer Informatics: Creating a Knowledge Management Infrastructure for Cancer.* New York, NY: Springer-Verlag; In press.
26. Quaglini S, Stefanelli M, Lanzola G, Caporusso V, Panzarasa S. Flexible guideline-based patient careflow systems. *Artif Intell Med.* 2001;22:65-80.

27. Patil RS, Fikes RE, Patel-Schneider PF, et al. The DARPA Knowledge Sharing Effort: Progress report. Principles of Knowledge Representation and Reasoning: Proceedings of the Third International Conference, Cambridge, MA. 1992.
28. E 1460 Standard Specification for Defining And Sharing Modular Health Knowledge Bases (Arden Syntax for Medical Logic Modules). ASTM Standards v 14.01. American Society for Testing and Materials, Philadelphia; 1992.
29. Pryor TA, Hripcsak G. Sharing MLM's: an experiment between Columbia-Presbyterian and LDS Hospital. Proc Annu Symp Comput Appl Med Care. 1993;10:399-403.
30. Arkad K, Gao XM, Ahlfeldt H. Query-handling in MLM-based decision support systems. Med Inform (Lond). 1995;20:229-40.
31. Starren JB, Hripcsak G, Jordan D, Allen B, Weissman C, Clayton PD. Encoding a post-operative coronary artery bypass surgery care plan in the Arden Syntax. Comput Biol Med. 1994;24:411-7.
32. Sherman EH, Hripcsak G, Starren J, Jenders RA, Clayton P. Using intermediate states to improve the ability of the Arden Syntax to implement care plans and reuse knowledge. Proc Annu Symp Comput Appl Med Care. 1995:238-42.
33. Silva J, Wittes R. Role of clinical trials informatics in the NCI's cancer informatics infrastructure. Proc AMIA Symp. 1999:950-4.
34. Peleg M, Boxwala AA, Ogunyemi O, et al. GLIF3: The evolution of a guideline representation format. Proc AMIA Annu Fall Symp. 2000:645-9.
35. Fox J, Johns N, Lyons C, Rahmzadeh A, Thomson R, Wilson P. PROforma: a general technology for clinical decision support systems. Comput Methods Programs Biomed. 1997;54:59-67.

36. Musen MA, Tu SW, Das AK, Shahar Y. EON: a component-based approach to automation of protocol-directed therapy. *J Am Med Inform Assoc.* 1996;3:367-88.
37. Patel VL, Arocha JF, Diermeier M, Greenes RA, Shortliffe EH. Methods of cognitive analysis to support the design and evaluation of biomedical systems: the case of clinical practice guidelines. *Journal of Biomedical Informatics.* 2001;34:52-66.
38. Tu SW, Musen MA. A flexible approach to guideline modeling. *Proc AMIA Symp.* 1999:420-4.
39. Boxwala AA, Mehta P, Peleg M, et al. Representing guidelines using domain-level knowledge components. *Proc AMIA Annu Fall Symp.* 2000:Abstr.
40. Woolf SH. Practice guidelines: a new reality in medicine. III. Impact on patient care. *Arch Intern Med.* 1993;153:2646-55.
41. Bero LA, Grilli R, Grimshaw JM, Harvey E, Oxman AD, Thomson MA. Closing the gap between research and practice: an overview of systematic reviews of interventions to promote the implementation of research findings. The Cochrane Effective Practice and Organization of Care Review Group. *BMJ.* 1998;317:465-8.
42. Langley C, Faulkner A, Watkins C, Gray S, Harvey I. Use of guidelines in primary care--practitioners' perspectives. *Fam Pract.* 1998;15:105-11.
43. Williams JG. Guidelines for clinical guidelines should distinguish between national and local production [letter]. *BMJ.* 1999;318:942.
44. Picken HA, Greenfield S, Teres D, Hirway PS, Landis JN. Effect of local standards on the implementation of national guidelines for asthma: primary care agreement with national asthma guidelines. *J Gen Intern Med.* 1998;13:659-63.

45. Shye D, Porath A, Brown JB. Adapting a national guideline for local use: a comparative case study in a US and an Israeli health maintenance organization. *J Health Serv Res Policy*. 2000;5:148-55.
46. Brown JB, Shye D, McFarland B. The paradox of guideline implementation: how AHCPR's depression guideline was adapted at Kaiser Permanente Northwest Region. *Jt Comm J Qual Improv*. 1995;21:5-21.
47. Boxwala AA, Clemenson SG, Salomon WL, Greenes RA. Implementing a hypertension guideline in a health care information system: insights, challenges and implications. *Proc AMIA Annu Fall Symp*. 2001:In press.
48. Shahar Y, Miksch S, Johnson P. An intention-based language for representing clinical guidelines. *Proc AMIA Annu Fall Symp*. 1996:592-6.
49. Fridsma DB, Gennari JH, Musen MA. Making generic guidelines site-specific. *Proc AMIA Annu Fall Symp*. 1996:597-601.
50. Miller PL, Frawley SJ, Sayward FG. Issues in accommodating national changes and local variation in a computer-based guideline for childhood immunization and in related knowledge maintenance tools. *Proc AMIA Annu Fall Symp*. 1998:563-7.
51. Headrick LA, Speroff T, Pelecanos HI, Cebul RD. Efforts to improve compliance with the National Cholesterol Education Program guidelines. Results of a randomized controlled trial. *Arch Intern Med*. 1992;152:2490-6.
52. Cimino JJ. Review paper: coding systems in health care. *Methods Inf Med*. 1996;35:273-84.
53. Patel VL, Allen VG, Arocha JF, Shortliffe EH. Representing clinical guidelines in GLIF: individual and collaborative expertise. *J Am Med Inform Assoc*. 1998;5:467-83.

54. Johnson PD, Tu SW, Musen MA, Purves I. A Virtual Medical Record for Guideline-Based Decision Support. Proc AMIA Annu Fall Symp. 2001:In press.
55. Beeler GW, Jr. On the RIM: the making of HL7's Reference Information Model. MD Comput. 1999;16:27-9.
56. Russler DC, Schadow G, Mead C, Snyder T, Quade LM, McDonald CJ. Influences of the Unified Service Action Model on the HL7 Reference Information Model. Proc AMIA Symp. 1999:930-4.
57. Schadow G, Russler DC, Mead CN, McDonald CJ. Integrating medical information and knowledge in the HL7 RIM. Proc AMIA Symp. 2000:764-8.
58. Jenders RA, Sujansky W, Broverman CA, Chadwick M. Towards improved knowledge sharing: assessment of the HL7 Reference Information Model to support medical logic module queries. Proc AMIA Annu Fall Symp. 1997:308-12.
59. Bakken S, Campbell KE, Cimino JJ, Huff SM, Hammond WE. Toward vocabulary domain specifications for health level 7-coded data elements. J Am Med Inform Assoc. 2000;7:333-42.
60. Bodenreider O, Nelson SJ, Hole WT, Chang HF. Beyond synonymy: exploiting the UMLS semantics in mapping vocabularies. Proc AMIA Symp. 1998:815-9.
61. Zollo KA, Huff SM. Automated mapping of observation codes using extensional definitions. J Am Med Inform Assoc. 2000;7:586-92.
62. Rector AL, Johnson PD, Tu S, Wroe C, Rogers J. Interface of Inference Models with Concept and Medical Record Models. Eight European Conference on Artificial Intelligence in Medicine. 2001.

63. Chute CG. Drugs, codes, standards, and other incompatible things in the dark. *MD Comput.* 2001;18:45-6.
64. Patel VL, Arocha JF, Diermeier M, How J, Mottur-Pilson C. Cognitive psychological studies of representation and use of clinical practice guidelines. *International Journal of Medical Informatics.* 2001:In press.
65. Panel on Clinical Practices for Treatment of HIV Infection. Guidelines for the use of antiretroviral agents in HIV-infected adults and adolescents. Department of Health and Human Services, Rockville, MD; 2001.
http://www.hivatis.org/guidelines/adult/Apr23_01/pdf/AAAPR23S.PDF.
66. Panel on Clinical Practices for Treatment of HIV Infection. Guidelines for the use of antiretroviral agents in HIV-infected adults and adolescents. Department of Health and Human Services, Rockville, MD; 2000. <http://www.hivatis.org/guidelines/adult/pdf/AAJan2000.pdf>.
67. Bench-Capon TJM, Coenen FP, Paton R, Nwana H, Shave MJR. Two Aspects of the validation and verification of knowledge based systems. *IEEE Expert.* 1993;8:76-81.
68. Shiffman RN, Karras BT, Agrawal A, Chen R, Marenco L, Nath S. GEM: A proposal for a more comprehensive guideline document model using XML. *J Am Med Inform Assoc.* 2000;7:488-98.
69. Boxwala AA, Greenes RA, Deibel SRA. Architecture for a multipurpose guideline execution engine. *J of the American Med Informatics Assoc.* 1999;6:701-5.
70. Gordon C, Veloso M. Guidelines in healthcare: the experience of the Prestige project. *Stud Health Technol Inform.* 1999;68:733-8.
71. Lobach DF, Gadd CS, Hales JW. Structuring clinical practice guidelines in a relational database model for decision support on the Internet. *Proc AMIA Annu Fall Symp.* 1997:158-62.

72. Paterno MD, Zielstorff RD, Teich JM, Segal M, Fox R. Protocols, pathways, and practice guidelines: Defining multiple step clinical algorithms for automated navigation. Proc AMIA Annu Fall Symp. 1998:1052.
73. Tierney WM, Overhage JM, Takesue BY, et al. Computerizing guidelines to improve care and patient outcomes: the example of heart failure. J Am Med Inform Assoc. 1995;2:316-22.
74. Ohno-Machado L, Gennari JH, Murphy SN, et al. The Guideline Interchange Format: a model for representing guidelines. J Am Med Inform Assoc. 1998;5:357-72.

Legends

Figure 1. Typical model for development and dissemination of narrative-text guidelines.

Figure 2. A cholesterol management guideline specified in a hierarchical format. This guideline consists of the broadly outlined steps: Assess risk for coronary artery disease, Cholesterol management, and Intensive cholesterol management. Each of these steps is specified in more detail through the nodes contained in it.

Figure 3. A hypothetical local adaptation of the dietary therapy step of the cholesterol guideline of Figure 2 is shown. In the adapted guideline, the subguidelines Step I Diet and Step II Diet have been further refined.

Figure 4. Mapping of patient data referenced in guidelines to the EMR. (a) illustrates the mapping scheme used by Arden Syntax MLMs where patient data references in each MLM is mapped to the institutional EMR. (b) shows an alternative approach where patient data references in guidelines are mapped to an institution-independent virtual EMR. At the institutional level, the virtual EMR can be implemented as “middleware” that maps request for patient data to queries into the institutional EMR.

Figure 5. A model for dissemination of computer-interpretable guidelines that accounts for local modifications made to a guideline and synchronization of these changes with revised versions of the guideline.

Figures

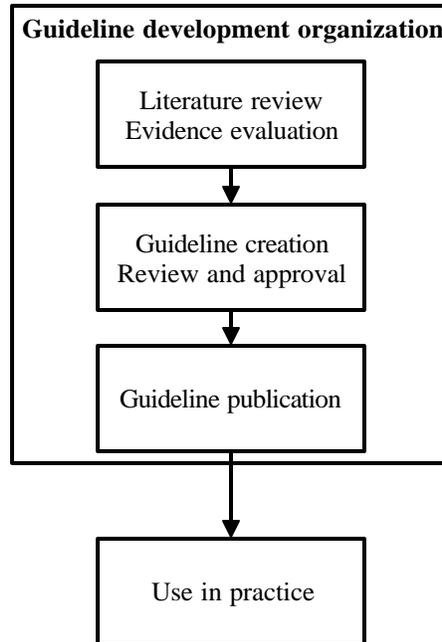


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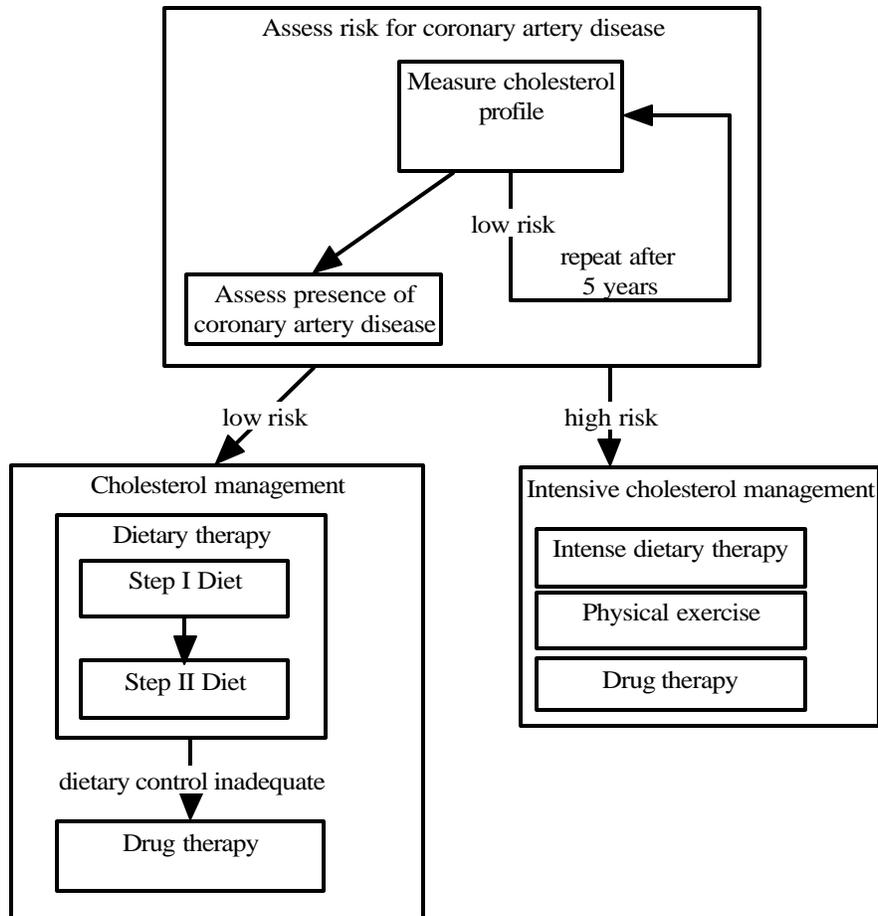


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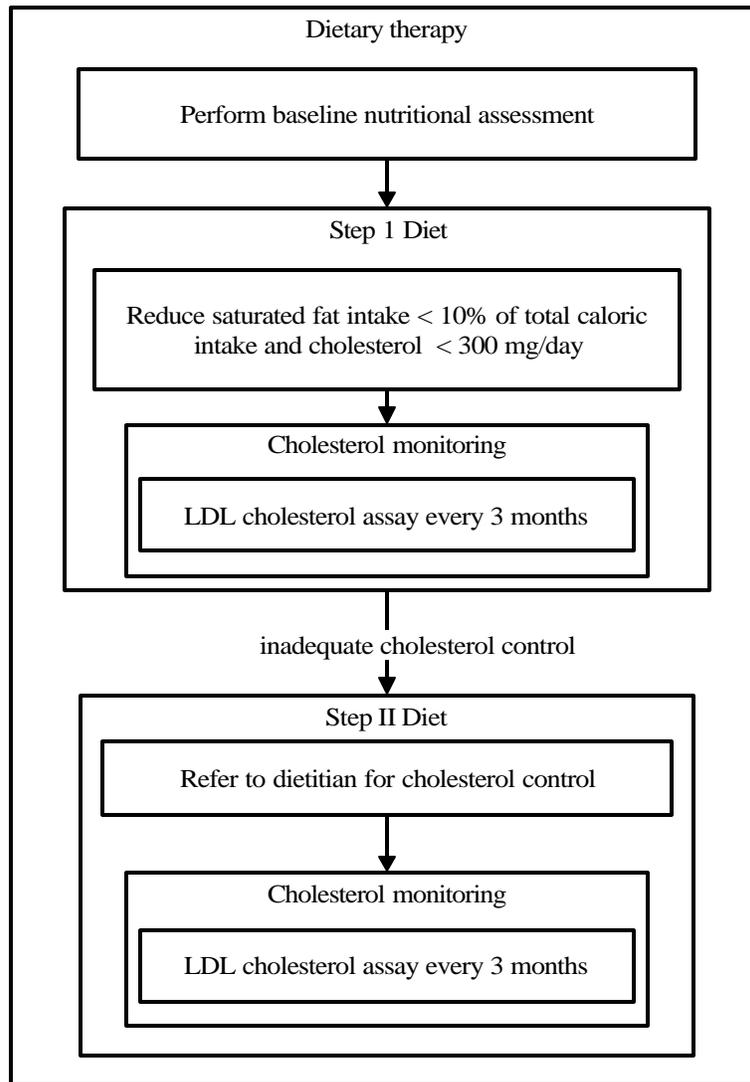


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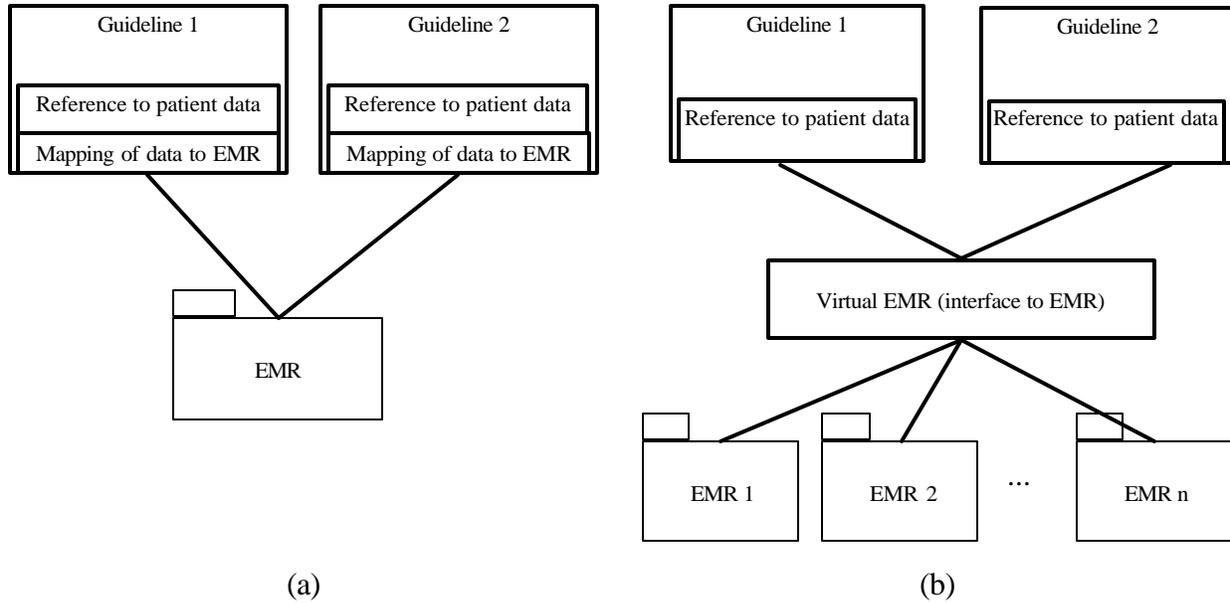


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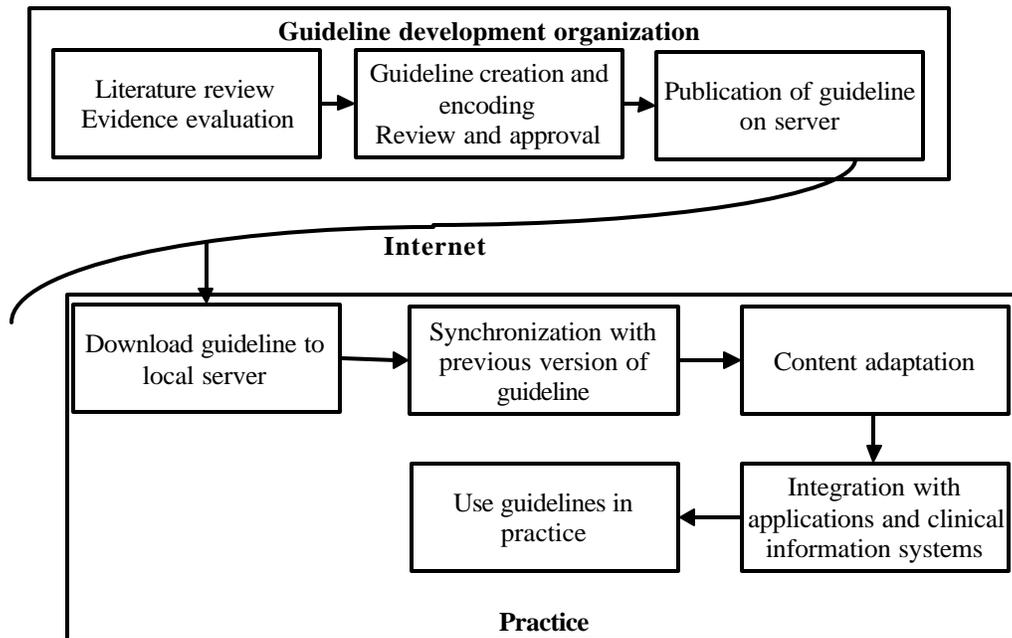


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