Medication Concepts, Records, and Lists in Electronic Medical Record Systems

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ABSTRACT

A well-designed implementation of medication concepts, records, and lists in an electronic medical record (EMR) system allows it to successfully perform many functions vital for the provision of quality health care. A controlled medication terminology provides the foundation for decision support services, such as duplication checking, allergy checking, and drug-drug interaction alerts. Clever modeling of medication records makes it easy to provide a history of any medication the patient is on and to generate the patient's medication list for any arbitrary point in time. Medication lists that distinguish between description and prescription and that are exportable in a standard format can play an essential role in medication reconciliation and contribute to the reduction of medication errors.

At present, there is no general agreement on how to best implement medication concepts, records, and lists. The underlying implementation in an EMR often reflects the needs, culture, and history of both the developers and the local users. A survey of a sample of medication terminologies (COSTAR Directory, the MDD, NDDF Plus, and RxNorm) and EMR implementations of medication records (OnCall, LMR, and the Benedum EMR) reveals the advantages and disadvantages of each. There is no medication system that would fit perfectly in every single context, but some features should strongly be considered in the development of any new system.

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MEDICATION CONCEPTS

Medications are an integral part of medical care, and an electronic medical record (EMR) system should be able to present usable medication choices and useful decision support for order entry, record and surface medication lists consistently and accurately, and transfer intelligible medication lists to and from other repositories of patient information.

The atoms of a medication system in an EMR are medication concepts. Medication concepts can be represented in EMRs at various levels of standardization and granularity, with various advantages and disadvantages.

At the very least, medications can be represented as "free-text" (strings of characters without any constraints). This representation is the most flexible, but has many disadvantages. Each medication concept could be represented in multiple ways, so that medication lists cannot be recorded in a consistent fashion. Comparing two medication lists or checking a medication against a list of allergies would not be straightforward if the same concept can be represented in more than one way.

A better way to represent medication concepts is as part of an encoded terminology. Each concept is associated with a single code, so that all references to that concept refer to the same code. Having a controlled medication terminology allows the recording of medication lists in a more consistent fashion and facilitates the development of decision support services, such as the comparison of medication lists and the checking of allergies.

Controlled Medication Terminologies

In a controlled medication terminology, the codes associated with medication concepts could either have intrinsic meaning (also called "smart codes") or no meaning at all (also called "dumb codes"). While there are some advantages to using codes that have intrinsic meaning, there are also major disadvantages, as will become apparent in the discussion of a few controlled medication terminologies below.

A second choice that has to be made in creating a controlled medication terminology is what exactly constitutes a medication concept. Is it an active ingredient? Is it a combination of an active ingredient and a route of administration? Is it a particular form that an active ingredient takes? Different controlled terminologies define medication concepts differently.

COSTAR Directory

The COmputer STored Ambulatory Record (COSTAR) is an EMR initially developed as a collaborative effort between the Massachusetts General Hospital (MGH) Laboratory of Computer Science and the Harvard Community Health Plan (HCHP). As early as 1969, it provided full operational support for HCHP administrative and medical information processing. COSTAR's controlled medication terminology is a subset of its overall controlled terminology, called COSTAR Directory.[1]

In information science, ontology is the hierarchical structuring of knowledge about things by subcategorizing them according to their essential (or at least relevant and/or cognitive) qualities.[2] The COSTAR Directory is ontological in this sense. The COSTAR medication terminology belongs to the "Medical" branch of the full COSTAR Directory hierarchy.

When COSTAR was designed in the 1960s, computer memory was relatively limited, and it made good sense to be as efficient as possible in the encoding of medication concepts. All COSTAR codes consist of a five-character base code (4 alphabetical characters and 1 check digit) and one or two optional single-characters modifiers. The first letter indicates the body system (Table 1).

Medications are first organized by body system, and then categorized in accordance with the hospital formulary. Antibiotics, for instance, all have codes that begin with the letter D (body system = "Systemic Infections") and are grouped according to the hospital formulary at the time the terminology was developed (Table 2).

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[1] COmputer STored Ambulatory Record User's Manual, p. 1.5 - 1. Massachusetts General Hospital, 1978.
[2] http://dictionary.reference.com/search?q=ontology. Accessed April 24, 2006.

Table 1. COSTAR Body Systems[3]

First Letter	Body System
B	LISTCODES (arrays of other codes)
C	Systemic
D	Systemic Infections
E	Endocrine
F	Hematologic
G	Skin
H	Eye
J	Ear, Nose, and Throat
K	Mouth and Teeth
L	Respiratory
M	Cardiac
N	Vascular
P	Breast
Q	Gastrointestinal
R	Female Reproductive
S	Male Reproductive
T	Renal
V	Musculo-skeletal
W	Nervous
Y	Psychiatric

Table 2. COSTAR Antibiotics[4]

Code Prefix	Hospital Formulary #	Class
DS	8:12	antibiotics
DSB	8:12.12	erythromycins
DSC-DSD	8:12.28	aminoglycosides (other)
DSE-DSF	8:12.24	tetracyclines
DSG-DSJ	8:12.16	penicillins
DSN-DSP	8:24	sulfonamides
DST-DSZ	8:12.28	other antimicrobials
DTA-DTE	8:16	antituberculars
DTF-DTG	8:36	urinary germicides
DTJ-DTM	8:40	other antibiotics
DVA-DVE	8:20	antimalarials
DVH	84:04.12	scabicides and pediculocides
DVN-DVW	8:12:04 84:04:08	antifungals
GTA-GTG	84:04:16	local anti-infectives

The guidelines are not strict, but trade names and other synonyms are generally assigned a single-digit numeric modifier, and forms are generally

[3] COmputer STored Ambulatory Record User's Manual, p. 3.3 - 3. Massachusetts General Hospital, 1978.
[4] COmputer STored Ambulatory Record User's Manual, p. 3.3 - 6. Massachusetts General Hospital, 1978.

assigned a single-letter modifier (Table 3). Modifiers may also be combined pair-wise, to indicate a form of a trade name, for example.

Table 3. Examples of COSTAR Base Codes and Modifiers

COSTAR Code	Medication Concept
DSTW3	ciprofloxacin
DSTW3-1	Ciprox
DSTW3-2	Cipro
DSTW3-3	Cipro XR
DSYS3	ciprofloxacin ophthalmic
DSYS3-O	ciprofloxacin ophthalmic ointment
DSYS3-W	ciprofloxacin ophthalmic drops
DSYS3-1	Ciloxan
DSYS3-1O	Ciloxan ointment
DSYS3-1W	Ciloxan drops

COSTAR does not allow more than one concept from the same base code cluster from being active in the same patient record. This feature prevents duplication of medications. This restriction also informs the decision of when new base codes need to be created.

In general, every active ingredient and route combination should have its own base code. A patient should not be on two oral or two ophthalmic forms of ciprofloxacin, but could theoretically be on one oral and one ophthalmic form. Having one base code cluster for oral ciprofloxacin and one base code cluster for ophthalmic ciprofloxacin has the desired effect.

Certain types of problems occur commonly in ontological classification schemes,[5] and some of these are apparent in this view into COSTAR's classification of antibiotics.

First, parts of the classification scheme have become less than ideal over time. For example, new types of antibiotics now in common use, such as fluoroquinolones and antiretrovirals, do not have categories of their own.

Second, the categorization is optimized for the efficient usage of valid COSTAR base codes rather than for the most rational classification. The number of COSTAR base codes is limited because each code must consist of 4 letters and 1 check digit. The initial assignment circa 1969 of COSTAR code prefixes for the classification of antibiotics optimized the distribution of codes for the antibiotics known at the time, and did not try to predict how the formulary of antibiotics would expand over time.

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[5] Clay Shirky. "Ontology is Overrated." http://www.shirky.com/writings/ontology_overrated.html. Accessed April 24, 2006.

Since then, the number of new antibiotics has overwhelmed the available codes under the "other antimicrobials" category, and they had to be redirected to the previously unused prefix "X." For example, there are currently 14 antiretrovirals that have base codes that begin with "X," and they share that prefix with other overflow concepts that may not even be antibiotics.

Third, an ontological classification system presumes a single correct place to place an entity. However, this is not the case when an entity can belong to more than one category. A combination medication such as enalapril/hydrochlorothiazide is both an antihypertensive agent (prefix "MT") and a diuretic (prefix "TT"), but it can only be placed in a single category, as each medication can have only a single code.

Besides the problems inherent in ontological classification schemes in general, COSTAR's coding system has a few other problems. Because of the ontological nature of COSTAR Directory, much information about the encoded concept should be readily apparent from the code itself. The prefix should indicate the drug class, and the modifier(s) should indicate whether the medication concept is a trade name and what particular form the medication concept takes. However, this does not always work as designed.

As already mentioned, the prefix is not always reliable because different overpopulated drug classes can overflow into the same previously unused prefixes. Similarly, when an active ingredient, such as guaifenesin, has more than 9 trade names, the convention of using only single digits as modifiers for trade names has to be broken.

However, despite these flaws, COSTAR Directory is completely serviceable in real clinical systems and has survived and thrived over the decades. The COSTAR controlled terminology has had an uninterrupted existence at Massachusetts General Hospital (MGH) and continues to serve the EMRs used by several outpatient care groups at MGH. Medication decision support, such as links to drug references, suggested dosages, insurance formularies, and Drug Enforcement Agency (DEA) schedules, are all linked to COSTAR codes.

The COSTAR medication terminology consists of approximately 1958 base code clusters and 6,898 medication concepts.[6]

It is worth mentioning that COSTAR is a customizable EMR that has been widely distributed since its inception. The COSTAR terminology discussed above is the state of the terminology in the MGH implementation of COSTAR. Over time, the terminologies in distinct implementations of COSTAR have diverged, and the same COSTAR code in different COSTAR implementations cannot be expected to (and most likely will not) refer to the same concept.

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[6] As of May 9, 2006.

Partners Master Drug Dictionary

Partners HealthCare was founded in 1994 by Brigham and Women's Hospital (BWH) and the MGH. It is an integrated healthcare system that includes primary care and specialty physicians, community hospitals, the two founding academic medical centers, specialty facilities, community health centers, and other health-related entities. Partners Information Systems (IS) develops and maintains clinical applications such as Provider Order Entry (POE) and the Longitudinal Medical Record (LMR), and these applications rely on a locally developed medication terminology called the Master Drug Dictionary (MDD).

In the MDD, there are three types of numeric codes associated with medication concepts (Table 4). The Rollup-ID represents a routed active ingredient. It is called a Rollup-ID because it is the active ingredient and a route "rolled up" into one concept. The Med-ID represents a medication name and ignores route. The Generic-ID is 0 for a concept that is a generic, and the Med-ID of the corresponding generic for a concept that is a synonym or trade name of a generic.

Table 4. Examples of MDD Codes

Rollup-ID	Med-ID	Generic-ID	Medication Concept	Route Group
4	4	0	ACETAMINOPHEN	oral
4	1497	4	TYLENOL	oral
5	11673	0	ACETAMINOPHEN SUPP	rectal
5	11820	11673	TYLENOL SUPP	rectal
159	137	0	CIPROFLOXACIN	injection
160	137	0	CIPROFLOXACIN	oral
1263	137	0	CIPROFLOXACIN	ophthalmic

Technically, the Rollup-ID is a combination of an active ingredient and a route group. The "oral" route group, for example includes all of the following routes: mouth (PO), nasogastric tube (NGT), gastric tube (GT), and jejunostomy tube (JT). However, for simplicity, we will speak of Rollup-ID as a routed active ingredient.

In the MDD, the basic medication concept is the routed medication. The Rollup-ID/Med-ID pair uniquely determines the routed medication, and the Generic-ID can be looked up once the Rollup-ID and Med-ID are known.

In Partners applications, most decision support is based on the Rollup-ID, because it was decided that the routed active ingredient is the most useful level at which to consider medications. Even available dosages, which may differ for different trade names of the same routed active ingredient, is presented to the user based on the Rollup-ID (and therefore are sometimes inaccurate for particular trade names).

Rollup-ID/Med-ID pairs differ markedly from COSTAR codes in that these pairs contain no intrinsic information. Whereas drug class, generic status, and form can sometimes be inferred from a COSTAR code, nothing can be inferred from a Rollup-ID/Med-ID pair. This is actually an advantage for the MDD. Information can be attached or detached from a Rollup-ID/Med-ID pair in separate database tables without affecting the pair itself. On the other hand, once a COSTAR code is created, it is not possible to change its implied drug class, generic status, or form.

There are approximately 6,089 Rollup-ID/Med-ID pairs.[7]

Granularity of Medication Concepts

When coded cleanly, COSTAR base codes are routed active ingredients, and COSTAR modified codes can be routed trade names, forms of routed active ingredients, or forms of routed trade names. Therefore, even when coded cleanly, COSTAR codes can exist on two levels – medication/route and medication/route/form. Further complicating the terminology are codes that contain strength, resulting in some COSTAR codes that represent concepts consisting of medication/route/strength and medication/route/form/strength.

The MDD also contains concepts that exist on a mixture of levels. The most basic concepts are a combination of medication and route, but there are also medication/route/form, medication/route/strength, and medication/route/form/strength combinations.

It turns out that it is non-trivial to define what a medication concept is. Different purposes require different granularities of medication concepts (Table 5).

Because COSTAR Directory and the MDD serve multiple purposes, they encode medication concepts at several levels, rather than a single one. In the case of describing therapy, sometimes one would actually prefer recording the drug class rather than the medication itself. For example, COSTAR Directory has a code for "birth control pills," so that a provider can record that the patient is on them without needing to specify which particular ones the patient is taking. If the pills were prescribed by a different provider, and the patient herself does not know which ones she is taking, recording the

[7] As surfaced in the Partners IS Medication Mapping Interchange Data Layer (MMIDL) Toolkit, alpha release, circa March 2006. MMIDL alpha actually access the quality assurance (QA) copy of the MDD, which can be up to a few months out-of-date when compared with the copy in production.

medication as "birth control pills" would be preferable to guessing the identity of the medication or not recording anything at all.

Table 5. Pertinent Levels of Medication Granularity for Various Purposes

Clinical Purpose	Most Pertinent Level of Granularity
description of therapy	drug class
allergy checking	ingredient (and drug class to a lesser extent)
DEA schedule	active ingredient
drug classification	active ingredient
duplication checking	active ingredient and route
formulation suggestion	medication name and route
hospital formulary	medication name and route
insurance formulary	medication name and route
dosage suggestion	medication name, route, and form
inpatient order entry	medication name, route, and strength
pediatric medications	medication name, route, form, and strength
prescriptions	medication name, route, form, and strength
pharmacy inventory	medication name, form, strength, and packaging

First DataBank National Drug Data File Plus

First DataBank (FDB) is a commercial provider of electronic drug information to the healthcare industry. FDB's drug knowledge base is called the National Drug Data File (NDDF) Plus, and medication concepts are encoded as Multiple Access Points (MAPs).

Because different purposes require medication concepts on different levels, NDDF Plus comprehensively encodes concepts on four levels: medication name, medication name/route, medication name/route/form, and medication name/route/form/strength. Whereas COSTAR Directory and the MDD contain concepts at different levels in a haphazard fashion, each level in NDDF Plus contains every possible concept belonging to that level.

These four levels form a strict hierarchy, with the name at the root and the name/route/form/strength combinations at the leaves. A medication concept is specified uniquely by a MAP-Level and a MAP-ID (Table 6). Like numeric codes in the MDD, the MAP-ID is a number that has no intrinsic meaning.

Table 6. Examples of Medication Concepts in NDDF Plus

MAP-Level	MAP-ID	Medication Concept
Name	361	Acetaminophen
Name/Route	362	Acetaminophen Oral
Name/Route/Form	5774	Acetaminophen Tab [oral implied]
Name/Route/Form/Strength	160401	Acetaminophen 325mg Tab

NDDF Plus contains on the order of 104,476 active concepts, divided among the four levels (Table 7). Even considering only the name/route level, where COSTAR and MDD concepts mostly reside, NDDF Plus is significantly larger, with a total of 22,379 concepts at that level, compared with the 6,847 medication concepts of COSTAR Directory and 6,089 of the MDD.

Table 7. Number of Active NDDF Plus Concepts at Each Level[8]

Map-Level	Number of Concepts
Name	21,391
Name/Route	22,379
Name/Route/Form	25,989
Name/Route/Form/Strength	34,717

The NDDF Plus system has separate database tables that link related concepts on different levels to each other, trade names to generics, medication concepts to packaging information, and medication concepts to drug classes. NDDF Plus also has a controlled terminology for routes, forms, and strengths.

Having made the massive investment of effort to systematically encode medication concepts comprehensively at four different levels of granularity and relating them to each other, NDDF Plus can provide medication concepts at the appropriate level for many different kinds of decision support.

It is not completely clear that NDDF Plus created the right ontology. Having a strict hierarchy that branches from name to name/route to name/route/form to name/route/form/strength help limit that number of concepts that have to be encoded, but there may be times when concepts may be needed that do not fit cleanly into this hierarchy. One could argue that form and strength are more a part of a medication's essence than route.

Take the example of a 325mg tablet of acetaminophen that is intended to be administered orally. It would be easier to imagine it being administered by a different route than to imagine it as something other than a 325mg tablet. Therefore, from this perspective, acetaminophen 325mg tablet is more correct a concept than oral acetaminophen. Acetaminophen 325mg tablet is what the thing is. Oral administration is what is done with it.

[8] Personal communication from Jaime Medina, Partners IS developer working with NDDF Plus, circa March 2006. These counts may include non-medication concepts in NDDF Plus, so they may be an overestimate of the number of medication concepts.

RxNorm

RxNorm is a controlled terminology of clinical drugs developed by the National Library of Medicine, with a clinical drug defined as "a pharmaceutical product given to (or taken by) a patient with a therapeutic or diagnostic intent."[9] RxNorm is both a source and subset of the Unified Medical Language System (UMLS) Metathesaurus.

RxNorm medication concepts are also UMLS concepts, and they exist on four overlapping levels:

1. Ingredient (ingredient)
2. Clinical Drug Component (ingredient + strength)
3. Clinical Drug (ingredient + strength + dose form)
4. Clinical Drug Form (ingredient + dose form)

There are also equivalents for branded drug concepts (Table 8), and all of these concepts are connected through well-defined relationships (Figure 1). Each RxNorm Concept is encoded as a numeric RXCUI, with "CUI" being short for "concept unique identifier."

Table 8. Examples of Related RxNorm Concepts[10]

Type	Example	RXCUI
Ingredient	Acetaminophen	161
Clinical Drug Component	Acetaminophen 325 MG	315263
Clinical Drug	Acetaminophen 325 MG Oral Tablet	313782
Clinical Drug Form	Acetaminophen Oral Tablet	369097
Dose Form	Oral Tablet	317541
Brand Name	Tylenol	202433
Branded Drug Component	Acetaminophen 325 MG [Tylenol]	569998
Branded Drug	Acetaminophen 325 MG Oral Tablet [Tylenol]	209387
Branded Drug Form	Acetaminophen Oral Tablet [Tylenol]	369070

RxNorm links related concepts on different levels to each other, trade names with generics, and concepts to National Drug Codes (NDCs) for specific drug products.

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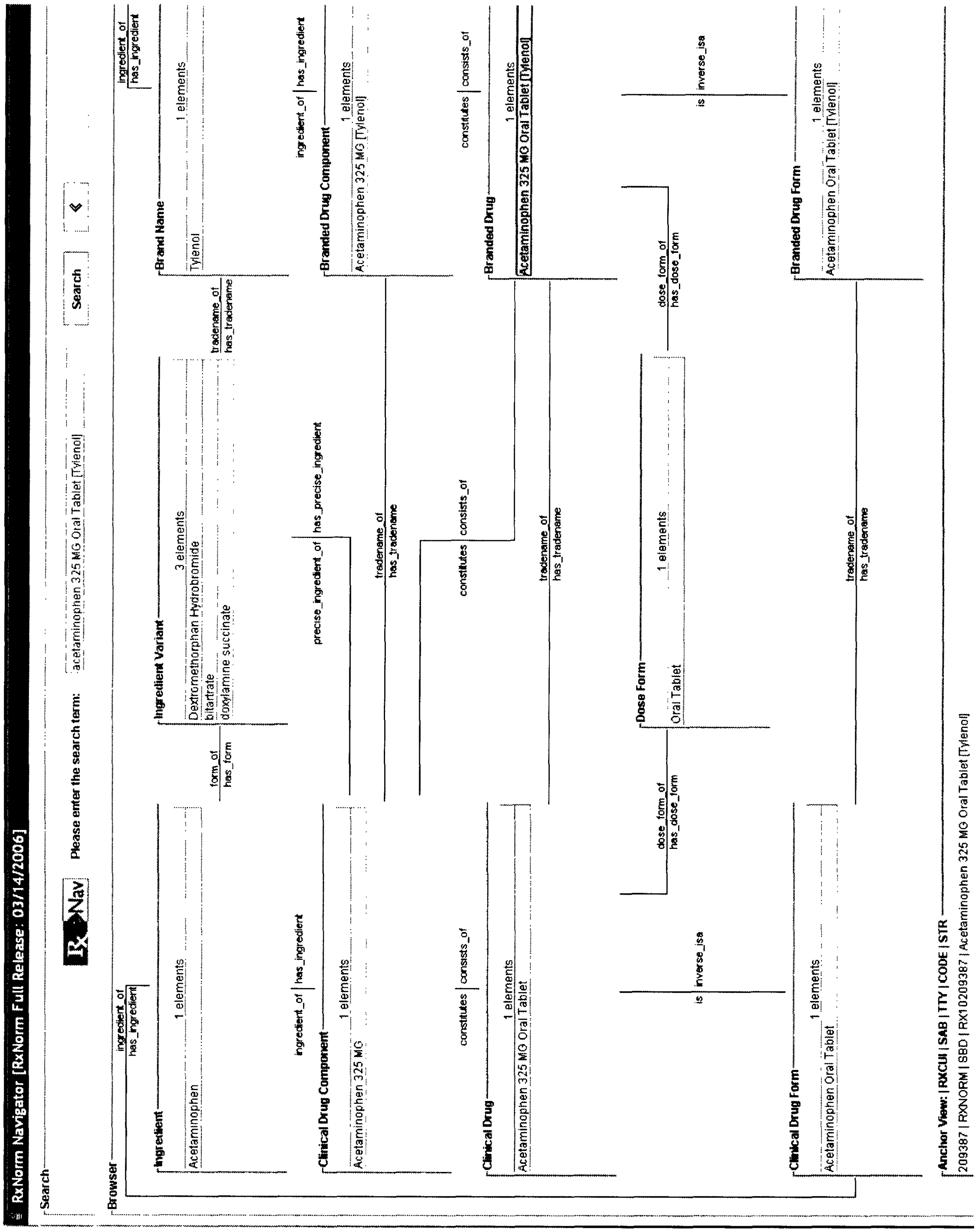
9 RxNorm Overview. http://www.nlm.nih.gov/research/umls/rxnorm/overview.html. Last accessed April 26, 2006.

10 RxNorm Navigator from RxNorm Full Release: 03/14/2006. Searched for "Acetaminophen 325 MG" on April 26, 2006.

Figure 1. Screenshot of RxNav Showing Relationships Between Types of RxNorm Terms[11]



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[11] RxNav (http://mor.nlm.nih.gov/download/rxnav/) search for "Acetaminophen 325 MG Oral Tablet [Tylenol]." Accessed May 8, 2006.

RxNorm also links its names to many other drug terminologies, such as those of FDB, Micromedex, MediSpan, and Multum. By providing links between these terminologies, RxNorm can mediate messages between systems not using the same software and terminology. However, since RxNorm concepts do not necessarily exist on the same levels of granularity as concepts in other terminologies, there may not be exact RxNorm equivalents for some concepts in other terminologies, and the translation cannot be expected to be perfect.

Dose form consists of route and form, and route and form do not exist independently in RxNorm. For example, "Acetaminophen Oral Tablet" is a concept in RxNorm, but "Acetaminophen Oral" and "Acetaminophen Tablet" are not. Therefore, the concept of "Acetaminophen Oral" in NDDF Plus does not have an exact equivalent in RxNorm.

Selecting or Creating a Controlled Medication Terminology

There are many commercial controlled medication terminologies on the market, some with extensive associated knowledge bases. Choosing to use NDDF Plus, for example, would allow access to FDB's clinical decision support modules, designed to prevent adverse drug reactions, reduce drug-related expenses, and otherwise improve the quality of patient care. However, NDDF Plus's ontology is incongruous to that of RxNorm, which may become the national standard.

RxNorm has the advantage of being free and having links to many other medication terminologies. However, it is currently incomplete. The stated scope of RxNorm is as follows:

> RxNorm is intended to cover all prescription medications approved for use in the United States. Prescription medications from other countries may be included as opportunities allow, a principal consideration being that there be an authoritative source of information about these drugs. OTC [over-the-counter] medications will be added and covered, as well, when reliable information about the medications can be found and when they appear to be represented in other UMLS source terminologies. Medications, whether prescription or OTC, with more than three ingredients are not fully represented at the present time. In some cases (e.g., multivitamins) it may not be possible to include all of them in a reasonable time frame. [12]

Creating a local controlled medication terminology is possible, as evidenced by the existence of COSTAR Directory and the MDD. When creating a new terminology, one has the opportunity of designing the underlying ontology to fit the needs of the EMR that uses the terminology.

[12] RxNorm Overview. http://www.nlm.nih.gov/research/umls/rxnorm/overview.html. Accessed April 26, 2006.

In some hospitals, one can order "Magic mouthwash" or "Miracle mouthwash" for painful oral mucositis. However, these are not manufactured medications, but are compounded locally, and not necessarily using the same compounds in different places. In COSTAR Directory and the MDD, Miracle mouthwash consists of diphenhydramine, lidocaine, and Kaopectate (bismuth). Miracle mouthwash used in other places may use Maalox (aluminum hydroxide, magnesium hydroxide, and simethicone) instead of Kaopectate. Using a customized local terminology gives the flexibility to define medication concepts in a way that corresponds with local practice.

It is also possible to include substances that are not technically medications, but for many purposes act as medications. COSTAR Directory and the MDD, for example, both include "beer" as a medication concept (COSTAR code QSTA7; Rollup-ID 72, Med-ID 61). While this may appear strange, there are advantages to being able to manipulate "beer" as a medication concept, such as checking for interactions with other substances.

COSTAR Directory also includes international medications as medication concepts. For a number of reasons, patients at MGH are sometimes on medications purchased in foreign countries (including Canada), and there may not always be an equivalent medication available in the United States. It therefore is useful to be able to record these medications and link appropriate decision support to these international medications.

The main problems with creating a local terminology is that it takes a lot of resources to maintain and one needs to map it to a recognized standard terminology for the sake of interoperability with other systems.

Ideally, one would like to have the simple, rational ontology and widespread acceptance of RxNorm, the comprehensiveness and extensive knowledge base of NDDF Plus, and the flexibility of COSTAR and MDD.

In any case, it is important to keep in mind the following points about medication terminologies:

1. A controlled terminology is essential for implementing medication decision support.
2. Medication concepts can exist at many different and possibly overlapping levels of granularity (specification).
3. Different levels of granularity are appropriate for different decision support services.
4. Ontology can limit the types of levels allowed, but care should be taken to choose levels that reflect reality or are otherwise useful in decision support.
5. The more levels that are encoded, the more resources it will take to cover all medications comprehensively at each level.
6. While standardization is important for interoperability between systems, there are still situations in which local customization is useful.

MEDICATION RECORDS

Having a controlled medication terminology is not enough. Medications must be recorded in context, which includes all the usual information that is collected on a prescription or inpatient order and any other information that is relevant from the perspective of the EMR.

Examples of Medication Records

OnCall Clinical Web Portals

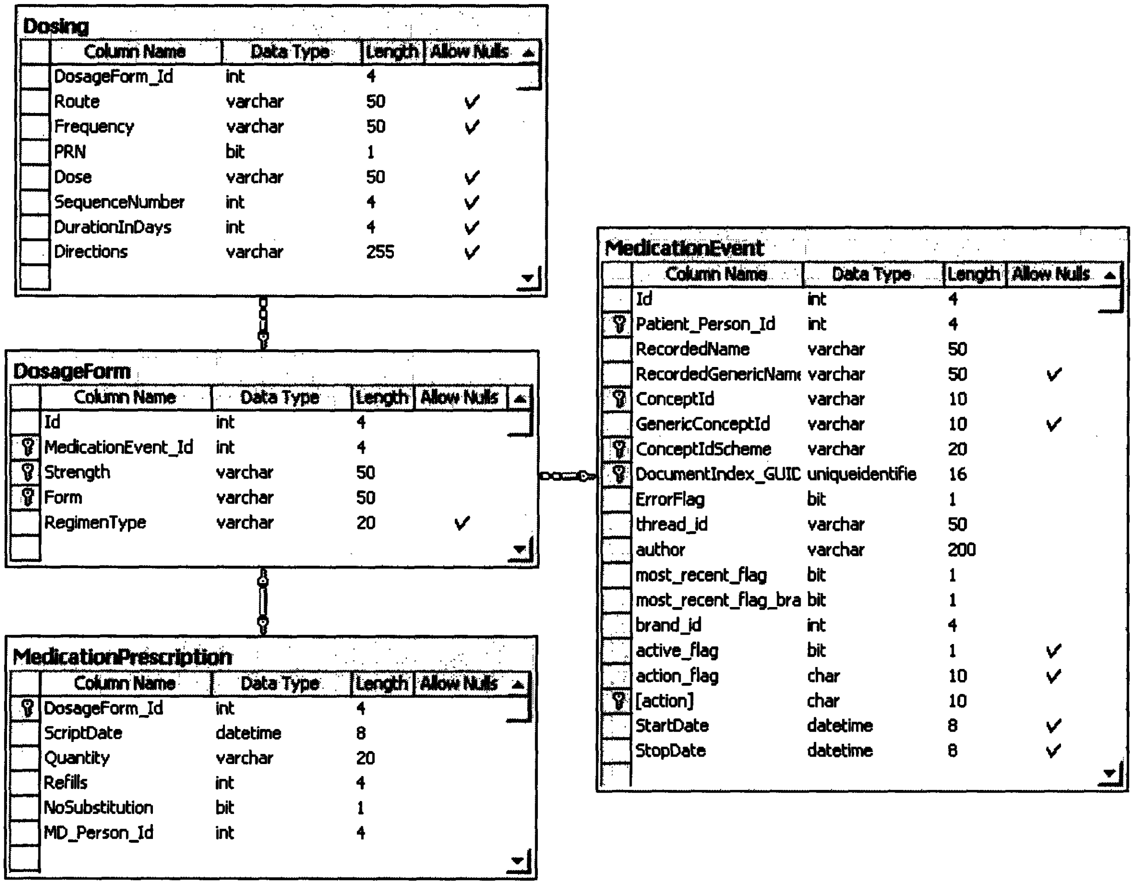
With the emergence of the Web, the MGH Laboratory of Computer Science developed OnCall, a Web-based front-end to COSTAR. The OnCall application architecture is based on Web services and Extensible Markup Language (XML). In OnCall, medication records were originally stored in the form of XML patient notes (a strict hierarchical format). Recently, however, data from OnCall notes were transferred to relational databases (Figure 2).

In OnCall, medication records are saved as "events." Events are uniquely defined by the patient (Patient_Person_ID), the medication concept's code (ConceptId and ConceptIdScheme), the patient note that includes this record (DocumentIndex_GUID), and the type of event ([action]). For now, the ConceptIdScheme is COSTAR and the ConceptID is the medication concept's COSTAR code, but this database leaves open the opportunity to include or migrate to a medication terminology other than COSTAR Directory. Start and stop times are associated with events.

Dosage forms are one level removed, and consist of strength and form. Each event, and thus each medication concept, may be associated with one or more dosage forms. Each dosage form, in turn, may be associated with one or more dosing regimens, which may consist of dose (the actual quantity of the dosage form), route, frequency, PRN (for use as needed) duration, and directions. Among other things, this means that a dosage form may have more than one associated route.

Finally, each dosage form may be associated with one or more prescriptions, which may consist of the quantity of the dosage form, the number of refills for the prescription, the option to substitute the generic for the trade name, and the prescribing healthcare provider. These prescriptions are independent of the dosing regimens.

Figure 2. OnCall Medication Database Diagram[13]



It is interesting to note that this database structure describes ontology different from that of the underlying COSTAR terminology. In COSTAR, the MDD, and NDDF Plus, route is more essential to a medication concept than form. The OnCall database, on the other hand, considers form more essential than route.

The OnCall medication database structure is clearly not bound to using COSTAR, leaving open the option of eventually including or migrating to another terminology. However, neither the MDD nor NDDF Plus is a natural fit for this structure either. RxNorm is a better fit, but in RxNorm, "dose form" is defined as route and form, whereas in OnCall, "dosage form" is defined as strength and form.

Unfortunately, as the example of dose form/dosage form illustrates, similar terms can mean different things in different terminologies.

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[13] Personal communication from Wayne Raila, OnCall developer. The diagram was last updated January 24, 2005.

Longitudinal Medical Record

LMR is the outpatient medical record designed and maintained by Partners IS. The medication terminology it uses is the MDD. The LMR provides a XML data service that surfaces medication records as follows:

```
<Medication-List>
 <Medication>
  <Rec-ID />
  <MPI-ID />
  <Service-Date />
  <Med-Name />
  <Generic-ID />
  <Rollup-ID />
  <Med-ID />
  <Med-Freq />
  <Med-Route />
  <Dose />
  <Units />
  <Take-dose />
  <Take-units />
  <Dispense />
  <Dispense-units />
  <Duration />
  <Duration-units />
  <Refills />
  <PRN />
  <Rx />
  <No-substitutions />
  <Directions />
  <Comments>
  <Start-date />
  <End-date />
 </Medication>
</Medication-List>
```

The LMR medication record XML is fairly straightforward. The structure is flat, and all the basic pieces information, such as route, dose, frequency, duration, PRN, quantity, and refills, are included in one place. Note that the underlying medication terminology (using Rollup-ID and Med-ID) is built into the structure of the medication record, so that it would have to be adjusted to accommodate other medication terminologies.

Benedum Geriatric Center EMR

The Benedum Geriatric Center (BGC) is a multidisciplinary geriatrics clinic at a university medical center serving a patient population of approximately 2,000, and the EMR was developed specifically to address the problem of medication data error. [14] Medication concepts are identified as a numeric formulary.id, and can a combination of name, strength, and form, e.g., "ampicillin, 250-mg tablet." This EMR thus appears to depend on the formulary for its medication terminology.

Table 9. The Benedum Geriatric Center EMR Medication-Record Schema[15]

Medication-record Schema in the Benedum Geriatric Center Electronic Medical Record

Field Name	Type	Description
1 medication_id	Number (Long)	Primary Key
2 pid	Number (Long)	Foreign key for the patient record
3 med_ancestor	Number (Long)	Medication_id of the record from which this record was created due to a dose change or correction
4 created_date	Date/Time	Date record was created
5 created_who	Text	Name of provider who created this record
6 creator_id	Number (Long)	Foreign key to provider table
7 created_reason	Text	Whether the event was a dose change or correction
8 created_encounterID	Number (Long)	Foreign key to the encounter table
9 archived_date	Date/Time	Date record became inactive
10 archived_reason	Text	Reason why record made inactive
11 archived_who	Text	Name of provider who made record inactive
12 archived_encounterID	Number (Long)	Foreign key to encounter table
13 archiver_id	Number (Long)	Foreign key to provider table
14 formulary_id	Number (Long)	Foreign key to formulary
15 sig_value	Text	Number of units of medication
16 sig units	Text	Units (e.g., tablet)
17 sig_route	Text	Route of administration
18 sig_interval	Text	Interval of administration
19 sig_prn	Text	Whether medication is prn
20 sig_comments	Text	Free-text comments
21 who	Text	Name of provider
22 provider_id	Number (Long)	Foreign key to provider table
23 disp_number	Number (Int)	Quantity dispensed
24 disp_units	Text	Units dispensed (e.g., tablets)
25 disp_refills	Number (Int)	Number of refills
26 disp_date	Date/Time	Date of last dispensing
27 disp_encounterID	Number (Long)	Foreign key to encounter table
28 disp_who	Text	Name of provider who last dispensed
29 dispenser_id	Number (Long)	Foreign key to provider table
30 disp_p	Yes/No	Whether the medication requires a prescription
31 verified_date	Date/Time	Date the medication was last checked with the patient
32 verified_who	Text	Name of provider who checked medication
33 verified_encounterID	Number (Long)	Foreign key to encounter table
34 verifier_id	Number (Long)	Foreign key to provider table

The BGC EMR's medication record is similar to the LMR's. However, it is noteworthy for linking a record to its predecessor record (ancestor.id) and for recording the name and numeric ID of the provider making changes to the medication under consideration. This provides an easy way to track the history of the patient's use of the medication. The record also explicitly records when the medication was last verified with the patient and the provider who performed the verification. We will discuss the meaning and importance of confirming medications later.

[14] Wagner WM, Hogan WR. The accuracy of medication data in an outpatient electronic medical record. JAMIA. 1996; 3(3): 234–244.
[15] As published in Wagner et al.

Recommendations for Implementing Medication Records

Just as there is no agreement on what medication concepts should be, there is no agreement on what medication records should be. However, some common elements are included in all three implementations described above (Table 10).

Table 10. Common Elements in Medication Records

Field	Comment
medication record ID	primary key
medication concept	preferably able to accommodate multiple medication terminologies
patient ID	foreign key for the patient
strength	strength of discrete unit or concentration of substance
dose	number or fraction of discrete units or quantity of substance per dose
route	
frequency	
PRN	indicator for whether the medication is only to be used as needed (PRN)
directions	
quantity	
refills	
prescription start time	
prescription stop time	not always mathematically related to quantity and refills

However, many other pieces of information are worth recording (Table 11).

If implemented with all the recommended pieces of information, medication records will exist as bidirectional chains. A new medication will start a new chain. Any change to an existing medication would be a link added to an existing chain. From any record, one could go up or down the chain to the previous or next record of this medication, respectively.

Table 11. Other Desirable Elements in Medication Records

Field	Comment
regimen	large free-text field for complicated regimens, such as variable strength or dose, cyclic frequency, or taper
PRN condition	condition under which a PRN medication should be used
substitution flag	indicator for whether a substitution is allowed
encounter ID	foreign key for the related office visit, telephone call, email, or other patient communication
record type	one of the following: • addition • change • renewal • completion • discontinuation • reactivation • verification
reason/indication	
action/documentation	distinction for indicating whether the record is an action being taken or a documentation of an action taken by someone else
actor ID	person who performed the action
actor name	ID may be unavailable, such as for a provider outside the EMR system or the patient himself
documenter ID	the person who documented the action
documentation time	also known as "service date"
actual start time	
actual end time	
comments	
replaced by	link to medication record of that replaced this record; is NULL if this is the most recent record for this medication
history	link to medication record replaced by this record; is NULL if this is the first record for this medication

To construct a list of a patient's medications (active and inactive) as it was on any particular time of interest, the EMR could use the following logic:

1. Query the database for all medication records associated with the patient ID.
2. Filter out all records that have a non-NULL "replaced by" field. This leaves only the most recent record for each medication record chain.
3. For each chain, do the following to find the relevant record in the chain.
    a. If the documentation time of the record at the end of the chain is the same as or earlier than the time of interest, this is the relevant record in this chain.
    b. If the documentation time of the record at the end of the chain is later than the time of interest, move up the chain to the first record with a documentation time that is the same as or earlier than the time of interest. If no earlier record fits these

requirements, drop this chain. (The medication was first documented at a time later than the time of interest.)

4. Separate out records that have record type of "completion" or "discontinuation." List these as "inactive medications."
5. Separate out remaining records that have "prescription end time" earlier than the time of interest. List these as "potentially inactive medications."
6. Separate out remaining records that have "prescription start time" later than the current time (and a NULL "actual start time"). List these as "medications to be started."
7. List the remaining medications as "active medications."

To get the current list, set the time of interest to the current time.

For both patient care and legal purposes, it is important to make a distinction between someone who is actually changing the status of a medication and someone who is merely documenting a change made by someone else. It is also important to document when medications were last verified with the patient, even when no changes are made.

Finally, the entire history of a patient's use of a particular medication can easily be discovered by successively following the links in the history field of the associated medication records.

MEDICATION LISTS

It is vitally important for patient care to have an accurate list of the patient's medications. As we already described, if the medication records are up to date, it is straightforward to generate a list of the patient's current medications. However, there are still subtleties to medication lists that need to be considered.

As described in the above section, it is possible to construct a medication list for any arbitrary point in time in the past or present. Because we do not use any records with documentation times later than the time of interest, the list we construct is always the same, regardless of when we construct it.

To avoid redundancy, a medication list can be constructed and stored as a list of links to medication records rather than with the actual medication data. The list should be linked to the patient and the specific encounter with the patient and indicate the type of list (Table 12).

Table 12. Proposed Database Fields for Medication Lists

Field	Comment
medication list ID	primary key
patient ID	foreign key for the patient
encounter ID	foreign key for the related office visit, telephone call, email, or other patient communication
list type	descriptive or prescriptive
documentation date	
documenter ID	the person who documented the list
records	foreign keys for the associated medication records

Descriptive versus Prescriptive Medication Lists

A medication list can be descriptive, prescriptive, or a combination of both. A descriptive medication list describes what the patient is taking. A prescriptive medication list describes what the patient should be taking, especially from the point in time at which the list is constructed. Sometimes a list contains some records that are descriptive and some records that are prescriptive.

It is best to separate descriptive lists from prescriptive lists. The two types of lists serve useful, but different, purposes. Discrepancies between a descriptive list and the immediately preceding prescriptive list show changes in medication usage since the prescriptive list was constructed. Such changes could include both provider-initiated changes and patient-initiated changes, including problems with compliance.

Symptoms and disease progression should be interpreted in light of the descriptive medication list to see how well the medications are working, whether they are causing any side effects, and whether there are any interactions among them. For these purposes, it is more important to know what the patient is actually taking than what he is supposed to be taking.

Prescriptive lists can be checked for potential drug-drug interactions and allergic reactions. They can also be given to the patient so that a patient has a current list of all the medications that he should be taking and how he should be taking them.

Lists that are a mixture of descriptive and prescriptive elements are confusing and should not be used unless each element is clearly designated as one or the other.

Reviewing versus Verifying Medications

There are times when a healthcare provider will review a patient's medication list without actually verifying each medication with the patient. The provider may do this when complete accuracy is not crucial to the task at hand, or when it is simply impossible to verify the medications with the patient at that point in time. For example, a provider may review the patient's medication list to get a general idea of the patient's medical problems before providing some minor treatment. If an unconscious patient presents to an emergency ward, a physician may review the patient's medication list in the EMR, but be unable to verify it until the patient regains consciousness.

There is value to reviewing medication lists, and there is value to documenting that a medication list has been reviewed, but review should be differentiated from verification. There is no need to update a medication record when the medication is only reviewed, as there is no basis to make a change to the record.

On the other hand, verification should be documented as a medication record with the verification time as the documentation time. Verification serves the important function of confirming that the medication record is still accurate at a time more recent than previously recorded.

Recommendations for Implementing Medication Lists

Because medication lists can be constructed from the underlying medication records, accurate medication lists can be maintained by maintaining accurate medication records.

When there is sufficient time, it would be good practice to create a descriptive medication list at the beginning of the provider-patient interaction and a prescriptive medication list at the end of the interaction. The provider should begin by asking the EMR for a current medication list. The EMR would construct one from the medication records in the manner already described.

When there is sufficient time in a patient encounter, the provider should verify each medication on the medication list. If any medication is not being taken the way it was prescribed, the provider should document who made the change (such as another provider or the patient himself) and how it is actually being taken. If the patient is taking new medications, the provider should document who is responsible for the new medication, when the medication was started, and how the patient is taking it. At the end of this process, the medication list becomes a descriptive list of what the patient is taking. This list should be saved in the medication list database as a descriptive list associated with this patient and this encounter.

By the end of the provider-patient interaction, the provider will have made any necessary changes to the patient's medications. Perhaps the provider prescribed new medications, changed the dose or schedule of existing medications, and even discontinued a few. At the end of the interaction, the provider should ask the EMR for a current medication list, which would incorporate all the changes the provider made throughout the course of this interaction. This list should then be saved in the medication list database as a prescriptive list associated with this patient and this encounter. This list could also be printed and given to the patient as an up-to-date list of what he should be taking.

Implementing medication records and medication lists as described above makes it easy to retrieve relevant medication lists. When pulling up the note for a particular patient encounter, the EMR can load and display any descriptive and prescriptive medication lists associated with that encounter. If no lists were specifically saved in association with that encounter, the EMR can construct and display, in real time, a medication list for the time of the encounter. This list, however, may be partly descriptive and partly prescriptive.)

EXCHANGING MEDICATION DATA

Accurate medication data is vital to providing good healthcare, but data is often scattered among the EMRs used at the various locations where a patient receives care. During each patient encounter, the provider often needs to expend time and effort on resolving discrepancies between what the patient is actually taking and what is recorded in the local EMR.

It would be ideal if the local EMR could gather medication data directly from other EMRs. While this would not help in the case of patient-initiated medication changes, it would help in the case of changes initiated by other providers. The local EMR would gather the most up-to-date medication lists from the other EMRs and allow the provider to modify the local medication list as needed.

The main problem in sharing medication data is that different EMRs use different medication terminologies and different implementations of medication records and medication lists.

Standards for Exchanging Medication Data

Developing medication standards for the purposes of exchanging medication data is not a trivial task. Health Level Seven (HL7) is a Standards Developing Organization (SDO) accredited by the American National Standards Institute (ANSI) to produce standards in the domain of clinical and administrative data.[16] Its mission is to create flexible, cost-effective approaches, standards, guidelines, methodologies, and related services for interoperability between healthcare information systems.[17]

It is HL7's position that while data can be exchanged between systems, its usefulness is compromised unless there is shared, well-defined, and unambiguous knowledge of the meaning of the data transferred. Medications that are available are finite, countable, and identifiable, and of all concepts that require representation in EMRs, medications should be the most straightforward to implement. However, there are no still no universally accepted standards for naming them.

The Food and Drug Administration's National Drug Code (NDC) is nationally recognized, but it is flawed because the codes can be reused, so that the same code can refer to different medication concepts at different times. NDC codes are also product-oriented and are assigned by the manufacturers

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[16] http://www.hl7.org/. Accessed May 8, 2006.
[17] Cimino JJ, Huff S, Broverman C, McNamara T, Nelson SJ. Development of a Standard Terminology to Support Medication Messages. SCAMC 1998.

rather than centrally. SNOMED, another available standard, has an opposite problem. It does not provide codes to the level of the actual products.

The HL7 Terminology Special Interest Group (SIG) consists of drug knowledge base vendors, users, regulators, and many others. They review the data models of the various vendors in order to develop a unifying model for sending and receiving medication messages. Their approach to terminology development is to collaborate with other SDOs and medication terminology builders, reference existing terminologies, and add only items that do not already exist.

The HL7 Terminology SIG recognizes that medication concepts at many different levels of granularity are useful: clinical drugs, trademark drugs, composite clinical drugs, composite trademark drugs, manufactured components, packaged products, and "not fully specified" drugs. "Birth control pills" for example, would be a not fully specified drug that could still serve a real and important purpose in documentation.

Mapping between Medication Terminologies

One strategy to achieve interoperability is to map medication terminologies to each other. However, there are a number of problems with this.

Terminologies may not agree on what medication concepts should be or what levels of granularity are acceptable. COSTAR Directory and the MDD favor routed medications, but include some concepts with form and/or strength information. NDDF Plus can accommodate name, name/route, name/route/form, and name/route/form/strength combinations. Concepts in RxNorm are on the levels of name, name/strength, name/route/form, and name/strength/route/form.

If one intends to map a concept in one terminology to a concept in another terminology, one may have to cross levels. For example, given the RxNorm concept of "Acetaminophen 325mg," it is unclear what it should be mapped to in NDDF Plus. "Acetaminophen" (level = name, MAP-ID = 361) is too broad, but Acetaminophen 325mg Tab (level = name/route/form/strength, MAP-ID = 160401) is too narrow.

In the best case scenario, mapping is one-to-one, but sometimes there are no equivalent concepts and sometimes there are multiple equivalent concepts. This can occur because of an anomaly in one or both terminologies or simply because the terminologies do not agree on what are allowed as medication concepts.

The exactness of mapping that is required depends on the intended purpose. In checking for allergies and drug-drug interactions, for example, it is sufficient to map concepts in one terminology to concepts in another that have the same ingredients. On the other hand, for formulary purposes, it is important to map trade names exactly.

The question of what is adequate mapping depends on the context, and the context can be any of the following:

- description of therapy
- allergy checking
- DEA schedule
- drug classification
- duplication checking
- formulation suggestion
- hospital formulary
- insurance formulary
- dosage suggestion
- inpatient order entry
- pediatric medications
- prescriptions
- pharmacy inventory

One possible solution is to grade mappings so that it is clear what purposes the mappings can be used for.

One-Way versus Two-Way Mapping

If a concept in one terminology is mapped to a concept in another, the reverse mapping is not necessarily a good one. For example, "Calcitrate" is a trade name of "calcium citrate" and is included in COSTAR Directory, but not in the MDD. One could reasonably map "[COSTAR] Calcitrate" to "[MDD] CALCIUM CITRATE." However, going in reverse, one would not want to presume that the best COSTAR equivalent of "[MDD] calcium citrate" is "[COSTAR] Calcitrate." In fact, the best mapping from MDD to COSTAR in this case is to "[COSTAR] calcium citrate."

```
[COSTAR] calcium citrate         -> [MDD] CALCIUM CITRATE (oral)
[COSTAR] Calcitrate              -> [MDD] CALCIUM CITRATE (oral)

[MDD] CALCIUM CITRATE (oral)     -> [COSTAR] calcium citrate
```

From a graded one-way mapping, it is possible to use some logic to reverse the mapping. However, this is translating to and back from another terminology, and the loss of information in the double translation can be significant.

To get a true two-way mapping between two terminologies, one would have to construct two one-way mappings.

Trying to map all terminologies to each other pair-wise would be a combinatorial nightmare. If each pair of terminologies were to have two mappings between them (one going each way), then *n* terminologies would require a total of n x (n-1) mappings. For example, if we wanted pair-wise mappings among COSTAR Directory, the MDD, NDDF Plus, and RxNorm, we would require 12 mappings. In general, the number of mappings required will be on the order of the square of the number of terminologies.

Mapping COSTAR Directory to the Master Drug Dictionary

A direct one-way mapping was made between COSTAR Directory and the MDD. The intended purposes of the mapping were the following:

- To export OnCall medication lists (based on COSTAR Directory) with the equivalent MDD codes, so that the OnCall lists can be used to update the lists in MDD-based EMRs.
- To leverage the MDD medication knowledge base for use in decision support in OnCall.
- To open up the option of migrating OnCall from using COSTAR Directory to using the MDD.
- To investigate how much a one-way mapping may inform a two-way mapping.

A simple ranking system was used, with a lower-numbered Rank indicating a better mapping (Table 13).[18]

Table 13. Quality of the COSTAR-to-MDD Mapping

Rank	Description	Count	Fraction
1	Good map	3,872	56.1%
2	Missing brand or synonym	707	10.2%
3	Probable map	145	2.1%
4	COSTAR concept is broader than MDD concept	205	3.0%
5	Ambiguous	6	0.0%
6	MDD is missing this concept	450	6.5%
7	COSTAR concept is not a valid medication	1,513	21.9%
Total		6,898	100.0%

In general, a lower-numbered rank indicates a better mapping. A Rank of 6 or 7 actually indicates that no reasonable mapping can be made, with the problem being in the MDD or COSTAR Directory, respectively.

[18] As of May 9, 2006.

The default route in COSTAR is oral if the medication is available orally. Otherwise, the default route is the most common non-oral route. In general, generic medications start with a lowercase letter and trade name medications start with an uppercase letter.

The following are **Rank 1** mappings from COSTAR concepts to MDD concepts:

- G CSF -> FILGRASTIM (G-CSF) injection
- leucovorin -> LEUCOVORIN CALCIUM oral
- Citracal -> CITRACAL (CALCIUM CITRATE) oral

There are two types of **Rank 2** mappings. The first type is a COSTAR concept that is a valid[19] synonym or trade name of a concept in the MDD, but the concept itself is not in the MDD. The second type is a COSTAR concept that is not a valid synonym or trade name, but the active ingredient can be inferred from the base code. Both types of COSTAR concepts are mapped to the MDD concept for the active ingredient.

- Vi dom "A" -> VITAMIN A oral
- Calcitrate -> CALCIUM CITRATE oral
- Folgard -> FOLIC ACID/PYRIDOXINE HCL/CYANOCOBALAMIN oral

Rank 3 mappings are inexact, but any error is probably insignificant.

- Betalin -> BETALIN COMPLEX (THIAMINE HCL) oral
- multivitamins and minerals -> MULTIVITAMINS oral
- Stuart prenatal with folate -> STUART-NATAL (PRENATAL MULTIVITAMINS) oral

When a COSTAR concept is broader than any MDD concept, the COSTAR concept is mapped to multiple MDD concepts, and each mapping is **Rank 4**.

- acetaminophen and codeine -> ACETAMINOPHEN W/CODEINE 15MG oral
- acetaminophen and codeine -> ACETAMINOPHEN W/CODEINE 30MG oral
- acetaminophen and codeine -> ACETAMINOPHEN W/CODEINE 60MG oral
- acetaminophen and codeine -> ACETAMINOPHEN W/CODEINE ORAL LIQUID oral

Note that there is no MDD concept for simply "ACETAMINOPHEN W/CODEINE." Depending on the context, one of the MDD concepts could be the right mapping, but they cannot all be the right mapping at the same time.

Sometimes, there is reason behind a mapping, but the mapping is much less than ideal. These mappings are **Rank 5**.

- perphenazine concentrate -> PERPHENAZINE oral
- phenylephrine solution -> PHENYLEPHRINE HCL nasal

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[19] A COSTAR concept is "valid" if it can be found in widely accepted drug knowledge references, such as Lexi-Comp Online (http://www.crlonline.com/crlonline).

When the COSTAR concept is valid (or is a modifier of a valid base code concept), and there is nothing reasonable to map to in Partners, the COSTAR concept are mapped to NULL and the mapping are **Rank 6**.

- Lenograstim
- niacin injection
- vitamin B2 injection

Finally, there are times when the COSTAR concept is not valid as a medication concept, possibly because of obsolescence, the use of a rare synonym, or irresolvable ambiguity. These concepts are mapped to NULL and the mappings are **Rank 7**.

- 4 way nasal spray
- Birth control pills
- Perihemin

Ranks 1 to 3 denote good one-way mappings. Of the 6,898 COSTAR medication concepts, 4,724 (68.4%) have one-to-one mappings of this quality. Another 3.0% have good one-to-many mappings (Rank 4). This gives a total coverage of 71.4% in the mapping from the medication subset of COSTAR Directory to the MDD.

While this may seem low, it turns out that the COSTAR concepts that do not have good mappings to the MDD are ones that are much less frequently or no longer used. Between March 1, 2005, and March 20, 2006, OnCall users documented, added, reactivated, renewed, or changed 221,077 medication records for their patients. Inactivations (completions or discontinuations) were not counted. These 221,077 prescriptions referred to 2,479 distinct COSTAR concepts (Table 14).[20]

There is reason for optimism. While only 68.4% (Ranks 1 to 3) of COSTAR concepts have a good equivalent in the MDD, these COSTAR concepts cover 95.3% of recent active medication records. If we include the one-to-many Rank 4 mappings, which would require some human user interaction or sophisticated logic to choose the right mapping depending on the context, then the COSTAR-to-MDD mappings cover 98.2% of recent active medication records.

Of the 1.8% not covered by good mappings, 1,761 (68.0%) do not refer to COSTAR concepts. In these medication records, users did not select an existing COSTAR concept, but put in free text in the medication concept field. The majority of the rest consist of nutritional supplements, vague drug classes (instead of identified medications), or herbal medications.

[20] Personal communication from Mary Morgan, OnCall developer.

Table 14. Active OnCall Medication Records from March 1, 2005, to March 20, 2006

Map Rank	Records	% Records	Concepts	% Concepts
NULL[21]	4	0.0%	3	0.1%
1	208,252	94.2%	2,012	81.2%
2	983	0.4%	112	4.5%
3	1,595	0.7%	68	2.7%
4	6,394	2.9%	124	5.0%
5	0	0.0%	0	0.0%
6	1,258	0.6%	64	2.6%
7	2,591	1.2%	96	3.9%
Total	221,077	100.0%	2,479	100.0%

Without further testing, one cannot be sure that 98.2% coverage is sufficient for decision support purposes. However, it is likely that this mapping is adequate to leverage MDD-based decision support in a COSTAR-based EMR.

Reversing a One-Way Mapping

Creating the one-way mapping from the medication subset of COSTAR Directory to the MDD was a labor-intensive process. It required access to the entirety of COSTAR and the ability to search MDD concepts by name.

A one-way mapping allows the exportation of COSTAR-based data to an MDD-based EMR and the possibility of using MDD-based medication knowledge in a COSTAR-based EMR. However, to maximize interoperability, it is necessary to have a two-way mapping between the medication terminologies.

Reversing the one-way mapping from COSTAR to the MDD would leverage the work that has already been done. It will not be adequate for a full two-way mapping, but it would be a start. The quality of a one-way mapping changes when it is reversed, and this must be taken into account. Let us use Reverse-Rank to denote the quality of the reversed mapping (Table 15).

Rank 1 mappings are good one-to-one mappings and reverse very well. The reverse mappings have **Reverse-Rank 1**.

Rank 4 mappings are one-to-many mappings and reverse well. The reverse mappings have **Reverse-Rank is 2**.

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[21] There are concepts in COSTAR Directory that have been intentionally left out of the OnCall reflection of COSTAR Directory. A new record referring to one of these concepts cannot be created in OnCall, but a record already referring to one of these concepts can be renewed in OnCall. No attempt has been made to map these deprecated COSTAR concepts to MDD concepts.

Rank 3 mappings are fairly good one-to-one mappings and can be reversed. The reverse mappings have **Reverse-Rank 3**.

Rank 2 mappings are good one-way, but poor when reversed. The reverse mappings have **Reverse-Rank 4**.

Mappings of Ranks 5 are already unreliable and reversing it would reduce reliability even more. Mappings of Ranks 6 and 7 are to NULL and cannot be reversed.

Table 15. Examples of Reversing COSTAR-to-MDD Mappings

Rank	Reverse-Rank	COSTAR Concept	MDD Concept
1	1	G CSF	CALCIUM CITRATE oral
2	4	Vi dom "A"	VITAMIN A oral
3	3	Betalin	BETALIN COMPLEX (THIAMINE HCL) oral
4	2	acetaminophen and codeine	ACETAMINOPHEN W/CODEINE 30MG oral
5	N/A	perphenazine concentrate	PERPHENAZINE oral
6	N/A	Lenograstim	NULL
7	N/A	4 way nasal spray	NULL

In the original mapping, distinct COSTAR medication concepts can map to the same MDD concept. Therefore, reversing the mappings can and does result in some one-to-many mappings.

What we really want is a one-to-one reverse mapping, so we need a tie-breaker to choose between the many whenever we have a one-to-many situation. We can use the following logic:

1. If an MDD concept reverse maps to multiple COSTAR concepts, and these mappings are not all of the same Reverse-Rank, keep only the mappings with the best (lowest) Reverse-Rank.

2. If two COSTAR concepts map to the same MDD concept, and one of these COSTAR concepts is a base code and the other is a modifier of this base code, then we prefer to reverse map the MDD concept to the base code. This is because the MDD concept is probably a generic rather than a trade name (because a COSTAR base code maps to it), and therefore the reverse mapping should be to the generic (the COSTAR base code) rather than possibly a trade name (the COSTAR modified code).

3. If multiple COSTAR base codes map to the same MDD concept or if only modified COSTAR codes map to the same MDD concept, then there is no a priori reason to choose any one over another. Arbitrarily, choose the one that is first alphabetically.

Let us go through an example to clarify this logic. Many COSTAR codes map to the MDD concept of "ACETAMINOPHEN oral," and the mappings have different Ranks. This leads to a one-to-many reverse mapping from "ACETAMINOPHEN oral" to COSTAR concepts (Table 16).

Table 16. Representative Subset of the Reverse Mapping of the MDD Concept "ACETAMINOPHEN oral" to COSTAR Concepts

MDD Concept	COSTAR Concept	Rank	Reverse-Rank	COSTAR Code
ACETAMINOPHEN oral	acetaminophen	1	1	WSHL1
ACETAMINOPHEN oral	acetaminophen liquid	1	1	WSHL1-Q
ACETAMINOPHEN oral	Anuphen	2	4	WSHL1-1
ACETAMINOPHEN oral	Capital	2	4	WSHL1-2

Note that these are all acceptable mappings from COSTAR to MDD (Ranks 1 and 2). However, the reverse of the Rank 2 mappings are poor. We do not want "ACETAMINOPHEN oral" to map to any specific trade names, if we can help it. Since we have a choice between Reverse-Ranks of 1 or 4, we can eliminate the reverse mappings with Reverse-Ranks of 4.

That leaves us with two possible mappings. Mapping "ACETAMINOPHEN oral" to "acetaminophen (WSHL1)" is clearly preferable to mapping it to "acetaminophen liquid (WHSL1-Q)." Fortunately, our second rule tells us to prefer the base code, WHSL1, to the modified code, WHSL1-Q, when there is a tie in Reverse-Rank.

We are then left with the single mapping for MDD's "ACETAMINOPHEN oral" to COSTAR's "acetaminophen" [oral implied], which is the desired result.

Applying the above logic to the reverse mappings results in each distinct MDD concept having only a single mapping to COSTAR (Table 17). By reversing the COSTAR-to-MDD mapping, we obtain an MDD-to-COSTAR mapping for 3,197 of the 6,089 MDD concepts. That is 52.5% coverage of the MDD. This is most likely insufficient for clinical purposes. However, pre-mapping 52.5% of the MDD medication terminology saves about half the work that needs to be done to map the entire MDD to COSTAR Directory.

Table 17. Quality of the Reverse of the COSTAR-to-MDD Mapping, Before and After Reducing One-to-Many Mappings to One-to-One Mappings

Reverse-Rank	Count (with 1-to-many)	Count (only 1-to-1)	% Reduction
1	3,892	2,814	27.7%
2	531	326	38.6%
3	144	48	66.7%
4	751	9	98.8%
Total	5,318	3,197	39.9%

Mapping Terminologies to a Single Common Terminology

The COSTAR Directory and the MDD are constantly being updated to add new medications that come onto the market, to remove medications that have been removed from the market, and to correct errors. To maintain a two-way mapping between the two terminologies would require the mapper to keep track of changes in either vocabulary and add or adjust the two-way mapping as needed. The mapper requires knowledge and access to both terminologies.

We already mentioned the combinatorial nightmare of creating pair-wise two-way mappings. However, maintaining all these mappings is an even greater problem. Any change in one terminology can potentially affect mappings from that terminology to and from every other terminology, and a group of mappers with a collective knowledge of every terminology is required to propagate all the necessary changes throughout the mappings.

For example, suppose we have pair-wise mappings between COSTAR Directory, the MDD, NDDF Plus, and RxNorm. If a change is made in COSTAR, three mappings are affected (COSTAR-MDD, COSTAR-NDDF Plus, and COSTAR-RxNorm), and knowledge is required of all four terminologies.

A better solution to connecting multiple terminologies to each other is to choose one terminology as a standard, and mapping all other terminologies to the one standard. For best results, the standard terminology chosen should be the most complete and consistent, be free and accessible to everyone, and have the broadest knowledge base for decision support. Of course, no terminology is best in all environment (which is why multiple terminologies exist in the first place), and one needs to choose the terminology with the combination of features that best serves the purpose of being a standard, even if these features would not be ideal for any particular environment.

Suppose we choose NDDF Plus to be the standard and create two-way COSTAR-NDDF Plus, MDD-NDDF Plus, and RxNorm-NDDF Plus mappings. We still need pair-wise knowledge to create and maintain the mappings, but we only need 4 types of mapping knowledge (COSTAR-NDDF Plus, MDD-NDDF Plus, and RxNorm-NDDF Plus) instead of 6.

Furthermore, maintenance is simplified. When a change is made in COSTAR Directory, only the COSTAR-NDDF Plus mapping needs to be examined and modified. Because COSTAR is not directly linked to the MDD or RxNorm, users of the latter two terminologies can remain blissfully ignorant of the change in COSTAR.

In this system, translating a COSTAR concept to an MDD concept would require two translations. The COSTAR concept is first translated to an NDDF Plus concept, and then the NDDF Plus concept is translated to an MDD concept. Translating twice may introduce more errors than a direct mapping between COSTAR and MDD, but this is the price of keeping the problem of universal translation between medication terminologies tractable.

Note that changes in the standard terminology will need to be propagated to each mapper responsible for maintaining the mapping between the standard terminology and the local terminology. If there is a change in NDDF Plus, for example, mappings between NDDF Plus and each of the other terminologies will need to be examined and modified as needed.

MEDICATION RECONCILIATION

Adverse drug reactions (ADRs) represent an important clinical issue. It has been estimated that in 1994, 2,216,000 hospitalized patients had serious ADRs and 106,000 had fatal ADRs, making these reactions between the fourth and sixth leading cause of death.[22]

The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) has a sentinel even database that includes more than 350 medication errors resulting in death or major injury.[23] Of those, 63 percent related, at least in part, to breakdowns in communication, and approximately half of those would have been avoided through effective medication reconciliation.

Medication reconciliation is the process of comparing a patient's medication orders to all of the medications that a patient has been taking. This is done to avoid medications errors such as omissions, duplications, dosing errors, or drug-drug interactions. One obstacle to medication reconciliation is the fragmentation of care among different providers, especially if they use different EMRs. However, medication reconciliation is important even when only one EMR is used in the care of the patient.

Medication List Accuracy

A study done in 1996 at a geriatric center about the accuracy of medication data in an outpatient electronic medical record highlights the importance of medication reconciliation.[24] Accuracy depends on how strict one wants to be, and the gold standard is real-time confirmation of the medications with the patient.

For medications that were on the EMR's list of active medications,

- 83% had the correct compound, dose, and schedule
- 92% had the correct compound from the clinician perspective (ignoring dose and schedule)
- 90% had the correct compound from the computer (decision support) perspective (must be in encoded in the controlled medication terminology)

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[22] Lazarou J, Pomaranz BH, Corey PN. Incidence of Adverse Drug Reactions in Hospitalized Patients. JAMA. 1998;279:1200-1205.
[23] Joint Commission on Accreditation of Healthcare Organizations, Sentinel Event Alert, Issue 35, January 23, 2006.
[24] Wagner WM, Hogan WR. The accuracy of medication data in an outpatient electronic medical record. JAMIA. 1996; 3(3): 234–244.

For each list, there was an average of

- 0.37 missing medications from the clinician perspective
- 1.38 missing medications from the computer (decision support) perspective

Types of error included the following:
- 27.8% extra medication listed
- 27.2% missing medication
- 34.8% inaccurate dose or schedule
- 10.1% other

Sources of error included the following:

- 36.1% patient-initiated changes
- 21.5% medical center specialists without EMR write privilege
- 13.3% handwritten orders not entered into the EMR
- 8.9% the clinic MD
- 8.2% data entry error
- 7.6% unknown
- 4.4% an outside MD

Given that much of the error (36.1%) comes from patient-initiated changes, medication reconciliation is always necessary at every encounter. Even if one records a perfectly accurate medication list at the end of an encounter and has access to changes to made by other providers, the list can only be expected to be about 96% accurate (in terms of compound/dose/schedule) by the next encounter, at best. The successful implementation of patient portals may improve the situation in the future by allowing patients to update their medication lists with changes they themselves initiate.

JCAHO Requirements for Medication Reconciliation

In July 2004, the JCAHO announced 2005 National Patient Safety Goal #8 to "accurately and completely reconcile medications across the continuum of care." Accredited healthcare organizations were required to develop and test processes for medication reconciliation and implement them by January 2006. The updated requirements for 2006 are as follows:

> (8a) Implement a process for obtaining and documenting a complete list of the patient's current medications upon the patient's admission to the organization and with the involvement of the patient. This process includes a comparison of the medications the organization provides to those on the list.
>
> (8b) A complete list of the patient's medications is communicated to the next provider of service when a patient is referred or transferred to another setting, service, practitioner or level of care within or outside the organization.

The implementation expectations for requirement (8b) state that at a minimum, reconciliation must occur any time the organization requires that orders be rewritten and any time the patient changes service, setting, provider or level of care and new medication orders are written. Because the scope of Goal #8 includes the entire continuum of care, it applies to ambulatory, emergency, urgent care, long term care, and home care settings as well as inpatient services.

Role of EMRs in Medication Reconciliation

The process of medication reconciliation often requires three different medication lists: the original medication list, the current medication list, and the discharge medication list. Building these lists manually is a time-consuming process, and the EMR should assist in this process if at all possible.

If all the settings of care share a single EMR, then building these lists and communicating these lists between settings is simplified. If medications in the EMR are encoded as a controlled terminology, then decision support could be implemented to check for omissions, duplications, dosing errors, or drug-drug interactions.

Building medication lists is more difficult when patients move between settings that do not use the same EMR. To assist in building the original medication list for medication reconciliation, the EMR at the new setting will need to import medication lists from all other settings, merge the multiple lists into one list, and then allow the transfer of medications on this merged list into orders and the use of this list as the basis for the discharge list.

Importing medication lists from other EMRs is only possible if the other EMRs provide standard services for exporting medication lists and the EMRs agree on a standard for medication lists and medication records. Merging medication lists requires either a standard medication terminology or a reasonably good mappings between the various terminologies, so that it is possible to tell which medication records refer to the same medications.

When the medication lists have been merged and re-encoded using the local controlled medication terminology, local decision support can come into play. Finally, when the patient leaves the current setting, the original list and the current list are reviewed and a discharge list is constructed and recorded. This discharge list is communicated to the patient and should be available to other EMRs through the same standard services already mentioned.

SUMMARY

Medications are an integral part of healthcare and they must be implemented carefully and rationally in EMRs.

Controlled medication terminologies are essential for decision support, but they are not trivial to build. There is no general agreement on what medication concepts should be because medication concepts at different levels of granularity serve different purposes. The ideal terminology can accommodate concepts at multiple levels of granularity in a consistent fashion. However, the number of levels should be restricted to keep the terminology from exploding beyond a manageable size.

Many different medication terminologies exist because different sets of providers of healthcare have different needs. It is too much to expect a common medication terminology to serve everyone's need. However, for the sake of communication, translation services are necessary. Translation will not be perfect and some information will be lost, but essential information should get through. To keep the problem tractable, it is better to choose a single common terminology for all translation services to go through than to create mappings between every pair of terminologies.

While medication terminologies form a foundation in EMRs, attention must also be given to the implementation of medication records and medication lists. Well-implemented medication records make it easy to navigate the patient's medication history. A good implementation of medication lists distinguishes between descriptive and prescriptive medication lists.

Finally, it is not enough to be able to translate concepts in one terminology to another. EMRs need to be able to communicate medication records and medication lists with each other as well. Standards need to be developed for the communication of medication records and medication lists.

Adverse drug reactions are a major problem in healthcare. EMRs that provide medication decision support and assist in medication reconciliation are expected to play a large role in solving this problem.