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Facilitating pre-operative assessment guidelines representation using SNOMED CT

Leila Ahmadian [a,b,*], Ronald Cornet [a], Nicolette F. de Keizer [a]

[a] Dept. of Medical Informatics, Academic Medical Center, University of Amsterdam, The Netherlands
[b] Kerman University of Medical Sciences, Kerman, Iran

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ABSTRACT

Objective: To investigate whether SNOMED CT covers the terms used in pre-operative assessment guidelines, and if necessary, how the measured content coverage can be improved.

Pre-operative assessment guidelines were retrieved from the websites of (inter)national anesthesia-related societies. The recommendations in the guidelines were rewritten to "IF condition THEN action" statements to facilitate data extraction. Terms were extracted from the IF–THEN statements and mapped to SNOMED CT. Content coverage was measured by using three scores: no match, partial match and complete match. Non-covered concepts were evaluated against the SNOMED CT editorial documentation.

Results: From 6 guidelines, 133 terms were extracted, of which 71% ($n = 94$) completely matched with SNOMED CT concepts. Disregarding the vague concepts in the included guidelines SNOMED CT's content coverage was 89%. Of the 39 non-completely covered concepts, 69% violated at least one of SNOMED CT's editorial principles or rules. These concepts were categorized based on four categories: non-reproducibility, classification-derived phrases, numeric ranges, and procedures categorized by complexity.

Conclusion: Guidelines include vague terms that cannot be well supported by terminological systems thereby hampering guideline-based decision support systems. This vagueness reduces the content coverage of SNOMED CT in representing concepts used in the pre-operative assessment guidelines. Formalization of the guidelines using SNOMED CT is feasible but to optimize this, first the vagueness of some guideline concepts should be resolved and a few currently missing but relevant concepts should be added to SNOMED CT.

1. Introduction

Clinical guidelines are effective tools to reduce practice variation and improve the quality of care [1,2] by summarizing and describing best practices for specific patient conditions. However, guidelines are frequently developed and implemented on paper. This reduces their availability at the point of care [3]. Paper-based guidelines require physicians to interrupt their workflow to locate, read, and process the guidelines. Therefore, although many guidelines have been developed to assist physicians in different clinical situations, adherence to guidelines, even those that are broadly accepted, is often low [4,5]. The excessive and growing number of guidelines makes it hard for physicians to remember, find, and appropriately apply guidelines. To help physicians in this regard, guidelines should be provided at the point of care.

Providing guidelines at the point of care can be facilitated by integrating them into a decision support system (DSS) or clinical information system. Integrated guidelines help physicians to deliver evidence-based care to patients. By providing patient-specific reminders and advice, a DSS can influence the physicians' behavior [6–9] to increase adherence to guidelines [6,7,10–12] thereby improving patient care significantly [7].

A success factor for DSS implementation is the integration into workflow and information infrastructure [7]. To enable this, guidelines should be represented in a format that enables automated inference based on patient data stored in the clinical information systems. Furthermore, guideline-based DSSs must be able to interact correctly with any clinical information system to enable broad adoption. This can be realized by using a standard information model and standard terminology in both the automated guideline and the clinical information system.

In the Netherlands, anesthesiologists intend to adopt SNOMED CT[1] as a standard terminology in the domain of pre-operative assessment [13]. SNOMED CT will be used to record pre-operative assessment patient data in a standardized way in order to be able to reuse the data for multiple applications including a guideline-based DSS. Therefore, in this study we will investigate whether SNOMED CT can be used for this purpose, by answering the

* Corresponding author. Address: Department of Medical Informatics, Academic Medical Center, University of Amsterdam, Room J1B-109, P.O. Box 22700, 1100 DE Amsterdam, The Netherlands. Fax: +31 20 6919840.
E-mail addresses: l.ahmadian@amc.uva.nl, lahmadian@kmu.ac.ir (L. Ahmadian).

[1] http://www.ihtsdo.org/

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following questions: (1) to what extent does SNOMED CT cover the terms used in commonly used pre-operative assessment guidelines? (2) If necessary, how can the measured content coverage be improved?

2. Background

2.1. Guideline composition and guideline representation

In general, a guideline consists of the description of the task that has to be performed, eligibility criteria that may evoke the guideline or parts of it, and abort criteria that may cancel following (parts of) the guideline. Furthermore, guidelines have validation attributes such as strength of evidence, which indicate whether a guideline or a task in a guideline is supported by the literature or by expert opinions.

Whereas most guidelines are formulated as unstructured text or as a simple flowchart, there is a growing need to create interoperable guidelines [14]. To this end, guidelines should be formalized. Efforts have been made toward formalizing guidelines and creating interoperable clinical guidelines and knowledge-based DSSs during recent years [15–20]. These formalizations are generally based on a logical statement that is activated by some relevant event, such as entering or storing patient data. The logical statement will be activated if the patient data is recognized as satisfying the eligibility criteria of a guideline or of a task in the guideline.

2.2. The use of terminologies in guideline representation

An important step in creating interoperable guidelines is the binding of terminology used in the clinical information system to terminology used in guideline representation.

In some guideline representations, such as old versions of the Arden syntax, institution-specific terms must be mapped to the specific terms used in the representation in order to activate a logical statement in the guideline [18]. This kind of guideline representation cannot support different synonyms used by different care providers for a clinical concept, e.g., K+, or serum potassium. Therefore, as the naming of patient data varies among institutions, patient data elements defined in the formalized guideline will need to be changed when the guideline is shared [18]. In the Arden syntax this problem has become known as the "curly braces problem", because the data-acquisition statements of Arden syntax contain non-standardized data names and expressions in curly braces [21]. To overcome problems caused by use of different terminology, the GLIF (guideline interchange format) formalization used a list of acceptable synonyms for each data element [16]. In EON, which is a component-based architecture for building guideline-based decision support systems, and Asbru, which is a machine-readable language used for guideline representation, specific domain ontologies are defined [15,20]. Patient data should be first mapped to these domain ontologies designed for guideline representation.

Recent researches have focused on increased interoperability using standard terminologies in guideline representation and clinical information systems [22,23]. Achour et al. [22], used the Unified Medical Language System (UMLS) to create a domain ontology and thereby facilitate interoperability and reusability of the guideline representation expressed by the Arden syntax. GLIF3 adopted a version of HL7 v3 RIM (Health Level 7 version 3 Reference Information Model) as its data model and used controlled terminologies such as ICD-9 and SNOMED [24]. Guidelines elements model (GEM) is an XML-based guideline document model intended to facilitate translation of natural language guideline documents into a format that can be processed by computers. GEM promotes this translation by describing concepts pertinent to guideline representation, attributes of those concepts, and relationships among the concepts. GEM also has an element called "definition" which stores important guideline terminology as well as the meaning of the terms [25].

Another application of standard terminologies in the context of guideline formalization was in the SAGE (Standards-based Shareable Active Guideline Environment) project in which a framework for encoding and disseminating guidelines has been developed [26]. A set of reference terminologies including SNOMED CT, LOINC,[2] National Drug File – Reference Terminology,[3] and RxNorm[4] was used to support semantic interoperability [23]. SAGE obtains patient data from the local clinical information systems to activate the logical statements in the guideline. Therefore, standards-based coded content in a SAGE guideline must be mapped to corresponding codes used in the clinical information systems. Bernstein and Andersen in their work describe how the guideline system and the electronic health records can be integrated by the use of archetypes and SNOMED CT [27].

To eliminate the process of context-specific mapping of data between the guideline and the patient data in the anesthesia information management systems, in our project we will use SNOMED CT as a standard terminology for recording patient data as well as within guideline representation.

3. Methods and materials

3.1. SNOMED CT

SNOMED CT is a comprehensive clinical healthcare terminology that can be used as the foundation for electronic medical records and other applications. It is constantly updated and its revisions are released twice a year. In this study, the July 2008 release was used. It contains more than 315,000 active concepts with unique meanings, about 807,000 descriptions, including synonyms of defined concepts, and approximately 1,236,000 relationships between the concepts. Concepts in this terminology are defined based on description logic and organized into hierarchies with multiple levels of granularity. This representation enables documentation of very detailed clinical data and, when required, aggregation on a more general level. SNOMED CT is a concept-based system that supports post-coordination. Post-coordination is the ability to express new concepts by combining pre-coordinated (pre-defined) ones. This provides the possibility of creating new concepts by qualifying pre-coordinated concepts [28].

SNOMED CT, with these possibilities, may have good coverage of terms used in the guidelines, because of the varying level (from very high to very low) of aggregation of terms used in the guidelines.

3.2. Selection of pre-operative guidelines

To perform this study, we retrieved (inter)national guidelines related to pre-operative assessment. As our goal was not to find a complete set of pre-operative assessment guidelines, but to retrieve widely accepted guidelines, extensive searches through the websites of the (inter)national anesthesia-related societies were performed. Table 1 shows a complete list of the websites explored. Guidelines were included if they completely or partially dealt with the pre-operative assessment.

3.3. Data extraction

The retrieved pre-operative assessment guidelines consisted of narrative text. To evaluate the content coverage of SNOMED CT

[2] http://loinc.org/
[3] http://www.nlm.nih.gov/research/umls/sourcereleasedocs/2008AB/NDFRT/
[4] http://www.nlm.nih.gov/research/umls/rxnorm/

Table 1
Websites of anesthesia-related societies on which guidelines were searched for.

Society	Website
ASA: American Society of Anesthesiologists	http://www.asahq.org/
IARS: International Anesthesia Research Society	http://www.iars.org/
ESA: European Society of Anaesthesiology	http://www.euroanesthesia.org/
APSF: Anesthesia Patient Safety Foundation	http://www.apsf.org/
EACTA: European Association of Cardiothoracic Anaesthesiologists	http://www.eacta.org/
ESCTAIC: European Society for Computing and Technology in Anaesthesia and Intensive Care	http://www.esctaic.org/
SCATA: Society for Computing and Technology in Anaesthesia	http://scata.org.uk
WFSA: World Federation of Societies of Anaesthesiologists	http://www.anaesthesiologists.org

Table 2
Examples of terms extraction from the included guidelines.

Free-text recommendation, extracted from guideline text	If (condition)	Then (action)
Patients indicated for bariatric surgery should undergo routine pre-operative assessment. . . .In addition to the routine pre-operative assessment, the patient undergoes further assessment (depending on the procedure. . .) for pulmonary function, bone density, indirect calorimetry	– Bariatric surgery	– Routine pre-operative assessment – Pulmonary function assessment – Bone density assessment – Indirect calorimetry assessment
These guideline focus on the perioperative management of patients undergoing surgery or other invasive procedures in which significant blood loss is expected. . . .Pre-operative evaluation should include checking for the presence of congenital or acquired blood disorders, the use of vitamins or. . .	– Surgery with significant blood loss expectation – Other invasive procedure with significant blood loss expectation	– Assessment of the presence of congenital blood disorder – Assessment of the presence of acquire blood disorder – Assessment of the use of vitamins

regarding concepts used in these guidelines, terms had to be extracted from these narrative texts.

First, from the guideline texts we determined those parts that explicitly represent *recommendations*. Some of the selected guidelines contained not only pre-operative assessment recommendations, but also per- and post-operative process recommendations. Only parts of the guidelines related to pre-operative assessment were included in this study. Then, to facilitate data extraction, each guideline recommendation was rewritten as an "IF condition THEN action" statement [29]. Each recommendation was analyzed to determine which part referred to the condition (e.g., eligibility criteria and abort criteria such as age or physiology of the patient), and which part referred to an action (e.g., performing a test, planning a procedure). Examples are described in Table 2. Conditions and actions were written as noun phrases by a medical informatician (LA) and ambiguities were discussed with other medical informaticians (RC, NdK) and an anesthesiologist. When analyzing the noun phrases, their semantics need to be fully understood. This means that the representation of the guideline terms not only contain the concepts relevant for SNOMED CT, but all semantic dimensions (qualities) identifiable in the guideline text as well as the logical structure of the resulting constructs [30].

3.4. Data categorization

To determine what kind of terms were contained in the included guidelines, extracted terms were categorized based on Virtual Medical Record (VMR) classes, the approach that was used in the SAGE project [31]. VMR is a set of classes that define a generic information model for the purpose of authoring guidelines [32]. These classes are consistent with the structures of the European pre-standard ENV13606, which is an architecture for the electronic healthcare record [32]. VMR classes can also be regarded specializations of HL7 RIM Act classes such as Clinical Observation, Healthcare Goal, and Patient Encounter [33]. Consistency with existing standards can open up the possibility of a standardized methodology for embedding guideline-based decision support systems in electronic medical records. VMR includes attributes that are suitable for modeling guidelines, whereas the HL7 RIM is a fundamental model, which is not directly usable as a representation of patient data relevant to the task of guideline-based decision support.

VMR consists of thirteen classes: Agent, Alert, Allergy, Appointment, Encounter, Goal, Medication Order, Observation, VMR Order, Problem, Procedure, Referral, and Composite Clinical Model[5] [31].

3.5. Mapping extracted terms to SNOMED CT concepts

Concept-based mapping was used to map all extracted terms to corresponding SNOMED CT concepts. The extracted terms were first mapped to pre-coordinated SNOMED CT concepts (concepts pre-defined in SNOMED CT). If an extracted term did not have a corresponding representation among SNOMED CT's pre-coordinated concepts, post-coordination was used. Post-coordination is the ability to express new concepts by combining pre-defined ones. To post-coordinate a concept, first we tried to compose it using SNOMED CT qualifiers. If this was not possible a concept was post-coordinated based on the SNOMED CT concept model, described in Appendix J of the "Technical Reference Guide of SNOMED CT" [34]. The final mapping was given one of three scores: no match, partial match or complete match. A match was considered complete when the semantics of the term extracted from the guideline were equivalent to those of the corresponding SNOMED CT concept [28]. For instance, the extracted term "pure central apnea" was considered a complete match with the SNOMED CT concept "central sleep apnea syndrome." A match was considered partial when one concept subsumed the other [28]. For instance, "length of upper incisors" extracted from a guideline was partially mapped to the superordinate "dental measure." A non-match was scored when a semantically equivalent SNOMED CT concept was not available and could not be post-coordinated, e.g., "impairment of upper airway protective reflexes."

Guidelines often use terms for aggregated concepts, e.g., "cardiovascular disease," to denote all concepts of a given type. Therefore, we also analyzed which guideline terms needed to be mapped

[5] http://sage.wherever.org/, last accessed 24 March 2009.

to a concept in SNOMED CT including its subordinates. For example, the term "cardiovascular disease" extracted from a guideline refers to the concept "disorder of cardiovascular system" and all concepts subsumed by this concept, which were more than 5200 concepts.

3.6. Partial and non-matches

To answer the second research question about how the content coverage of SNOMED CT can be improved, we further investigated all partial and non-matches. This investigation was done based on the editorial documentation of SNOMED CT regarding the content inclusion principles and process [35]. This document describes what should and what should not be included in SNOMED CT. It contains three basic principles for creating and sustaining semantic interoperability of clinical information: Understandability, Reproducibility and Usefulness (URU). These principles are defined as follows:

- Understandability: The meaning must be able to be communicated and understood by an average health care provider without reference to inaccessible, hidden or private meanings.
- Reproducibility: It is not enough for one individual to say they think they understand a meaning. It must be shown that multiple people understand and use the meaning in the same way.
- Usefulness: The meaning must have some demonstrable use or applicability to health or health care.

Next to the basic principles, the SNOMED CT documentation contains specific rules for submission of new content. These rules are related to content that should not be included in SNOMED CT, e.g., classification-derived phrases, numeric ranges, and procedures categorized by complexity.

To investigate whether there is a justification why SNOMED CT does not completely capture concepts used in the pre-operative assessment guidelines, partially matching and non-matching concepts were evaluated against the URU principles and the rules for submission of new content. Concepts that did not follow the principles and rules were categorized based on the violated principle or rules. Investigation and categorization of concepts were done by two experts (LA, NdK) in SNOMED CT and in case of disagreement solved by consensus discussions together with a third SNOMED CT expert (RC), based on input provided by the chief terminologist of the International Health Terminology Standards Development Organization (IHTSDO), which maintains SNOMED CT.

4. Results

4.1. Selected guidelines

The explored websites contained six guidelines [36–41] related to pre-operative assessment, all of which were included in this study. Five of the included guidelines were developed by the American Society of Anesthesiologists and one, concerning obesity, was developed by the Bariatric Scientific Collaborative Group: a joint group of the major European Scientific Societies, which are active in the field of obesity management. The publication dates of the included guidelines were between 1999 and 2007. At the time of the study, the latest versions of the guidelines were used. Five of the guidelines have been published in Anesthesiology Journal and one in the International Journal of Obesity.

4.2. Data extraction and categorization

Recommendations were extracted from the included guidelines. These recommendations were subsequently transformed into 24 IF–THEN statements. Each IF–THEN statement included one or more terms to describe conditions and/or actions. In total, 133 terms were identified in the IF–THEN statements. Forty-one terms (31%) were extracted from the IF part of the statements (condition part) describing eligibility and abort criteria; 92 terms (69%) were extracted from the THEN part of the statements (action part) describing the tasks that should be done. Extracted terms were categorized into six VMR classes: Encounter, Observation, Procedure, Problem, VMR order, and Referral. Fig. 1 shows the distribution of the terms based on the VMR classes.

4.3. Mapping results

SNOMED CT had better coverage for actions than for conditions (Fig. 2). Twenty-seven percent of the conditions had no matching SNOMED CT concepts against 10% of the terms describing actions.

In total, 71% ($n = 94$) of the extracted concepts were completely matched with SNOMED CT concepts (Fig. 3). About half of the non-complete matches ($n = 19$) were represented partially and mapped to the closest concepts. The other half ($n = 20$) did not have an appropriate corresponding representation in SNOMED CT.

In total, 22.3% of all complete matches and 30% of all partial matches were achieved through post-coordination. The class "observation" had the lowest percentage of complete matches and the highest percentage of non-matching concepts.

Some terms in the guidelines that express aggregations needed to be mapped to a concept with its subordinates. In this study 63% ($n = 46$) of complete pre-coordinated concepts ($n = 73$) needed to be mapped to a concept with its subordinates. Table 3 shows some examples of these concepts. Furthermore, guideline concepts are

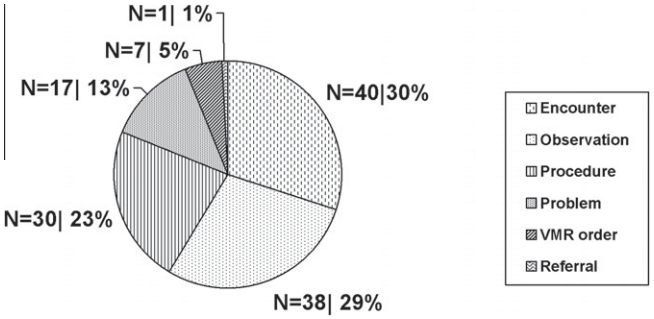

Fig. 1. Distribution of extracted terms based on VMR classes.

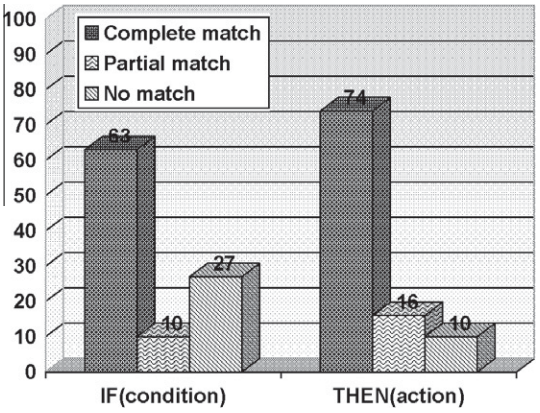

Fig. 2. Content coverage of SNOMED CT based on concepts extracted from IF part or THEN part of the logical statements coming from six commonly used guidelines ($n = 133$).

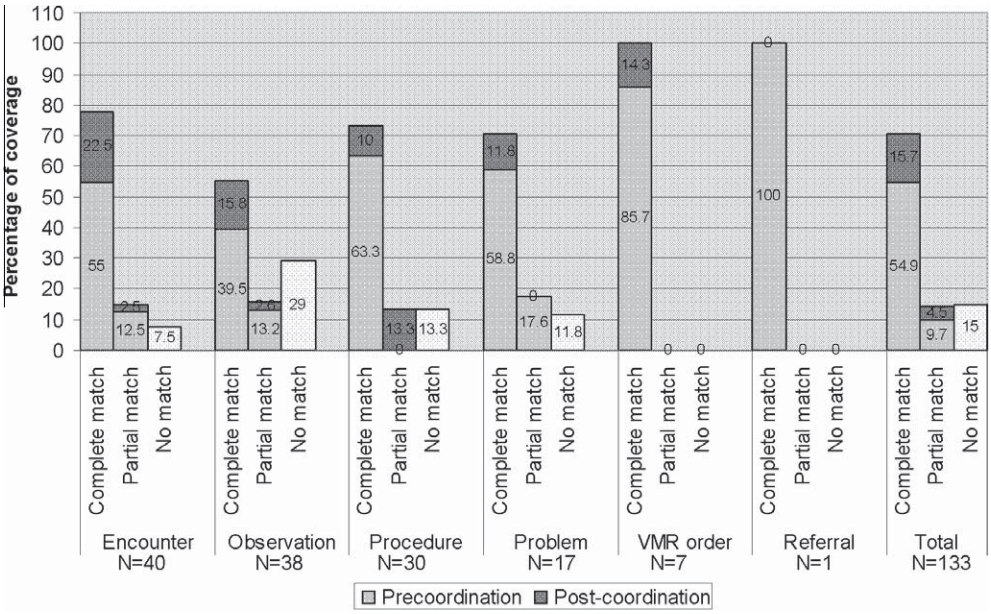

Fig. 3. Content coverage of SNOMED CT based on VMR classes.

often complex and may not always be appropriately mapped to a SNOMED CT concept. This occurs when an extracted concept refers to a set (more than one) of concepts that does not completely cover one entire branch (a concept with its subordinates) of SNOMED CT but just a part of a branch. For instance, the extracted concept "physical examination" can be mapped to the SNOMED CT concept "physical examination procedure" while the concept "physical examination under local anesthesia," a subordinate of the aforementioned SNOMED CT concept, is not a concept of interest of the guidelines' authors when stating the aggregated term "physical examination."

4.4. Partial and non-matches

The result of the in-depth investigation of partially and non-matching concepts, based on the SNOMED CT editorial documentation (28), shows that 69% ($n = 27$) of these concepts should not be represented in SNOMED CT because they violated at least one of the basic principles or rules for submission of new content. Disregarding these concepts the coverage of SNOMED CT was 89% (94/106) (see Table 4). Most of these concepts were non-reproducible. Table 5 categorizes the reasons for not representing an extracted guideline term by a SNOMED CT concept. The categories consist of the violated basic principle (in all cases lack of reproducibility) and rules. Concepts violating a rule for submission of new content may also violate the basic principle. For instance, classification-derived phrases can be rejected because they fail the basic tests of understandability, reproducibility, and usefulness. These kinds of concepts such as "other cardiovascular problems" are vague, as they depend on what has been specified in the context. Most of the concepts categorized under classification-derived phrases were concepts including the word "other."

Table 4
Coverage of SNOMED CT for concepts extracted from guidelines.

SNOMED CT coverage	Concepts from the guidelines	
	Non-vague concepts	Vague concepts
Complete matches	94	0
Partial and non-matches	12	27
Total	106	27

One third ($n = 12$) of the partially and non-matching concepts did not violate any basic principle or rule (Table 6). Partial matches mostly consist of mappings to a generic concept, which is a superordinate of the extracted concept. For instance, the extracted concept "Length of upper incisors" has been mapped to the generic concept "dental measure."

5. Discussion

Our study shows that to facilitate pre-operative assessment guideline representation using SNOMED CT not only SNOMED CT needs to be extended, but also deficiencies in the guidelines should be solved. The guidelines that we included in this study are common in the pre-operative assessment practice. SNOMED CT cov-

Table 3
Examples of extracted concepts that need to be mapped to a concept including its subordinates.

Extracted terms from the guidelines	SNOMED CT concepts	Examples of SNOMED CT subordinates
General anesthesia	50697003 | general anaesthesia |	– Inhalation general anesthesia – Total intravenous anaesthesia
Physical examination	5880005 | physical examination procedure |	– Taking patient vital signs – Cardiovascular physical examination
Metabolic disorders	75934005 | metabolic disease |	– Amyloidosis – Disorder of acid–base balance
Obstetric procedure	386637004 | obstetric procedure |	– Removal of ectopic fetus – Artificial rupture of membranes|

Table 5
Concepts that could not be represented by SNOMED CT.

Violated principle or rules	Concepts
Non-reproducibility	Factors related to difficult airways Risk factors of pulmonary aspiration Diseases that may affect gastric emptying or fluid volume Minimizing regurgitation opportunity Minimizing pulmonary aspiration opportunity Directed physical examination Organ ischemia risk factors Coagulopathy risk factors Medication causing an allergic reaction Increased perioperative risk from obstructive sleep apnea Frequent arousals during sleep
Classification-derived phrases	Procedure without anesthesia Other gastrointestinal motility disorders Other invasive procedures Surgeries with occurrence or expectation of significant blood loss Abnormalities of the upper or lower airway not associated with sleep apnea Daytime hypersomnolence from other causes Obesity in the absence of sleep apnea Other cardiovascular problems Other congenital medical conditions Other acquired medical conditions
Numeric ranges	<28 days <35 kg <1 year*
Procedures categorized by complexity	Major noncardiac surgery Extensive airway examination

* This data item reported in two guidelines.

ered 71% of the total concepts used in the included guidelines and 89% of the non-vague concepts of the pre-operative assessment guidelines.

SNOMED CT has higher coverage for the terms related to actions (the extracted terms from THEN part of the logical statements) than for the terms related to conditions (the extracted terms from IF part of the logical statements). A logical statement in a guideline will be activated if patient data is recognized as satisfying the condition that is defined in the guideline representation. Therefore, a condition in the guideline representation should be defined in a concept-based way, mapped to several synonyms that physicians may use for stating patient data related to that condition in the clinical information system. Providing conditions in the guideline representation with the help of terminological systems containing synonyms eases proper guideline activation. If the guideline-based DSS is only designed for clinical advice, it is less important that the action part of a guideline can be mapped to patient data; the advice can even be presented as free text. However, in case the system is used for accountability to evaluate the delivered care, actions as well as conditions need to be defined in the guideline formalization in a concept-based way.

Partial and non-matching conditions were mostly related to the aggregated terms, which authors used for referring to a set of conditions, e.g., "surgeries with occurrence of significant blood loss." Therefore, to facilitate guideline representation presenting guidelines with more specific and detailed data items is required.

Evaluation of partially and non-matching concepts, which were 29% of the extracted concepts, based on editorial documentation of SNOMED CT(28) revealed that 69% of these concepts should not be included in SNOMED CT because they correspond to underspecified concepts in the pre-operative assessment guidelines. These concepts did not follow the URU principles required for semantic interoperability and/or the SNOMED CT rules regarding submission of new content. Some terms used in the pre-operative assessment guidelines such as "extensive airway examination" are vague and non-reproducible, and require clarification before guidelines can be formalized. In our study 81% of the underspecified concepts were related to the IF part of the statements referring to inclusion and exclusion criteria of a guideline or a recommendation in a guideline. Some of the guidelines refer to other external resources for more information on inclusion and exclusion criteria and some of them request the knowledge of the experts in the field. To create an interoperable guideline to be implemented in a DSS all these concepts should be elicited and automatically extracted from the electronic medical records. A terminology can be used to assess whether specific inclusion or exclusion criteria are met. Disregarding the vague concepts, the evaluation shows that SNOMED CT could adequately represent 89% of the total number of extracted terms. This result is in line with the coverage achieved in other studies [3,42–44], i.e., between 86% and 94%, in representing guidelines' concepts by using SNOMED CT.

Sonnenberg and Hagerty [45] did a study about the number of clinical concepts required to implement two selected guidelines and the degree to which they are currently captured by the electronic medical records. They found that only a minority of terms (24%) referred to simple concepts, collected in the medical records in the form required for application of the guideline. They found that guidelines lack explicit definitions of many important terms necessary for automating guidelines. This finding is described in more studies [46,47]. Similar to the study of Peleg et al. [46], we also often encountered that a guideline term was too general to appear as a patient data item in electronic medical records. Guidelines often employ general or aggregated terms that require

Table 6
Partially matching and non-matching concepts that should be represented by SNOMED CT.

Extracted concepts	Closest matches
Partial matches	
Length of upper incisors	251291004 | dental measure |
Relation of maxillary and mandibular incisors during normal jaw closure	25272006 | dental occlusion |
Visibility of uvula	424242006 | on examination – soft palate, fauces and uvula visible |
Length of neck	364412008 | measure of neck |
Expected severity of post-operative pain	405161002 | pain level |
Acquired blood disorders	414022008 | finding of cellular component of blood |
No matches	
Relation of maxillary and mandibular incisors during voluntary protrusion of mandible	
Compliance of mandibular space	
Impairment of upper airway protective reflexes	
Non-surgical procedure	
Invasiveness of the procedure	
Shape of palate	

knowledge not contained in the guideline document [45]. For example, one of our guidelines used the general term "metabolic disorders," without mentioning different types of this class of diseases, whereas the clinical information system stores e.g., "amyloidosis." Providing this type of knowledge and determining if actual patient data belongs to the concept mentioned in the guideline requires a terminology service that can return all valid subordinates for the concept used in the guideline [23]. SNOMED CT fully supports this functionality by its hierarchical structure. However, in some cases mapping of the aggregated concepts to SNOMED CT seemed to be possible, but the subordinates under the mapped SNOMED concept had a different meaning compared to the guideline. This makes representation of the guidelines hard. For example, the subordinates of the SNOMED CT concept "nose and throat examination" includes the concept "rhinolaryngologic examination under general anesthesia" that is not part of the pre-operative airway examinations, which is mentioned in the guideline. Creating a SNOMED CT subset with excluding such subordinates of a concept may often allow for a precise definition of the set of concepts of interest [23].

Evaluating partially and non-matching concepts using the editorial documentation of SNOMED CT(28) helped us to achieve a better understanding of the coverage of SNOMED CT in the evaluated pre-operative assessment domain. To our knowledge, this is the first study that took a closer look at non-covered concepts to find out the possible reasons. This helped us to clearly distinguish deficiencies attributable to the guidelines or to SNOMED CT. Thus, it made clear where to put our efforts to further improve the content coverage of SNOMED CT for the evaluated domain. Moreover, highlighted deficiencies of guidelines may lead to revisions that make those guidelines more useful [48]. Other studies can apply our approach to explicitly distinguish the deficiencies associated to the terminological systems and deficiencies associated to the guideline.

The results of our study confirm the results of other studies [16,49,50] that point out vague terms in the paper-based guidelines. This vagueness reveals the necessity of defining more specific guidelines as a first prerequisite to achieve the goal of guideline formalization [49]. The use of unstructured text hampers the unambiguous clarification and identification of all terms used in the guidelines. Given that most guidelines contain recommendations that are formulated as unstructured text, the results of our study regarding the guidelines in the field of the pre-operative assessment are probably generalizable to guidelines developed in other fields. To overcome this problem, we recommend developing the guideline and guideline implementation by a DSS concurrently and collaboratively. Studies have demonstrated that such an approach provides both benefits to the quality of the guideline as well as to the DSS [51].

Using one terminological system to present the guideline concepts in our study can be a limitation. As shown in other study [3], possibly better results could have been achieved when different standard terminologies covering different domains were combined, e.g., UMLS.[6] This limitation should be addressed by future work. We decided not to use UMLS to represent the pre-operative assessment guideline concepts as we intend to make use of the compositional (i.e., ability to use post-coordination) and formal functionalities (i.e., formal definition of concepts) of SNOMED CT, which are not included in UMLS. These functionalities are needed for guideline representation to present generic terms.

The problem of non-covered concepts will be solved partly by combining other terminological systems. Some of these concepts (those presented in Table 6) such as "Visibility of uvula" should be presented in SNOMED CT because they are non-vague and they follow the SNOMED CT editorial principles or rules. We will submit the list of non-covered concepts to the International Health Terminology Standards Development Organization (IHTSDO) for possible inclusion in the next international SNOMED CT release. More sophisticated post-coordination mapping can be developed in order to provide more mappings. For instance, to present the concepts like "length of upper incisor" and "length of neck", it should be possible to combine the anatomical sites with different measurements to create a post-coordinated concept. An additional recommended solution is for guideline developers to identify how such information is documented in electronic medical records as part of the guideline development process. In the medical records it is more likely to specifically write "removal of ectopic fetus" instead of general term "obstetric procedure."

The overall goal of this study was to facilitate interoperable guidelines and decision support systems in routine pre-operative assessment practice. It is important to consider that the problem of guideline sharing is more than just a terminology problem; it is a conceptual problem of the interface between the electronic medical records and guideline-based CDSS [52]. A standard terminology would solve only a part of the problem. Guidelines dependent on the structure of local electronic medical records and the structures of the medical records in different settings are often too different. Therefore, a common information model such as HL7 RIM might help to create a uniform model [21].

Differences in the selection and naming of patient data are a fundamental problem for sharing guidelines that act upon patient data in clinical information systems. Lack of structured and standardized methods for data recording may result in lack of semantic interoperability between terms used for data recording and terms used in guidelines. This has to be solved before guideline formalization [16]. In our case, we first tried to solve this problem by using SNOMED CT subsets as domain ontology for data recording in the pre-operative assessment setting [13]. Then, based on the result of this study, we will extend these subsets to cover the required concepts for guideline representation. Based on mapped concepts; new concepts, attributes, and relations will be added to the defined domain ontology.

6. Conclusion

Encoding guidelines using SNOMED CT highlights the importance of consistent and explicit definitions of concepts when creating a guideline. Many guidelines are significantly difficult to formalize as they include vague terms. This negatively affected the content coverage of SNOMED CT in representing concepts used in pre-operative assessment guidelines. To optimize and implement SNOMED CT, guideline vagueness should be resolved first and a few currently missing concepts should be added to this terminology.

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