SNOMED CT Implementation
Mapping Guidelines Facilitating Reuse of Data

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Summary
Clinical practice as well as research and quality-assurance benefit from unambiguous clinical information resulting from the use of a common terminology like the Systematized Nomenclature of Medicine – Clinical Terms (SNOMED CT). A common terminology is a necessity to enable consistent reuse of data, and supporting semantic interoperability. Managing use of terminology for large cross-speciality Electronic Health Record systems (EHR systems) or just beyond the level of single EHR systems requires that mappings are kept consistent. The objective of this study is to provide a clear methodology for SNOMED CT mapping to enhance applicability of SNOMED CT despite incompleteness and redundancy. Such mapping guidelines are presented based on an in depth analysis of 14 different EHR templates retrieved from five Danish and Swedish EHR systems. Each mapping is assessed against defined quality criteria and mapping guidelines are specified. Future work will include guideline validation.

1. Introduction
To support a consistent and unambiguous representation of information in eHealth, clinical terminology systems have been a focus of attention in scientific research. The unique identifiers and the conceptual structure representing each concept in a terminology system allow an unambiguous interpretation of the concept’s meaning across systems. This is beneficial for the use of information in both clinical practice and for secondary purposes [1]. In clinical practice the potential benefits are the capability of creating patient oriented overviews, based on specific queries, which can provide the physician information relevant for a current treatment or diagnostic process. For secondary purposes different actors may benefit from an unambiguous data representation for aggregation and comparison of clinical data supporting quality assurance and research.

The Systemized Nomenclature of Medicine – Clinical Terms (SNOMED CT) is a promising clinical terminology system. SNOMED CT contains more than 311,000 active concepts organized into hierarchies. The top level hierarchies define the types of concepts available to describe clinical information e.g. clinical findings, observable entities, procedures and body structures. Also concepts are available to clarify the meaning of other concepts as e.g. social context and qualifier value. SNOMED CT has a complex multi axial and compositional structure. Compositional means that if a given term cannot be mapped to SNOMED CT, two or more SNOMED CT concept can be combined to form the meaning of the term. This is referred to as post-coordination whereas terms that can be represented with one SNOMED CT concept are pre-coordinated [2]. SNOMED CT has shown superior coverage and flexibility compared to other terminologies [3–6], and studies have been performed in multiple clinical fields [7–9]. The current content and structure gives rise to expressiveness of SNOMED CT, but there are also a number of issues. Actually, studies show that even by the use of SNOMED CT, as a common clinical terminology system, redundant representations of identical clinical information occur [10, 11]. The issue of redundancy leads to a limited applicability of SNOMED CT, as retrieval and comparison of clinical data across systems cannot be done in an accurate and trustworthy manner.

Redundancy problems are highlighted in coding variability studies. In a study performed by Andrews et al. [11] the variability found was partly due to different levels of contextualizing the data and also due to different approaches to perform post-coordination. Overall, the study emphasizes the need for consensus and communication regarding the use of SNOMED CT. Additionally [12], documents comparable results. Also, redundancy is not the only shortcoming in SNOMED CT that hinders efficient use, also gaps in the terminology, a lack of compositional structure and consistency problems are reported issues [13].

At least two main approaches, not mutually exclusive, has been proposed to improve the limited applicability of SNOMED CT, namely, structural improvement and selective retrieval. Structural improvement denotes the wide range of re-thinking the formal logic/formalism of SNOMED CT. The research includes e.g. improvements of formal logic [14], standardising the formal logic by using OWL [15] and improving
consistency of post-coordination [16]. As for the second approach, Dolin et al. has introduced the method of ‘selective retrieval of pre and post-coordinated concepts’, to overcome the issue of redundancy and coding variation. The idea with this method is to use the defining characteristics of a concept expressed in a common form to query and retrieve stored information. So, instead of being limited to only retrieve information based on the hierarchical structure, each of the defining characteristics of a concept can be used as entries for detailed queries. However, the primitive concepts in SNOMED CT hinder the use of this approach, due to the lack of established definitional roles [10, 17]. “If a concept is primitive its place in the subtype hierarchy may be known but it cannot be checked for equivalence with another concept expression or post-coordinated expression” [18].

Even though the research community continuously adds to the improvement of SNOMED CT, reported use of SNOMED CT for practical purposes is limited [19]. One possibility for practitioners could be to wait until the structure and content of SNOMED CT is complete. However, completeness is seldom cost effective, since much of the terminology would never be used in practise [20]. Therefore, how can the use of a terminology system like SNOMED CT be beneficial for primary and secondary purposes despite its incompleteness?

2. Objective

The objective of this study is to provide a clear methodology for SNOMED CT mapping to enhance applicability of SNOMED CT despite incompleteness and redundancy. Redundancy can be reduced by applying a set of rules that clarifies which SNOMED CT term to choose among a set of candidate mappings. Earlier studies has shown that consistency can be improved through mapping guidelines [1, 21]. In this study guidelines are designed to make sense in a multi-organisational and multi-speciality context and to allow clinically meaningful querying for primary and secondary purposes.

3. Methods

The method section contains a presentation of the material chosen for this study, the guideline design method, the mapping quality criteria, and the mapping process.

3.1 Material

In order to obtain a multi organisational and multi speciality focus, the guidelines presented are based on an in depth analysis of 14 different Electronic Health Record (EHR) templates from five EHR system implementations – three Danish and two Swedish. The EHR templates describes the mark up of clinical information rather than the clinical information itself and are used for documentation in clinical practise (see example in Figure 1).

The EHR templates, included in this study, represent a variety of granularity, as both general and specialty specific information is represented. Thus, the guidelines can be adapted to different types of information and different levels of granularity. Also, the variety allows investigation of how mapping on different granularity levels can be kept consistent. The EHR templates, included in the study, are shown in Figure 2.

3.2 Iterative Guideline Design Method

The guidelines are developed iteratively as shown in Figure 3. Initially, we developed a set of quality criteria that would support meaningful querying. We used these to de-
fine the first set of guidelines. The guidelines were used to map the interface terms of EHR templates to SNOMED CT. The mapping result was assessed using the quality criteria. Problems were identified and possible solutions formulated as new guidelines that replaced or supplemented the original guidelines. The refined guidelines were used to edit earlier mappings and continue with mapping the interface terms of more EHR templates. We continued until all 14 templates were mapped and fulfilled the quality criteria.

### 3.3 Quality Criteria

The quality criteria were formulated on a basis of the objectives of supporting meaningful querying in a multi-organisational context. Meaningful retrieval requires relations between SNOMED CT concepts, so that querying for e.g. findings of the cardiovascular system will retrieve various related information like ECGs, pulse and narratives describing cardiac assessments. Also, consistency is important, so that different interface terms in different organisations with similar semantic content are mapped to the same term. This means that querying for e.g. blood pressure will result in retrieval of blood pressures from EHR systems in the organisations.

These quality criteria have to be refined, given the incompleteness of SNOMED CT. Firstly, the primitive concepts miss defining relationships. Secondly, the redundancy causes different organisations (or even the same organisation) to choose to map similar content to different SNOMED CT codes. The implications of not refining the quality criteria can be illustrated with an example. The three interface terms ear, nose and throat can be used to represent three text fields in an EHR template. Without considering the shortcomings of SNOMED CT, the mapping could be done in various ways as illustrated in Figure 4 (left side figure), where the term ‘ear’ could be found in the observable entity hierarchy, the term ‘nose’ could be found in the clinical finding hierarchy and the term ‘throat’ could be found in the body structure hierarchy. In Figure 5, the same interface terms are mapped to the clinical finding hierarchy. Mapping to the same hierarchy means the IS-A relationships provide the information that the three concepts are inherited from the concept ‘Finding of head and neck region’. A single query on ‘Head and neck region’ will therefore result in information about ear nose and throat coming from the three text fields, without having to specify their exact concept IDs.

Being aware of the importance of consistency in the selection of hierarchies and concepts facilitate the possibility of introducing fields for more granular information within the same clinical domain. Selecting concepts that are inherited by the coarse grained information will solely enlarge the sample space for a given query without being dependent on any query modification. Therefore, this approach supports the bridging between the coarse grained expressions applied in most of the general EHR templates and the fine grained expressions that are seen in the specialty specific templates.

In conclusion, the quality criteria are:

- Meaningful relationships between SNOMED CT concepts must be ensured. Given the issues of SNOMED CT, meaningful relationships are IS-A relationships, as these are always present.
- Consistent mapping should be ensured within and across organisations.

### 3.4 Mapping Process

The mapping was done by the two authors, who are both familiar with official SNOMED CT guides [2, 18, 22]. Our own...
set of guidelines was chosen over official guides, when they conflicted, to ensure fulfillment of the quality criteria. The first encoding of an EHR template was done by one of the authors in accordance with the guidelines. Furthermore, all encoded terms were reviewed by the other author to ensure accordance between coding and guidelines. When the guidelines were not sufficient to ensure unambiguous mapping, the cases were assessed and discussed using the quality criteria as guidance. When in doubt about the meaning of an interface term, we discussed the meaning of the term with the organisation, from which the term originated. Also, difficult mapping cases were discussed with the national release centre. We chose not to measure inter-rater variability, because we wanted to formulate a clear methodology to ensure similar coding practice. Discussions throughout the encoding process were therefore considered more appropriate. Doing this, in the beginning, many discussions and a lot of time was used to ensure consistency, this continued until the point where all the guidelines were formulated. After this point we mapped the rest of the material without needing much discussion.

4. Results

The result section presents the guidelines in three parts: The first part is about how SNOMED CT hierarchies can be chosen based on types of information in the EHR template. The second part is about how mapping consistency can be balanced with mapping precision. The third part is about consistency in post-coordination. An overview of the developed guidelines is shown in Figure 5.

4.1 Hierarchy Selection Based on Type of Information

In Figure 4, the hierarchy selection based on type of information is illustrated. The types of information are presented in the following.

4.1.1 Types of Information

The highest level is ‘organizing elements’ and ‘result elements’. The title of an EHR template, such as ‘Physical examination’ or ‘Nursing status’ is considered an ‘organizing elements’. However, an EHR template may consist of multiple section headings e.g. ‘smoking behavior’ or ‘cardiovascular stress testing’. These are also organising elements. Result elements can be subdivided into text fields, numerical fields and lists – and lists of cause consists of list items. They specifies result fields where the underlying SNOMED CT concept should represent the meaning of the interface term. Lists can refer to both drop down menus, check boxes and radio buttons.

The mapping result is presented in Table 1. The expressions were categorized as ‘not mapped’ when the exact meaning of the clinical expression were not represented in SNOMED CT, and thereby hindered achieving the quality criteria.

As we have mapped templates with similar clinical purpose from different organi-

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Fig. 4  Left: Illustration of how the expressions, ear, nose and throat can be represented by SNOMED CT without considering the sufficient hierarchy and concept selection. Right: Illustration of how the expressions, ear, nose and throat can be represented by SNOMED CT considering the sufficient hierarchy and concept selection.
sations, many fields have similar semantic content. This is actually the strength of the material since a clear encoding methodology will reveal similar information in different templates. This meant that in our study 234 SNOMED CT pre-coordinated concepts represented 435 interface terms. The number of unique SNOMED CT concepts is reflected in the ‘unique’ categories in Table 1.

4.1.2 Organizing Elements

As a main rule ‘organizing elements’ were represented by procedures or clinical findings. Procedures were selected when the ‘organizing element’ represented an evaluation method for obtaining a set of results. E.g. ‘physical examination (procedure)’ were chosen for the outer ‘organizing element’ as it represented the content of the entire EHR template and the concept ‘respiratory finding (finding)’ were selected as ‘organizing element’ for the expressions ‘Finding of rate of respiration’, ‘Finding of arterial oxygen concentration’ and ‘Peak expiratory flow rate’. Because ‘organizing elements’ served as parents for a group of more detailed expressions, and therefore represented a coarse grained expression, SNOMED CT performed with high pre-coordinated coverage, as only three cases of post-coordination were needed.

4.1.3 Text Fields

These are fields where the content is represented by free text narratives. The SNOMED CT concept representing the content of ‘text fields’ should balance the issue of not being too general and thereby insignificant for the meaning of the content, and not too specific and thus peril to insignificance for the meaning of the content. This is actually the strength of the material since a clear encoding methodology will reveal similar information in different templates. This meant that in our study 234 SNOMED CT pre-coordinated concepts represented 435 interface terms. The number of unique SNOMED CT concepts is reflected in the ‘unique’ categories in Table 1.

4.1.4 Numerical Fields

Both clinical findings and observable entities can be chosen. In some situations where clinical expression covers a numerical field it is seen that observable entities cover a whole group of concepts better than that of clinical findings. There were 121 numerical fields in the material of which 85 were descriptive for the content of the field and not solely describing the type of supplementary field. Figure 6 exemplifies how to map the supplementary fields of the sections ‘physical examination’ and ‘respiratory finding’ by the use of this guideline. An additional finding was that the qualifier values available for representing supplementary fields lack consistency in their composition and lack coverage.

Table 1 Overview of the mapping result. A total of 583 clinical expressions were included in the 14 EHR templates, divided into the different types of information. The table shows the distribution of applied pre and postcoordination.

<table>
<thead>
<tr>
<th>Type of information</th>
<th>Organizing elements</th>
<th>Result elements</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Text fields</td>
<td>Numerical fields</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>326</td>
<td>121</td>
</tr>
<tr>
<td>Pre coordination</td>
<td>24</td>
<td>242</td>
<td>85</td>
</tr>
<tr>
<td>Unique pre coord.</td>
<td>21</td>
<td>106</td>
<td>38</td>
</tr>
<tr>
<td>Post coordination</td>
<td>3</td>
<td>42</td>
<td>24</td>
</tr>
<tr>
<td>Unique post coord.</td>
<td>3</td>
<td>31</td>
<td>18</td>
</tr>
<tr>
<td>Not mapped</td>
<td>4</td>
<td>42</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 2 Examples of the two types of lists represented in this study. The guideline for mapping the list and additional list items is also illustrated.
were mapped as pre-coordinated concepts, 24 as post-coordinated concepts and 12 concepts were not mapped (Table 1). Of the 38 concepts unique pre-coordinated SNOMED CT concepts, 23 were represented by clinical findings and 15 expressions by observable entities. A corresponding result was found in the post-coordinated expressions where clinical findings were the primary concepts in 7 cases, and observable entities were primary concept in 5 cases. Additionally, situations with explicit context are used to represent 6 cases as they facilitate the possibility to specify the ‘family history of’ some specific clinical finding.

In general observable entities are used to represent groups of information, such as a group of information related to the respiratory measures or cigarette consumption etc. However, it is not clear when SNOMED CT discriminate the use of observable entities and clinical findings regarding such specific measures. Therefore, it is recommended to search both hierarchies when representing an expression covering the content of a numerical field.

4.1.5 Lists and List Items

In this study two types of lists are present, representing either:
1. a result of some specific evaluation
2. a procedural status

The mapping of the lists and the list items depended on the actual type of list. Hence, for ‘lists’ that represent an evaluation result, as ‘text fields’, clinical findings are selected as the main hierarchy. For the latter, the procedural hierarchy is selected as the ‘list’ that should be represented by the exact concept for the procedure. Examples of the two types of lists are given in Table 1.

In this study a total of 27 lists with a total of 78 list items were represented. From the 27 lists, 14 cases represented results of a specific evaluation whereas 13 represented procedural statuses. In five cases, it was not possible to map the list to SNOMED CT, but for all other cases the described mapping guideline was adapted. Post-coordination was applied in five cases to specify the semantics of the expression.

When mapping ‘list items’ for ‘lists’ representing result values for an evaluation, clinical findings are used, as they per definition represent the result of a clinical observation, assessment or judgment, and include both normal and abnormal clinical states [2]. For the list items representing a specific status of a procedure, the list item is represented by the post-coordinated expression of the specific procedural concept combined with a qualifier value descriptive for the status of the procedure.

Balancing mapping consistency with mapping precision This guideline specify that consistency in the concept mappings are prior to performing the most exact concept mapping. This recommendation is included, because the most precise mapping due to the actual clinical expression may in some cases induce inconsistency in the SNOMED CT concept representation of the total set of interface terms, hereby violating the quality criteria. This can either be due to inconsistency in the terminology composition or due to inexpedient choice of expressions in the EHR templates. Fig. 7 shows the interface terms in ‘Spiro-

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**Fig. 5** Illustration of the mapping guidelines related to the type of information of the clinical expression. Through the iterative approach, we selected concepts from as few hierarchies as possible to represent the interface terms.
metrical measurements. The example in Table 3 illustrates how mapping consistency is selected prior to precision.

The three underlined mapping selections in Table 3 were selected even though part of the information in the interface term 'reversibility trial' and 'beta 2 agonist' is neglected. It is assessed that the main semantics of the expression is maintained, as the reversibility trial typically is performed by a spirometry trial, and the beta 2 agonist is a type of bronchodilator.

4.2 Consistency of the Primary Concepts of Post-coordinations

As a main rule, pre-coordinated expressions are chosen over post-coordinations. However, post-coordinated expressions may be chosen if that means improving the overall consistency, like in the spirometry example in Table 3.

Post-coordination by refinement or post-coordination by qualification is used in accordance with the official SNOMED CT guides. However, the primary concept in the post-coordination should follow the additional guidelines specified in this study. The primary concept is the concept that is subject to the refinement or the qualification. This means that querying can be based on the primary concept but not the other parts of the post-coordination.

Mapping the EHR templates showed that interface terms can be compound expressions like 'Family/network' or 'Sexuality and reproduction'. These expressions usually involve 'AND' or in some situations the symbol '/'. It would be best from a semantic viewpoint, to divide the concepts into separate concepts and fields, each with their unique SNOMED CT representation. Thus, each term representing the contents of a single free text field, leading to a more accurate and consistent registration compared to keeping the terms composite. E.g. in the example of 'sexuality and reproduction' keeping the concepts composite will inflict a situation where it is not possible to distinguish whether the information relates to:

- a) The patient’s sexuality, related to the patient’s behavior.
- b) The patient’s abilities in relation to reproduction, related to the patient’s physiology.

But, in situations where this is not possible or feasible, or as in this study, where we did not change the structure of the EHR templates, post-coordination by combination is performed. Post-coordination by combination is defined in [22] as the type of post-coordination to be used for cases where neither of the concepts is really a qualifier of the other. To ensure consistency, the concepts in the post-coordination should inherit from the same top level hierarchy. This is possible for all of composite clinical expressions involved in this study, as only expression from the hierarchy 'clinical findings' were used.

5. Discussion

Meaningful relationships and consistency has been prioritized in the mapping process. This means that queries will make sense even though the EHR templates are developed in different organisations i.e. the
EHR templates related to physical examinations now all have coded their ‘eye/vision finding’ field with the same SNOMED CT code. Also, aggregations can be made e.g. searching for ‘Cardiac finding’ and descendants will retrieve information like ‘blood pressure finding’, ‘pulse rate finding’ and ‘finding of peripheral pulse’ from various EHR templates. However, searching for ‘Cardiac finding’ and descendants will not retrieve ‘electrocardiogram findings’ because of missing relationships between them. The missing IS-A relationships should be handled either by refining SNOMED CT or in queries. Another issue arises, because numerical fields are coded with both observable entities and clinical findings. This means that e.g. the lung parameter ‘Forced expired volume in 1 second before bronchodilation’ is an observable entity, and will not be obtained when searching for ‘respiratory finding’. Queries should therefore be designed to use both the clinical finding and observable entity hierarchy as point of departure if the content of numerical fields should be obtained. This will also apply for the other types of information where more than one hierarchy is used. Still, querying is simpler than if only official SNOMED CT mapping guidelines had been applied, because the developed guidelines makes the limitations known and manageable.

Throughout the study, we assessed the mapping result using predefined quality criteria. However, practical experimental testing of the guidelines, showing whether they improve real cross organisation query tasks, is not within the scope of this paper. We agree with the concerns stated by Rogers in [20] that testing terminology can only be done if they are tightly integrated with complex information systems. This induces a fundamental evaluation problem, since it is difficult to distinguish the success or failure of the information system from the success or failure of the terminology. Sample retrieval tasks are a good suggestion in terms of meaningful evaluation but, basing the test on the same material that we used to develop the methodology would not be a fair evaluation. For evaluation, a method based on a new set of EHR templates and sample retrieval of information will be explored.

The fact that SNOMED CT has shown great coverage within many clinical domains may be regarded as a quality measure due to the extensive amount of pre-coordinated concepts. However, Zhang et al. state that the amount of pre-coordinated concepts can challenge the applicability of the terminology in terms of reusability. “From a quality assurance perspective, what is important is to ensure that pre-coordinated concepts can challenge the applicability of the terminology in terms of reusability. “From a quality assurance perspective, what is important is to ensure that pre-coordinated concepts can challenge the applicability of the terminology in terms of reusability. For example, consider a term such as ‘electrocardiogram finding’ which is mapped to various SNOMED CT concepts, but not to ‘electrocardiogram finding’ itself. This is because the ‘electrocardiogram finding’ concept is not part of the SNOMED CT hierarchy. Similar mapping issues have been addressed in other papers. Bakhshi Raiez et al. have developed an interface terminology on SNOMED CT for intensive care using the Apache IV terminology as a point of departure [26]. To ensure consistency they e.g. applied general rules for mapping certain Apache IV categories to certain hierarchies in SNOMED CT, much like we have mapped types of information to certain hierarchies in SNOMED CT. They also accepted partial matches to superordinate concepts, which show that considering the precision of mappings, is not a new phenomenon. Also, Park et al. have studied content coverage of SNOMED CT representing INCP concepts. They included similar rules in their guidelines, both in terms of categories to hierarchy mappings and partial matches. Furthermore, they discuss that sometimes INCP parent and child concepts

Fig. 7 Illustration of the expressions and the composition of the organizing elements related to the spirometry trial

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were mapped to different hierarchies e.g. ‘weight’ in the observable hierarchy and ‘overweight’ in the findings hierarchy [27]. The fact that we, as well as others, have developed SNOMED CT mapping guidelines, indicates that official IHTSDO guidelines should be expanded to ensure a more comprehensive official standard.

The guidelines provided by this study are based on a limited set of templates, and therefore not adequate for the entire spectrum of EHR templates and exceptions. However, the guidelines provide a starting point for unambiguous representation of information in EHR systems. Therefore, exception situations, or situations not covered by this material, should be assessed and the best compensation should be argued and documented.

This study shows that guidelines can be designed to support consistent mapping in a cross institutional and cross speciality context. However, the study has not touched upon how the resulting consistent sets of concepts can contribute to cross organisational interoperability and cooperation. Obtaining semantic interoperability requires both consistent terminology and information models, which was beyond the scope of this paper. Future investigations could explore how the proposed guidelines would affect the reported overlap between data models and terminology, which can lead to a conflict between the semantics of a given expression [28, 29]. How to balance the benefits of consistent encoding with the time and resource consumption of the mapping process is another unexplored theme that will be subject of future research.

### 6. Conclusions

This study has resulted in a methodology to obtain consistency and meaningful relationships in SNOMED CT mapping processes. The heterogeneous material applied in this study ensures that the mapping guidelines do not solely conform to a single EHR system or a single organization. The vision of semantic interoperability demands for a unique data representation across borders. The variety of the material, characterized by the different EHR systems and the different clinical specialties show that common guidelines can be developed to facilitate semantic unambiguosity, despite differences in IT solutions and clinical practices.

Even though, a common terminology system can support reusable clinical information, it is necessary to be rigorous in the selection of the concepts from the terminology. Otherwise, redundancy or unsuitable hierarchy selection can challenge the possibility to request uniform information. The prerequisite of the quality criteria, is to apply SNOMED CT in accordance with the refined guidelines, considering the type of information, the balance between consistency and precision and consistency of the primary concepts of post-coordinations.

In conclusion, the overall mapping rule is to represent related information homogeneously by selecting concepts from the same sub-hierarchy. The guidelines provide a framework for achieving a consistent mapping procedure and thereby a well-defined foundation for data retrieval. This approach is practical when we want to compare clinical information based on the hierarchical structure in SNOMED CT. Also, it will not limit the use of selective retrieval methods, as proposed by Dolin et al. [17] when sufficient definitions is added to SNOMED CT as the future. Future work should strive at qualifying and validating the specified guidelines by applying them to other domains and EHR systems.

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