Using OWL Ontologies for Clinical Guidelines Based Comorbid Decision Support

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Abstract

In this paper we present an ontology-based clinical decision-support framework for handling comorbidities by alignment of ontology modeled clinical practice guidelines (CPG). Our knowledge management approach to develop clinical decision support systems for co-morbid conditions entails: (a) knowledge synthesis to derive disease-specific clinical pathways (CP) from evidence-bases sources; (b) knowledge modeling to abstract medical and procedural knowledge from the CP; (c) knowledge representation to computerize the CP in terms of a CP ontology; and (d) knowledge alignment by aligning multiple CP to develop a unified CP knowledge model for comorbid diseases. We present the COMET (Co-morbidity Ontological Modeling & ExecuTion) system that provides decision support to handle comorbid chronic heart failure and atrial fibrillation. COMET is web-accessible and is designed for family practitioners.

1. Preamble

Comorbidity is the existence of medical conditions concurrent with a primary condition in the same patient. Chronic diseases are frequently associated with comorbidities. For instance, Chronic Heart Failure (CHF) is a common chronic condition that is often associated with comorbidities such as Atrial Fibrillation (AF), diabetes, chronic lung disease and stroke. CHF and AF are frequently referred to as two new epidemics of cardiovascular diseases [1]. Not only does CHF-AF commonly co-exist, they also complicate management of each other [2] so that the choice of the treatment depends on individual factors and therefore, needs to be individualized. Moreover, a significant care gap exists in the management of these cardiovascular diseases reflecting a discrepancy between the applied care processes and the evidence-based care processes [3]. The application of evidence-based Clinical Practice Guidelines (CPG) and clinical pathways (CP), at the point-of-care has the potential to reduce this care gap. According to definition provided by the American Institute of Medicine, CPG can defined as “systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances” [4]. A CP on the other hand provides a road map and timelines of the patient’s course of treatment and also lists the demands, activities and the capacity of the health care facility [5]. While CPG are based on a critical appraisal of scientific evidence and offer explicit recommendations, for clinical decision making along with supporting evidence, CP are used to implement these recommendations in actual clinical practice [6]. Recently, a number of initiatives have been taken to computerize and execute CPG. The approaches tend to range from classical knowledge based systems to data-driven to semantic web based systems. The emergence of semantic web based technologies; in particular the logic-based knowledge representation formalism offered by OWL ontologies, is of particular interest for modeling the rather complex medical knowledge encapsulated within CPG [7, 8, 9, 10, 11].
The state-of-the-art in computerization of CPG entails the computerization of a single CPG, connecting the executable CPG to electronic medical records, and embedding the system within the clinical workflow of the institution to offer case-specific decision support. Current CPG-driven decision support systems deal with a single disease and are unable to handle comorbid conditions. In order to deal with comorbid conditions, Notwithstanding the utility of current CPG-driven decision support systems to deal with single diseases (as per the CPG for that disease), such systems are unable to handle co-morbid conditions—i.e. when a decision support system has to refer simultaneously to multiple CPG and align the clinical workflow/activities stipulated by the multiple CPG to present a single pragmatic clinical workflow that takes into account the care activities for multiple diseases. The resultant co-morbid clinical pathway recommends clinical activities that are safe and consistent with the patient’s overall comorbid condition.

We argue that it is clinically prudent to handle comorbidities by applying evidence-based CPG. However, the simultaneous execution of more than one CPG, in order to handle comorbid situations, in a clinical decision support system is a formidable undertaking. The major challenge is the systematic synthesis and formalization of medical knowledge covering multiple conditions and applying this formalized knowledge with respect to the patient’s profile whilst maintaining clinical pragmatics. In comorbid situations, the complexity of decision support comes from the requirement to reconcile/align the interventions recommended by multiple disease-specific CPG/CP whilst ensuring clinical appropriateness, patient safety and task pragmatics.

In this paper, we present our knowledge management solution for clinical decision support to handle co-morbid diseases. We are particularly interested in primary care settings as they are the first point of contact with patients. We present the COMET (Co-morbidity Ontological Modeling & ExecuTion) system, which is capable of handling three patient care scenarios: (i) patient has CHF; (ii) patient has AF; and (iii) patient develops a CHF-AF co-morbidity. COMET is designed to address the knowledge needs of General Practitioners (GP) and is based on semantic web technologies for knowledge representation and execution. COMET has been evaluated by both simulated cases and by health professionals for its ability to handle single disease and comorbid case scenarios.

2. Methodological Approach

The use of Semantic Web technologies (SWT) for clinical decision support and care planning is well established. Our approach is to model the medical knowledge as an OWL (Web Ontology Language) ontology, and execute the modeled knowledge based on patient data [7, 8, 9, 10, 11]. OWL is endowed with declarative semantics and therefore allows association of natural language descriptions with formal semantics, allowing human and machine readability. Thus, the OWL based representation of CPG allows their enactment in a clinical setting [12, 13, 14]. To provide decision support to handle comorbid diseases, our approach is to align multiple CP (for the comorbid diseases) along common clinical care activities to develop a unified knowledge model that encapsulates the medical and procedural knowledge to handle comorbid diseases.

![Figure 1: Methodological Approach](image-url)

From a knowledge management perspective, there are two main approaches to aligning multiple CP to handle comorbidities: (a) aligning CP at the knowledge modeling level; and (b) aligning CP at the knowledge execution level [15]. In our work, we pursued CP alignment at the knowledge modeling level. We aligned ontologically modeled CP by establishing a conceptual mapping between their common concepts to realize a single comorbid CP.
Our solution approach entails four main aspects (Fig 1):
1. **Knowledge identification and synthesis** involves the development of specialized CP for handling the diagnosis and management of (i) CHF, (ii) AF and (iii) co-morbid CHF-AF. This involves the derivation of clinically pragmatic workflows and recommendations from a large number of existing CPG for CHF and AF. We developed two new CP for CHF and AF that target the clinical needs of primary care physicians.
2. **Knowledge modeling** involves the ontology-based modeling of the CHF and AF clinical pathways in order to semantically describe the diagnostic and treatment concepts in terms of clinical processes, tasks, decision-points, patient data, recommendations and information items. The knowledge modeling exercise resulted in an elaborate CP ontology that describes the CHF and AF diagnostic and treatment concepts and their interrelationships, and instantiates the CP for CHF and for AF.
3. **Knowledge alignment** involves the synthesis of the individual CP of comorbid diseases to yield a comorbid knowledge model. Through knowledge modeling the individual ontologically modeled CP for CHF and AF were aligned by establishing relationships between the care processes of CHF and AF, resulting in an ontologically modeled co-morbid CHF-AF CP.
4. **Knowledge execution** involves translation of the modeled CP to deliver clinical decision support to the physician to handle CHF, AF and comorbid CHF-AF.

3. **Knowledge Identification and Synthesis**

This phase involved the identification of relevant knowledge sources and their synthesis to develop specialized CP for CHF and AF. The primary sources of knowledge were paper-based CPG [16, 17]. The CPG are written as lengthy systematic reviews and essential do’s and don’ts of practice as well as clinical decision logic are embedded in these complicated documents. Since our approach towards comorbid knowledge alignment is to create a unified ontological model to represent and combine comorbid care pathways, we need to extract comorbid knowledge along with all the constraints on diagnosis and management of comorbid illnesses. Therefore, the main purpose of knowledge synthesis phase is to distill clinically useful task specific heuristics from respective CPG, in terms of their decision logic, available decision options, treatment constraints and preconditions and temporal ordering of tasks. We also incorporated information from locally developed treatment protocols to account for the scheduling of treatment tasks and resources availability at primary care clinics in Nova Scotia. We engaged domain experts to seek their experiential knowledge.

Given the complex nature of the CPG, a key challenge was to identify the essential task-specific heuristics in terms of decision logic, decision options, actions and sequence of actions in accordance with a general practice setting. We identified the essential do’s and don’ts of practice by using class I and class IIa recommendations in the CPG. According to the Canadian CPG, Class I recommendation refers to the evidence or general agreement that a given procedure or treatment is beneficial, useful and effective. Class IIa recommendation on the other hand means that the weight of the evidence is in favor of usefulness or efficacy. The knowledge synthesis exercise yielded algorithms for the diagnosis of CHF (shown in Figure 2) and AF.

**Figure 2: CHF Diagnosis Algorithm**

In the final step of this phase, we developed two CP packages—one for CHF and another for AF. Development of the CHF and AF CP involved setting the systematic ordering and scheduling constraints—such as the sequencing, concurrency, branching and synchronization—between the various task specific heuristics distilled from the CPG, and relating them through decision and ordering constructs. Given the complexity of CHF and AF, each CP consisted of multiple care plans corresponding to various patient care activities and interventions, such as the initial clinical assessment, diagnostic investigations, pre-treatment evaluation and correction of electrolytes, treatment plans and patient education.

The CP algorithms developed during the knowledge synthesis phase, despite being an unambiguous enactment of the guideline logic, are still high-level overviews and simplified idealizations of the comorbid individual CPG. These CP are used to develop a unified ontological model using OWL (Web
Ontology Language) to create an expressive model that can encompass the comorbid CP along with treatment constraints and preconditions. The choice of OWL, for comorbid knowledge alignment, was guided by the fact that it offers declarative semantics that allows us to associate natural language descriptions with formal statements, thereby allowing human and machine readability. Section 4 describes comorbid knowledge modeling phase of this research.

4. Comorbid Knowledge Modeling

In this phase, the synthesized knowledge (two comorbid CP) is modeled and formalized in terms of a dedicated ontology; developed using OWL. The main purpose of knowledge modeling is to generate an explicit and formally described semantic structure based on the clinical pathways synthesized in the previous stage, so as to (i) formalized comorbid care plans, their alignment points and preconditions for the comorbid alignment, (ii) instantiate the formalized model with comorbid CP and (iii) enable the computer applications to execute the formalized model at the point of care.

First we conceptualized the CP knowledge in terms of main concepts, relationships among them and their restrictions in order to outline the dependencies among the care plans that are to be represented in the CP ontology.

Table 1: Open, Axial and Selective Coding

<table>
<thead>
<tr>
<th>Open Coding</th>
<th>Axial Coding</th>
<th>Selective Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taking patient’s history</td>
<td>Initial diagnosis assessment</td>
<td>Diagnostic assessment</td>
</tr>
<tr>
<td>Performing physical exam</td>
<td>Ordering and evaluating routine blood tests</td>
<td></td>
</tr>
<tr>
<td>Evaluating patient’s NYHA functional class</td>
<td>Ordering and evaluating thyroid functional tests</td>
<td></td>
</tr>
<tr>
<td>Ordering and evaluating Chest X-ray</td>
<td>Ordering and evaluating BNP</td>
<td></td>
</tr>
<tr>
<td>Ordering and evaluating ECG</td>
<td>Ordering and evaluating of echocardiography</td>
<td></td>
</tr>
<tr>
<td>Determining left ventricular systolic dysfunction</td>
<td>Final heart failure diagnosis</td>
<td></td>
</tr>
</tbody>
</table>

The data analysis process of Grounded Theory (GT) [18] was used as a key method for the conceptualization of the domain. In our work, a great deal of data analysis was carried out in the knowledge synthesis phase that involved the disambiguation and interpretation of guideline logic and organization of care processes. We regard the series of flowcharts for CHF and AF diagnosis and management as appropriate high level theory and relevant textual data. We further analyzed the flow-charts line-by-line in order to identify comprehensible patterns. We performed open, axial and selective coding (Table 1) on all data in order to achieve a conceptualized model of concepts and their relationships.

The key activity in this phase was the development of an ontological model to represent the CP knowledge. The CP ontology is designed as a care flow model, whereby it models the patient’s induction into the clinical pathway and captures his/her transition through various stages of diagnosis and treatment depending on whether the patient has a single disease or comorbidity. The care pathway is modeled through a series of properties that relate these main classes and subclasses. Fig. 3 & 4 shows some exemplar properties.

Figure 3: Properties linking main classes

Figure 4: Classes and properties modeling medication dose uptitration

The ontology is built in OWL using the ontology editor Protégé. We provide a description of the structure of the CP ontology. For the purpose of clarity,
class names are written in UPPERCASE letters. The properties (i.e. relationship between the classes) are italicized and the Individuals (instances) are capitalized.

The main concepts are represented as a hierarchy of high-level classes as follows:
- **PATIENT** refers to individual patients who enter the system.
- **CLINICAL_PATHWAY_ENTRY_POINT** refers to points in the CP where a patient depending on his/her current clinical status may enter in the pathway.
- **DIAGNOSTIC_CONCEPT** refers to all the concepts related to diagnosis of CHF or AF, such as history, physical exam and tests results etc.
- **MEDICATION** refers to all the medication groups involved in the treatment of CHF or/and AF, such as ACEI, BB, Diuretics, calcium channel blockers, etc.
- **TASK** refers to diagnostic and therapeutic tasks in the CHF or/and AF CP.
- **TREATMENT_CONSTRAINT** refers to the different kinds of constraints on the treatment of CHF or/and AF, such as treatment contraindications, medication dosage, uptitration schedules, treatment monitoring etc.
- **DECISION_OPTION** refers to all the decision points in the CHF and AF CP.
- **TEMPORAL_CONCEPT** represents all time annotations, such as wait interval between two tasks, or the frequency of certain actions etc.
- **STATUS** refers to current clinical status of the patient.

Table 2 depicts key properties in the ontology with their domain and ranges.

### 5. Comorbid Knowledge Alignment

From a knowledge modeling perspective, the requirements to handle comorbidities are: (i) identifying common comorbid care activities; (ii) ensuring clinical tasks are not replicated; (iii) temporal relationships between the activities are clearly identified; (iv) preconditions for specific tasks are explicitly stated; (v) potential risks and harmful events when aligning the comorbid processes are noted; and (vi) care for comorbids diseases are coordinated to improve efficiency and patient safety.

Knowledge alignment in the context of this research is defined as alignment of discrete and ontologically defined care plans in response to single disease or comorbid preconditions. Comorbid knowledge alignment is therefore different from ontology alignment. The knowledge alignment is thus manual alignment. Thus no ontology alignment techniques were used in this work. Our approach towards the comorbid knowledge alignment is to develop a unified ontological model that encompasses the combined knowledge of ontologically aligned CP. This means that any potential terminological or conceptual heterogeneity that might arise as a result of comorbidity has been resolved manually during the knowledge synthesis and modeling phases. Also, relationships between the comorbid individual care plans and treatment/safety constraints on these relationships have been established during the ontological modeling of the comorbid CP.

![Figure 5: Aligning CHF and AF plans. The dashed arrows indicate the alignment between the plans of CHF and AF to handle comorbid CHF+AF](image)

We pursued the alignment of the CHF and AF CP at the knowledge modeling level—i.e., concepts and relationships were systematically aligned manually within the CP ontology to realize an instantiation of a comorbid CHF-CHF AF CP. Our ontology alignment approach formalizes the functional relationships between the care processes within different CPG leading to them being combined to handle comorbidities. Thus, the above requirements to handle comorbidity are taken care of during knowledge synthesis and formalization stages. In such a way we are able to validate the formalized knowledge against the above constraints before it is executed. We explain below the alignment of the CHF and AF CP.
The class CLINICAL_ENTRY_POINT is instantiated by a number of plans to account for the various points during the patient care process. These plans are classified into: (i) discrete care plans that are valid only when a patient has either CHF or AF, and (ii) comorbid plans that are valid when patient has a concurrent illness.

Figure 5 gives a schematic of the alignment of the CHF and AF plans, where the last two care plans from the CHF pathways—i.e. ‘CHF entry point 4 - Pre-treatment electrolytes correction and assessment’ and ‘CHF entry point 5 - initiation of the treatment of heart failure’ are aligned with the comorbid plans—i.e. ‘CHF-AF entry point 1- Thromboprophylaxis for patients with AF and CHF’, and ‘CHF-AF entry point 2- Treatment for atrial fibrillation for patient with heart failure’.

Table 2: Key properties in the model with their Domains and Ranges

<table>
<thead>
<tr>
<th>Domain</th>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Patient</td>
<td>has pathway entry point</td>
<td>Clinical Pathway Entry Point</td>
</tr>
<tr>
<td>2 Clinical Pathway Entry point</td>
<td>has task</td>
<td>Task</td>
</tr>
<tr>
<td>3 Task</td>
<td>is followed by task</td>
<td>Task, Clinical Pathway Entry Point</td>
</tr>
<tr>
<td>4 Task</td>
<td>apply to</td>
<td>Medication</td>
</tr>
<tr>
<td>5 Decision Option</td>
<td>apply to clinical feature</td>
<td>Contraindication, Treatment Precondition</td>
</tr>
<tr>
<td>6 Decision Making Task</td>
<td>has decision option</td>
<td>Decision Option</td>
</tr>
<tr>
<td>7 Medication</td>
<td>has uptitration schedule</td>
<td>Uptitration schedule</td>
</tr>
<tr>
<td>8 Medication</td>
<td>has dose</td>
<td>Dose</td>
</tr>
<tr>
<td>9 Medication Dose Uptitration</td>
<td>has next step</td>
<td>Decision Option</td>
</tr>
<tr>
<td>10 Medication Dose Uptitration</td>
<td>has wait interval</td>
<td>Wait Interval</td>
</tr>
</tbody>
</table>

To model the alignment of the treatment plans we established relationships among five main classes, these classes are the sub-classes of the main class discussed in section 4:

PRE-TREATMENT_DECISION_TASK
TREATMENT
DRUG_ADMINISTRATION_DECISION_TASK
PHARMACOLOGICAL_DECISION_TASK.

These preconditions are modeled as instances of PRE-TREATMENT_DECISION_TASK. For example, the instances ‘Determine any contraindication to ACEI’, ‘Determine any contraindications to Digoxin’, or ‘Determine any risk factors of digitalis toxicity’ are responsible for checking the presence of any contraindication or serious risk associated with any medication. ‘Determine presence of any signs of fluid overload’ is responsible for checking if the patient needs treatment with diuretics.

We related PRE-TREATMENT_DECISION_TASK to DECISION_OPTION through the property has_decision_option, such that the instances of DECISION_OPTION are available as options to the physician—i.e., decision options such as ‘ACEI is not contraindicated’ or ‘No risk factors associated for digitalis toxicity’ or ‘ACEI is contraindicated due to’ and ‘digitalis toxicity risk factors are present’. The last two instances of DECISION_OPTION are related through the property apply_to_clinical_feature to CONTRAINDICATION, which is a sub-class of TREATMENT_CONSTRAINT. Table 2 depicts key properties in the ontology with their domain and ranges.

In the CP ontology we modeled various therapy related constraints when handling comorbidities, such as: checking the presence of contraindications, potential risk factors, uptitration of drugs, informing the patient about side-effects, and so on.

This phase yielded an ontologically modeled CP for comorbid CHF and AF that was derived by systematically aligning the independent CHF and AF CP. The unified ontological model encompasses the combined knowledge of aligned CHF and AF CP. The model represents each CP as a combination of both common and unique concepts thus ensuring that each modeled CP maintain its unique identity.

6. Comorbid Knowledge Execution

The COMET system executes the ontology that is based on comorbid CP to provide CP based recommendations to primary care physicians to handle CHF, AF and comorbid CHF-AF. Knowledge execution involved the traversal of the CP workflow, as modeled within the CP ontology, where each state of the workflow contains two elements: (i) actions to be performed whilst satisfying relevant constraints; and (ii) potential next state [12]. To execute the CP, we used the Resources, Properties, and Property-Values of the CP ontology. The potential property-values are either a pre-specified range, or of type Resource. This allows the presentation of a range of property-values to
the user—the selections by the user determine the next step in the CP.

COMET assists physicians through a series of screens to help collect the patient information and then provide CP-based recommendations and actions. Based on the patient information, the patient is placed in a diagnostic class, say NYHA (New York Heart Association) class II. Next, COMET recommends tests and based on the results prompts the physician to calculate a cumulative Boston criteria score [19]. Given the high Boston score of the patient, COMET recommends echocardiography for confirmation of the diagnosis and the assessment of left ventricular.

Figure 6: COMET CDSS. The left window allows the selection of patient parameters and the right window displays the relevant recommendations and text

COMET proceeds with the initiation of heart failure therapy with inquiries to check for the presence of any contraindications to medications. For uptitration of drugs, COMET presents a separate uptitration pathway in a new tab.

Figure 7: Screen showing the launch of comorbid CHF and AF pathway

Suppose this patient complains of palpitations and the ECG tests is abnormal for AF in addition to the above clinical features. This launches the comorbid CHF+AF CP (Figure 7) and subsequently medication for the treatment of CHF and AF are concomitantly prescribed to the patient as shown in Figure 7. In this manner, COMET traverses through the entire active CP (see the multiple tabs in Figure 7), and at each step provide advice to monitor for treatment risks, contraindications, adverse events and prescription of assessments and medications. At the end of a CP COMET presents education material for the patient.

7. Evaluation

Evaluation of COMET was carried out in three stages: (i) Evaluation of the CP ontology for logical consistency; (ii) Internal validation based on clinical cases; and (iii) External validation by domain experts.

The CP ontology was evaluated for Consistency, Completeness and Conciseness [20]. We used an open source Description Logic reasoner—Pellet to perform subsumption tests to derive concept satisfiability and consistency. The consistency was checked on the basis of class descriptions as modeled in the ontology. The results conclude that the CP ontology is consistent and satisfiable, since it did not contain any contradictory information. To evaluate the ontology for completeness, we instantiated the CHF and AF CP. Our results indicate that the ontological definitions of structural criteria such as necessary and sufficient conditions of a predicate, domain and range of relations, generalization and specialization of classes, etc., have adequate representational capacity to capture comorbid domain and procedural concepts. We used Pellet to check the conciseness of the CP ontology by running tests on the classes to compute the inferred class hierarchy. Our tests did not show any redundant arcs in the ontology; hence the CP ontology was deemed to be concise.

One cardiologist and two primary care physicians performed the external validation of COMET. The purpose of external validation was to determine the correctness of clinical content in COMET. Our external evaluation entailed three separate testing sessions with the domain experts. In these testing sessions, we walked the experts through the main features of COMET—i.e., showing its knowledge, features and functionality—for the management of CHF and comorbid CHF-AF. The sessions were interview style and informal, in which the experts provided their feedback to medical content in COMET and to some extent, its functionality.

The cardiologist examined the medical knowledge and suggested some changes to the medical procedures; diagnostic tests decision values and drug choices. The recommended changes were readily implemented within the CP ontology by simply
reversing the sequence of individuals representing assessment of the electrolytes, so that checking of potassium is performed before that of sodium (Fig. 8).

Figure 8: If serum potassium < 5.5 mmol/L then the next step is to ‘evaluate serum sodium’

We were able to readily incorporate recommendations provided by the primary care physicians as well to our CP knowledge model. For example, physician-1 recommended the addition of certain tests such as Hba1c (glycosylated hemoglobin) and thyroid-stimulating hormone to the CP. We were able to add these two tests to the individual list of class INVESTIGATION in the CP ontology. Physician-2 felt that an application like COMET can be very beneficial in general practice, whereby a physician is able to identify low risk patients and can take appropriate steps for diagnosis and treatment. In particular, he was pleased to see additional task-specific information displayed with each recommended task, such as assessment of B-type Natriuretic Peptide (BNP) or using NYHA functional classification for identifying low risk patients. In general, reactions among the domain experts who tested COMET were unanimous that this application could help in the decision-making process with respect to diagnosis and treatment of CHF and CHF-AF. Our evaluation demonstrates the robustness of our CP ontology, as it was able to incorporate most of the suggested updates without the need to alter the structure of the ontology.

8. Conclusion

We have presented a knowledge management approach for handling comorbid diseases through (a) developing CP from various evidence based sources, (b) modeling the knowledge within individual disease-specific CP in terms of a CP ontology, and (c) aligning the ontologically-modeled CP of multiple co-morbid diseases to generate a unified knowledge model that contains procedures specific to the handling of comorbid diseases—these procedures are drawn from disease-specific CP. The comorbid CP model helps to (a) avoid duplication of intervention tasks, resources and diagnostic tests; (b) re-uses results of common activities; (c) ensures that different clinical activities, across different CP, are clinically compatible and their simultaneous application does not compromise patient safety; and (d) standardizes care across multiple institutions. Our unified ontological model encompasses the combined knowledge of aligned clinical pathways, i.e., it represents each CPG/CP as a combination of both common and unique concepts. This unified model coordinates the care activities necessary for handling comorbidities—this is different from simply concurrently executing the health care flow for individual diseases. We posit that alignment of CP is best pursed at the knowledge modeling level as it allows for a priori validation of clinical tasks for handling comorbid diseases, whereas the alignment of CP at the knowledge execution level may lead to inconsistencies in terms of clinical pragmatics. Our COMET system offers knowledge translation whereby primary care physicians are able to access evidence-based recommendations for the management of comorbid diseases at the point-of-care.

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10. References


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