An ontology approach to enhance interoperability for musculoskeletal problems

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Abstract - Musculoskeletal problems are leading causes of disability in adults with high health related costs to the system. Evidence suggests that obscure and inconsistent domain knowledge can create challenges to timely and relevant communication among multidisciplinary care providers in the management of these conditions. The primary objective of this study was to develop, test and evaluate a model and a methodology for creating an ontology in the heterogeneous domain of musculoskeletal and pain related problems. The methodology applied a two-staged approach for enabling interoperability, namely, development of a controlled vocabulary followed by an ontology. The ontology was developed from the knowledge that existed in 100 patient charts and among 8 domain experts. The chronic pain ontology contained 182 classes and over 51 data and 38 object properties. Sixty-seven percent of clinicians agreed on the overall usefulness of the ontology as a boundary object. Goal of this research was to enable better communication among multidisciplinary care providers through an ontology based interoperability.

Keywords: Ontologies, musculoskeletal problems, interoperability, multidisciplinary.

1 Introduction

Multidisciplinary care teams have come to the forefront as an effective management strategy for musculoskeletal problems [1–4]. Chronic low back pain (CLBP) is a complex condition requiring timely, cost effective and multidisciplinary care management and is significant in terms of related healthcare costs in Canada and the rest of the world [3,4]. CLBP is usually caused by a trauma to the lower back or certain diseases such as, arthritis. Acute back pain is typically managed by family physicians. However, individuals with chronic back pain are more complex in their needs and require multidisciplinary care management [1,2]. Studies have shown the consequences of poor communication among multidisciplinary care providers resulting in poor care experiences, over prescription of medical tests, misdiagnoses, delayed care and inaccurate treatment plans [5-7]. Studies have also demonstrated that clinical documentation is the primary source of communication in multidisciplinary management [8-11]. Studies have discussed the significant need to identify methods to improve collaboration and communication among care providers in order to facilitate seamless care for patients with complex health conditions [8].

In homogeneous environments, there are many approaches that have been discussed as methods to improve collaboration in health care such as controlled vocabulary, ontology, through health care routines, and medical rounds [12, 13].

There are many challenges to effective collaboration among multiple disciplines in the management of complex health conditions. Barriers to effective communication include dealing with poorly categorized knowledge with multidisciplinary, inconsistent and non-standardized clinical documentation with new knowledge emerging among various knowledge communities or groups of experts.

Figure 1 shows these important challenges to communication among care providers in the management of complex chronic conditions.

Figure 1: Interoperability in heterogeneous domains

CLBP and many other musculoskeletal problems have many of the outlined challenges to communication. Knowledge management and organization in heterogeneous domains of such complex conditions is a grand challenge for health informatics. In this paper, heterogeneous domains are defined as domains that are poorly categorized, multidisciplinary, non-standardized and inconsistent.

Ontologies have gained importance in recent years as a knowledge management platform in many areas including health care [13-15]. An ontology is “an explicit and formal specification of a conceptualization” [16]. An ontology consists of a finite list of terms or concepts and the relationship between these terms. Ontologies are preferred to conventional classifications due to the higher level of expressiveness that is possible in describing concepts and their relationships [14]. Despite their high level of
specification of these classes and relationships, ontologies also allow a great deal of flexibility. Ontologies have been typically developed in stable knowledge domains [17,18].

2 Related Work

Challenges in developing ontologies in heterogeneous domains have been discussed in the literature. Dominigue et al. [14] identify the key requirement for an ontology approach to knowledge management as a community’s perspectives being stable on an issue with “well defined roles”, “specified criteria” and “codified procedures”. Challenges related to developing ontologies when there is a lack of consensus in a community are discussed in the subsequent paragraphs.

A study by Larson and Martone [17], the challenges of formalizing knowledge for neuroscience were explored. The authors claimed that formalizing knowledge about poorly understood biological systems presents many obstacles to the development of ontologies. This study highlighted the importance of developing a layer of standardization prior to attempting higher level specification such as the creation of ontologies in the domain.

In a study by Lin et al. [18], the challenges of a mental health group of professionals working with emerging knowledge was discussed. This study describes the challenges and importance of building knowledge through ontologies in heterogeneous situations. This study presented the preliminary challenges that exist in the knowledge capture for a domain that has obscure definitions, lack of consensus, unstructured data, inconsistent use of vocabulary and assessment scales. A significant challenge encountered in this work was to bring structure to knowledge that continues to be generated in an ad hoc manner.

In a study by Qin and Paling [19], the importance of developing ontologies in heterogeneous domain was examined. The research describes the creation of an ontology from a well defined and well used controlled vocabulary in order to provide a higher level of semantics to the concepts in the vocabulary. Digital objects, such as those in the Gateway to Educational Materials (GEM ontology) encompass multiple dimensions of characteristics which often play important roles for users in search of precise information in an efficient manner. The authors suggest that a conventional cataloguing code will be inadequate to describe these details in a lesson plan, as many of these elements do not even exist in the vocabulary. In this study, the authors developed an ontology with the intention of adding another layer of semantic operability to the terminologies found in controlled vocabularies.

In this paper, we discuss the development of a model and methodology to enable interoperability through an ontology in the heterogeneous domain of musculoskeletal problems such as chronic low back pain.

3 Proposed Model for Interoperability

Figure 2 illustrates the architecture of our proposed two-staged approach to develop interoperability in the heterogeneous domains of complex conditions.

The first stage was the development of a controlled vocabulary to enable standardization, organization and consistency of the heterogeneous domain knowledge [20]. The second stage was the development of an ontology from the controlled vocabulary to enable formal representation of the domain concepts, description of the domain concepts and specification of relations between the concepts [19]. The interoperability developed have the characteristics at the pragmatic level (knowledge translation) of shareability, have the capacity to be dynamic in nature and are in standardized forms.

![Figure 2: Architecture of the model and methodology](image)

The first stage of the two-staged approach included the creation of a standardized and controlled clinical vocabulary. SNOMED CT® [21], a widely used reference terminology was used to standardize the concepts and terminologies found in the patient charts. A pragmatic approach [20] was applied in the development of the controlled vocabulary as the domain knowledge is heterogeneous.

The method for creating the controlled vocabulary was driven by the purpose of generating the goal and usage of the vocabulary. The development of the controlled vocabulary involved the creation of standardized and controlled clinical vocabularies at the levels of syntactic, semantic and pragmatic interoperability: chart audit and interviews with experts to identify key concepts in the domain of the complex condition (syntactic), standardization of the vocabulary by establishing concrete meaning for concepts (semantic), and testing and evaluation of the vocabulary by the users to evaluate the potential for knowledge translation (pragmatic). The chart audit and interviews with experts helped generate the vocabulary. SNOMED CT® was used as a reference.
terminology to standardize the terms retrieved in the chart audit process. The re-coding of patient profiles, evaluation and feedback from the domain experts tested and evaluated the vocabulary. A further step in the evaluation included feedback from clinicians in the community.

The second stage of the two-staged approach was the creation of an ontology in the heterogeneous domain consisting of 3 phases: Development, testing and evaluation. The development phase included the experts in the domain specifying and organizing the knowledge in the domain. This phase primarily drew the knowledge from the controlled vocabulary. The testing phase included the clinicians browsing the profile ontology developed in this research to examine the concepts in the ontology, the relationships between concepts, concept attributes and the individuals populated in the ontology. Following this was an evaluation phase that included feedback from the domain experts on the overall usefulness of the ontology in patient care with emphasis on usefulness from a health discipline perspective, from other health disciplines and the multidisciplinary nature of interactions captured in the ontology.

Protégé 3.4.2 was used to implement the patient profile ontology [22]. The profile ontology was exported into the Web Ontology Language (OWL). A consistency check of the classes in the ontology was conducted. Consistency checking helped detect classes that cannot have instances.

The implementation phase also included the evaluation of the ontology by domain experts for accuracy, completeness and usefulness of the knowledge represented in the ontology. The evaluation phase included the clinicians browsing the ontology using an ontology browser. They browsed various aspects of the ontology such as the classification scheme, multidisciplinary relations between concepts, instances, and standardization of concepts. Google ontology browser was used by clinicians to browse the ontology [23]. They provided feedback on the usefulness of the ontology through a survey questionnaire. Specifically, they offered feedback on the overall usefulness of the ontology, the relevance of the ontology in the context of patient care and the value of shared knowledge in the multidisciplinary domain. Individuals or instances are used in the profile ontology to present list of concrete concepts of relevance for each class.

4 Results

A complex and chronic health condition, namely, chronic pain was selected to test the viability of the proposed methodology in heterogeneous knowledge systems. One-hundred patients, 8 domain experts and 42 multidisciplinary community clinicians participated in the development of the chronic pain vocabulary and ontology.

4.1 Profile ontologies for chronic pain and musculoskeletal problems

The ontologies present a detailed taxonomic overview of the domain of complex health conditions.

The profile ontology for chronic pain contained 345 classes describing the profile concepts for the condition of chronic pain. At the basic level there are three relevant superclasses under the primary areas of health focus identified for the condition of chronic: Medical, Physical and Psychosocial as shown in Figure 3. The profile ontology includes definitions of over 80 properties, with 51 data and 38 object properties.

![Figure 3: Vocabulary for chronic pain](image)

The profile ontologies contained explication of all concepts included in the ontology such as the multidisciplinary nature of patient profile, the management scheme and the various concepts under each area of health focus. The properties in the ontologies introduce relations among concepts. A patient HasOrganization and the organization are inversely linked to the class Patient by HasPatient. The class Profile is linked to the class Management Scheme by property hasCollaborativeManagement. The class Psychosocial Profile is linked to the management scheme by property ManagementRequired which has individual dietitian_referral or physician_referral.

Standardized concepts are specified with their SNOMED CT ID number (Concept Unique Identifier) and with a list of synonyms. In the chronic pain ontology, standardized concepts are specified with their SNOMED CT ID number (Concept Unique Identifier) and with a list of synonyms. Class Lumbar spine - tender has a SNOMED CT® concept ID of 298673002 with parent concept being Finding of sensation of lumbar spine with finding site as lumbar spine structure.

![Figure 4: Query of “chronic low back pain” in the ontology](image)
Figure 4 shows the query of “chronic low back pain” in the ontology retrieving that 53 patients have this diagnosis in the ontology.

Query of a symptom such as *Lumbar spine – tender* shows the number of patients with the symptoms and the super class of the concept in the ontology. The instances in profiles show the multifaceted nature of symptoms as substantiated under each area of health focus that exist in the domain of a patient.

*Pain symptom* as presented in the patient charts has been viewed in the patient charts by a psychotherapist, physician or physiotherapist from various angles of importance such as pattern of pain, anatomical site or in relation to the pain threshold. Figure 4 shows the view of a patient profile that shows the multidisciplinary care involved in the management of *Pain symptom* shown in Figure 5.

![Figure 5: Multidisciplinary interactions in the categorization of Pain.](image)

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4.2 Evaluation of the ontology

Community clinicians (n=42) and domain experts (n=8) reviewed the vocabulary for chronic pain. Only the domain experts (n=8) reviewed the ontology. Google ontology browser [23] was used by clinicians to browse the ontology and offer their evaluation as shown in Figure 7. They viewed the individual patient profiles, multidisciplinary information relevant to their discipline and other disciplines, in-depth query of symptoms and their management scheme.

The clinicians also viewed information on various symptoms including the profiles under which a symptom was categorized, the number of patients that had a symptom and the standardization information for the symptoms.
Figure 7: View of ontology using Google Ontology Browser.

Figure 8 shows the evaluation of the ontologies by the domain experts (n=8). Sixty-seven percent of clinicians agreed on the overall usefulness of the ontology as a boundary object. Higher levels of agreement (83%) were reached on the usefulness of the ontology to view the information generated from other health disciplines in the categorization of a patient profile. The ontology had a consistently small to moderate percentage of clinicians showing strong agreement on its usefulness on all categories of the questionnaire. The ontology also had a very small percentage of disagreement on all categories of the survey questionnaire. Cohen’s Kappa and Kendall’s Tau was used to determine level of agreement among the raters. Kendall’s Tau was calculated at 0.6 with a moderate level of concordance among the 42 (multiple) raters with a p value of 0.03. Cohen’s Kappa for the dietician’s group showed the highest level of agreement with a score of 0.84.

5 Discussion and conclusions

A novel methodology and model has been presented in this research for the development of ontologies in heterogeneous knowledge domains. The broad objective of the research was to enhance communication in the multidisciplinary care management of chronic, complex and lesser known health conditions. The ontology approach was selected to develop consistency, standardization, organization and interoperability of domain knowledge with the broad goal of improving collaboration and communication for multidisciplinary clinicians involved in the care of patients with complex chronic conditions.

The development of the profile ontologies in this study was divided into three phases: specification, conceptualization and implementation [16]. The methodology includes several key components or criteria that were identified in past research such as acknowledging the heterogeneous nature of the domain knowledge [17] involving clinicians (experts and non-experts) in the process of development and evaluation and exploring the potential of the study by testing it in clinical workflow [18]. However there are several limitations to this research such as the scope being limited to the domain of patient profile information, a convenience sample of participants, size of the sample, the fact that the potential of the boundary objects in improving communication or collaboration among clinicians or the impact on patient care was not explored. The results do indicate that this direction of research has significant potential and requires further exploration.

0An ontology can reach a wider audience and has been deliberately selected to explicate the knowledge of lesser known and complex health conditions. Ontologies provide a pragmatic interoperable format for collaborative sharing of knowledge across communities of practice. The ontology has the potential to get richer as more users contribute new knowledge and as more patient instances are populated in the ontology. The overall agreement shown by experts in this study is very promising for the use of ontologies in the heterogeneous domains of complex health conditions.

6 References


