An ontological treatment of clinical prediction rules implementing the Alvarado score.

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Abstract. A lack of acceptance has hindered the widespread adoption and implementation of clinical prediction rules (CPRs). The use of clinical decision support systems (CDSSs) has been advocated as one way of facilitating a broader dissemination and validation of CPRs. This requires computable models of clinical evidence based on open standards rather than closed proprietary content. The on-going TRANSFoRm project has developed ontological models of CPRs suitable for providing CPR based decision support. This paper presents a description of the design and implementation of the ontology model for CPRs that has been proposed. The conceptual validity of the ontology is discussed using the example of a specific CPR in the form of the Alvarado Score for acute appendicitis. We demonstrate how the model is used to query the structure of this particular rule, providing a computable representation suitable for CPRs in general.

Keywords. Clinical prediction rules, ontology, clinical decision support

Introduction

Although many diverse examples of clinical prediction rules (CPRs) can be identified in research literature, their use has yet to gain widespread acceptance among clinicians[1-2]. Poor CPR validation and impact analysis can limit their use to restricted patient populations. Rules derived by different researchers for the same clinical conditions cause confusion about which CPR variations to use. With some exceptions the format for dissemination of CPRs is literature based, putting an onus on clinicians to search literature for suitable CPRs[3]. This is compounded by the fact that rules are static in nature and do not record versioned rule changes. These may take place over time as the demographics of the original rule study population evolve.

One way of addressing these limitations is through development of clinical decision support systems (CDSSs) based on computable models of clinical evidence[4-6]. The ultimate vision is to allow derivation, dissemination and on-going revision of CPRs from electronic patient data, complemented using extraction of patient cues from electronic health records (EHRs) as a trigger for rule execution. The TRANSFoRm

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project is developing computable ontological models of CPRs to support their electronic derivation, implementation and validation[7]. We describe the models and conceptual validity through implementation of a well studied CPR, the Alvarado score[8-9]. We demonstrate how clinical questions are expressed as ontological queries for use by a CPR based CDSS being developed by the TRANSFoRm project.

1. Methods

Three patient safety use cases where chosen as a basis for development of a CPR ontology. An extensible and generic ontology was developed to allow for dynamic addition of new diagnoses and rules. This defines the core knowledge base to provide future CPR based decision support on demand.

1.1. Patient Safety Use Case Formulation and Clinical Evidence Review

Three primary care patient safety use cases will be used to test and validate the final CDSS to be developed by TRANSFoRm: chest pain, abdominal pain and dyspnoea. They were chosen for the cognitive challenge they present in primary care with potential for diagnostic error[10-11]. Reviews of evidence based sources identified CPRs supporting selected diagnoses for the patient safety use cases[9, 12].

A CPR *"is a clinical tool that quantifies the individual contributions that various components of the history, physical examination, and basic laboratory results make toward the diagnosis, prognosis, or likely response to treatment in a patient"*[13-14]. The Alvarado Score categorises patients with potential acute appendicitis into three risk categories with associated treatment options. This is suitable for primary care and based on the presence of diagnostic cues without the need for imaging[8]. Reviews highlight the importance of capturing the demographic context of the study population. Score performance varies in different populations depending on gender and age, performing best for adult males[9]. This should be reflected in any model design.

CPRs can be used as part of "refinement" phase within a broader recognised diagnostic strategy to formulate the correct differential diagnoses to consider. This is done by "ruling out" differentials based on the results of the CPR score obtained when applied to any particular patient case[14]. The aim is to reduce the possibility of diagnostic error at the outset through correct formulation of differentials[10-11]. In our selected use cases for example, a patient presenting with abdominal pain who scores less than 4 on the Alvarado score, could indicate a potential "rule out" for appendicitis for that patient.

1.2. Ontology Design and Conceptual Validation Methodology

An ontology was chosen as the basis for the CPR model to support dissemination of CPRs using open standards. Many methodologies have been proposed for design and development of ontologies[15]. An application focused design was selected to define the ontology based on the functional requirements of the CDSS. The functional requirements are stated as clinical competency questions we wish to ask our ontology[16]. Using the example of appendicitis and the Alvarado Score we identified the following questions as functional requirements to answer using the CDSS:

- What are the differential diagnoses to consider for a reason for encounter (RFE) of abdominal pain?
- What are the CPRs associated with the differential diagnosis of appendicitis?
- What are the cues, criteria and associated scores of the Alvarado score?
- What are the scoring interpretation schemes of the Alvarado score?
- What are the population characteristics associated for application of the Alvarado score?
- What is the clinical setting associated for application of the Alvarado score?
- What are the supporting literature sources for the Alvarado score?
- What is the current version number of the Alvarado score?

Competency questions were deconstructed into formal classes and relationships. All competency questions were expressed as ontology queries, executed and results checked for consistency with the evidence sources used to populate the ontology[8-9].

2. Results

The core CPR ontology concepts identified are described in Table 1.

Table 1. Core CPR Ontology Classes with Descriptions and Examples

***Class Name* and Description**	**Class *Instance* / Relationships**
EvidenceRFE - The patient reported reason for encounter (RFE)	*AbdominalPainRFE*
EvidenceDiagnosis - A differential diagnosis of a particular RFE	*Appendicitis* hasCPR
ClinicalPredictionRule - A versioned CPR associated with a particular diagnosis with links to supporting literature URLs	*AlvaradoScore1_0* hasRuleVersion 1_0 hasSupportingLiteratureURL
ClinicalPredictionRuleElement - One individual element of the CPR that is associated with one cue and the criteria to apply to it	*AlvaradoScoreElement1*
EvidenceCue – An associated sign, symptom, risk or clinical test	*ReboundTenderness*
EvidenceCriteria - The criteria and weighted rule score associated with a ClinicalPredictionRuleElement where the criteria is true	isPresent = True hasScoreInterpretation 1
ClinicalPredictionRuleScore - A score range to be used for clinical interpretation of the rule along with the textual interpretation of that score level	*AlvaradoScoreLevel3* hasStartScore 7 hasEndScore 10 hasScoreInterpretation “Surgery”
EvidenceContext - A group of classes that defines the evidence population demographics used to derive the rule	*Adult ,Male, Europe*
EvidenceClinicalEnvironment - The clinical setting or context	*PrimaryCare*

This ontology is implemented using ontology language/resource description framework (OWL/RDF) and Protégé 4.1[17-19]. It is hosted using a Sesame triple store for query formulation, testing and future dynamic programmatic update of ontology content[20-21]. Queries and results are shown in Table 2 for four competency questions.

Table 2. Competency Questions 1-4 (from Table 1) Expressed as SPARQL Queries with Associated Results

SPARQL (Protocol and RDF Query Language)	**Query Result (*Instance* Relation Value)**
SELECT ?anyDifferentialDiagnosis WHERE {?anyDifferentialDiagnosis isDifferentialDiagnosisOf *AbdominalPainRFE* .}	*Appendicitis, BacterialEnteritis* *ChronsDisease, CorPulmonale* *EctopicPregnancy, Pyelonephritis* *UrinaryTractInfection*
SELECT ?anyCPR WHERE {?anyCPR isCprOf *Appendicitis*.}	*AlvaradoScore1_0*
SELECT ?anyCueElement ?anyProperty ?anyValue WHERE {?anyRuleElement isRuleElementOf *AlvaradoScore1_0*. ?anyCriteriaElement isCriteriaOf ?anyRuleElement. ?anyCueElement isCueElementOf ?anyRuleElement. ?anyCriteriaElement ?anyProperty ?anyValue. ?anyProperty rdf:type owl:DatatypeProperty. } ORDER By ?anyCriteriaElement	*MigrationOfPain* isPresent true *MigrationOfPain* hasScoreInterpretation 1 *Anorexia* isPresent true *Anorexia* hasScoreInterpretation 1 *Nausea* isPresent true *Nausea* hasScoreInterpretation 1 *RightLowerQuadrantTenderness* isPresent true *RightLowerQuadrantTenderness* hasScoreInterpretation 2 *ReboundPain* isPresent true *ReboundPain* hasScoreInterpretation 1 *ElevatedTemperature* isPresent true *ElevatedTemperature h*asScoreInterpretation 1 *Leucocystosis* isPresent true *Leucocystosis* hasScoreInterpretation 2 *WhiteBloodCellShiftLeft* isPresent true *WhiteBloodCellShiftLeft* hasScoreInterpretation 1
SELECT ?anyScoreElement ?anyProperty ?anyValue WHERE {?anyScoreElement isScoreSchemeOf *AlvaradoScore1_0* . ?anyScoreElement ?anyProperty ?anyValue. ?anyProperty rdf:type owl:DatatypeProperty. } ORDER By ?anyScoreElement	*AlvaradoLevel1* hasScoreInterpretation "Discharge" *AlvaradoLevel1* hasStartScore1 *AlvaradoLevel1* hasEndScore 4 *AlvaradoLevel2* hasScoreInterpretation "Observation/Admission" *AlvaradoLevel2* hasStartScore 5 *AlvaradoLevel2* hasEndScore 6 *AlvaradoLevel3* hasScoreInterpretation "Surgery" *AlvaradoLevel3* hasStartScore 7 *AlvaradoLevel3* hasEndScore 10

3. Discussion

The query results are consistent with the Alvarado Score as described in literature demonstrating the conceptual feasibility of ontology based CPRs. Flexible queries can answer clinical questions required of computable CPRs. The model has also been used to represent more complex CPRs including the Finnish Diabetes Risk Score, the Edwards Score (tuberculosis) and the Little Symptom rule (urinary tract infection).
Future research will focus on developing a CDSS that integrates CPRs with the TRANSFoRm vocabulary service[22], data mining and EHRs. A vocabulary adds

semantic meaning to the ontology through binding of ontology instances to Unified Medical Language System (UMLS) terms and can facilitate CPR execution based on diagnostic cues extracted from individual patient EHRs. The wider use and acceptance of clinical prediction rules by clinicians is encouraged in three ways; by making CPRs more accessible and searchable than literature equivalents; through development of versioned rules from data mined sources of aggregated primary care data that are more sensitive to clinicians own patient populations; through deployment of CPRs as part of decision support tools linked to EHRs to facilitate easier use and execution.

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