MEDINFO 2010
C. Safran et al. (Eds.)
IOS Press, 2010

doi:10.3233/978-1-60750-588-4-1140

Verification & Validation of the Knowledge Base for the Hypertension Management CDSS

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Abstract

To implement a knowledge-based clinical decision support system for clinical information systems, it is crucial to verify and validate the knowledge base. This study developed and tested the hypertension management CDSS, named LIGHT. This study used a knowledge representation framework based on SAGE and developed a knowledge converter to translate knowledge encoded into the knowledge engine. To verify knowledge converted through the knowledge converter that is included in the knowledge representation framework, expected recommendations were made according to the knowledge encoded based on 201 test cases. The expected recommendations were compared to those generated by the knowledge engine. To validate the knowledge base, two physicians reviewed the test cases and made medication orders according to the knowledge base. These medication orders were compared to recommendations generated by the LIGHT. The concordance rates for compelling indication and absolute contraindication were 85% and 100%, respectively. Another senior physician reviewed and analyzed the discrepancy cases between the orders of the two other physicians and system recommendations. Accordingly, the authors conclude that the knowledge base for hypertension management became more accurate and practical through the testing process.

Keywords

Verification, Validation, Knowledge base, Hypertension Management, Clinical Decision Support

Introduction

Knowledge based-CDSS integrated with an electronic medical record can provide clinicians with evidence-based patient-specific recommendations at the point of care [1]. Clinical practice guidelines (CPGs) are usually used as resources of evidence based knowledge for Knowledge based-CDSS. However, in order to use CPGs for CDSS, there are a lot of tasks such as non-computer interpretable and non-executable narrative CPGs are translated into executable knowledge.

Research has been done on guideline ontology for knowledge representation to support more efficient knowledge authoring of computer interpretable guidelines (CIGs). There are several guideline modeling methods, such as EON, Asbru, GEM, GUIDE, PROforma, PRODIGY, GLIF, SAGE. SAGE is built upon previous work on another guideline modeling and has been evaluated as an effective guideline modeling framework, which provides a systemic way to create sharable clinical interpretable guidelines and standardized vocabularies [2, 3].

A knowledge based CDS service, named Lightening pressure with computer-Implemented Guidelines on Hypertension Treatment (LIGHT), as a part of the EHR project in Korea. The LIGHT system provides recommendations for hypertension management, and integration into a hospital information system as an interoperable and sharable CDSS [4]. An EHR knowledge representation framework based on SAGE was used. However it was not possible to use a practical execution engine for SAGE-based guidelines. To execute SAGE-based guidelines, the u-BRAIN execution engine is developed as a knowledge engine that is an integrated process engine and rule engine. In addition, a knowledge converter to translate SAGE based guidelines into u-BRAIN is also developed, which is applied as an "Export" plug-in on Protégé (Figure 1) [5. 6].

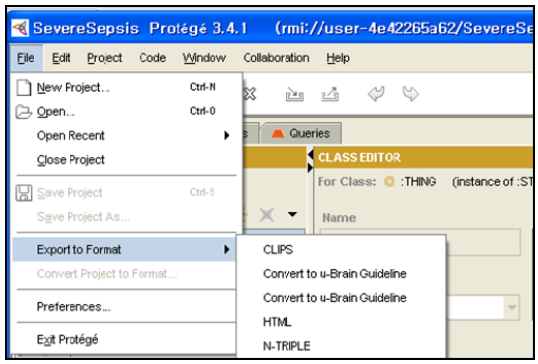

Figure 1 - The framework of EHR knowledge representation framework

It is possible to make wrong representation during the translation from narrative CPGs into computer interpretable guidelines. Clinical guidelines are often vague and incomplete with possible serious omissions and inconsistencies [7]. As well, newly developed software may have errors. It is essential to ensure that the recommendations generated by CDSS are accurate. One of the reasons for testing a system is to discover problems. The testing of the accuracy of the KB should be required at every step of the development of the system to ensure qualified software and to discover problems [8, 9].

The testing process was conducted in three phases (Figure 2). This paper focused on verifying knowledge converted (second phase) and validating the KB (third phase). Preece (2001) explained that *verification* is the process of checking whether the software system meets the specified requirements of the users, while *validation* is the process of checking whether the software system meets the actual requirements of the users [10].

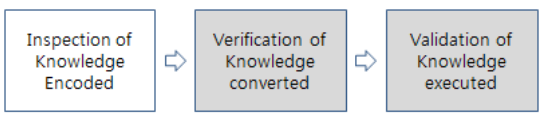

Figure 2- The process of testing the KB

The knowledge module for the LIGHT system is based on The Seventh Report of the Joint National Committee on the Detection, Evaluation, and Treatment of High Blood Pressure (JNC7) [11]. The knowledge module has 256 rules including the criteria of compelling indication and absolute contraindication for hypertensive medication. The LIGHT system makes recommendations for drugs of compelling indication or absolute contraindication. If blood pressure is not controlled (over goal BP), the system gives information about the maximum dose of the current medication.

The testing process in the development of the LIGHT system is described in this paper.

Materials and Methods

Test cases selection

This study used a set of 201 test cases selected from a data set of 430 patients with hypertension diagnosis (ICD 10 code; I10, Essential (primary) hypertension) in a general hospital. The inclusion criteria for the patient were history of two encounters from Dec 2007 to Dec 2008.

Verification of knowledge converted

The purpose of verification for the knowledge converted is to ensure that the knowledge converter correctly translates knowledge encoded into the u-Brain knowledge engine. The functional (black box) testing paradigm was used to verify the knowledge converted (Figure 3). Functional testing is concerned with the inputs and outputs of the LIGHT system [8].

The knowledge encoded based on our representation framework was inspected prior to the verification of knowledge converted. The semantic correctness and completeness was checked by two knowledge engineers who did not participate in the knowledge encoding. The research team including the knowledge encoders made the expected results in 201 real test cases, and compared them to the outputs of the generated knowledge executed through the knowledge converter in order to find errors of the knowledge converter.

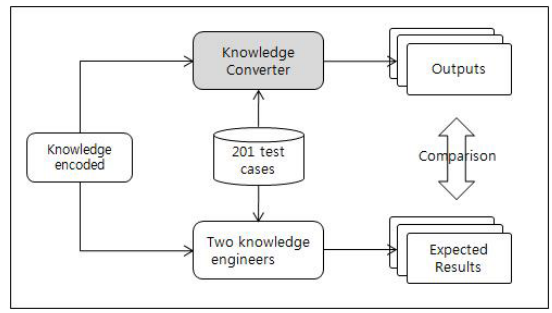

Figure 3 - The process to verify knowledge converted

Preparation of physicians for validation

Three physicians (internists) from a university hospital were involved in this phase. One physician had more experience and was regarded as the advanced physician. They had no previous involvement in the development of HT management KB. The document written 256 rules and the knowledge source of JNC7 were explained [9]. The documents were a semi-formal representation type such as excel and visio files. This study represented knowledge more explicitly on the documents than the CPGs.

Figure 4 - Screenshot for retrieving patient information and selecting medication for physicians

The LIGHT system was developed to present patient information and to obtain the recommendations from physicians. They reviewed patient information and prescribed medication according to information provided by the LIGHT system that would allow them to change the prescription after seeing the recommendation of system (Figure 4).

Patient information included age, most recent blood pressure measurement, previous blood pressure measurement, combined disease, signs and symptoms, most recent results of laboratory tests (potassium, sodium, glucose, urinalysis, lipid profile, creatinine, white blood cell count) and current medication. Physicians selected ADD, MAINTAIN, INCREASE and REMOVE 6 classes (thiazide, DHP and NDHP calcium channel blocker, ACE inhibitor, ARB, beta blocker) of hypertensive medication according to the current medication and the condition of the patient. These 6 classes of antihypertensive drugs were chosen because they were most frequently used in primary health care in Korea, according to the research that was conducted from May 2005 to Feb 2006 by R&D Center for Interoperable EHR.

Validation of knowledge executed

The medication recommendations generated by the CDSS were compared first with the medication selection made by physicians and then cases were searched for discrepancies. The advanced physician reviewed the cases and presented a third opinion about each test case. The KB was refined by consensus if the reason of the discrepancy originated form the HT management KB (Figure 5).

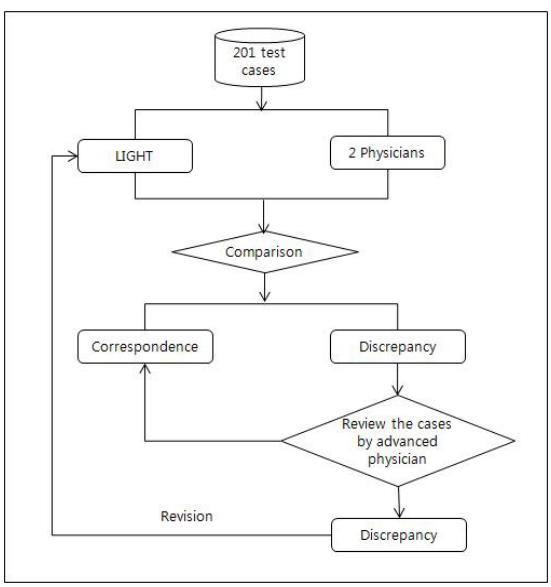

Figure 5 - The process to validate knowledge base

Framework to compare medication recommendations

An analysis of correspondence was made by compelling indication or absolute contraindication related to the condition of the patient.
The cases that were not matched according to the correspondence framework were regarded the cases as a discrepancy.

Table 1 - Framework of correspondence analysis

	Physician	LIGHT
Correspondence	Add	Compelling indication
	Maintain	Compelling indication
	Increase	Compelling indication and Not controlled BP
	Remove	Absolute contraindication

Evaluation of usefulness of recommendations

Two physicians were required to evaluate the usefulness of the patient specific recommendations generated by the LIGHT system. After the physicians prescribed medications for each patient, the system provided recommendations for the patient. And the system allowed them to change the prescription after seeing the recommendations and gave a user interface to evaluate the usefulness of recommendations.

Results

The correctness of knowledge converted

Outputs from the knowledge converter and expected results from the knowledge engineers based on knowledge encoded were exactly corresponded. The result showed that the knowledge converter could convert all knowledge elements used in SAGE into the knowledge engine [6]. To represent knowledge elements of CPGs, elements on SAGE were used such as activity graphs to represent the procedural knowledge, expression to represent rule based knowledge and virtual medical record (vMR) to identity the data of patients [2]. The knowledge converter used in this study can accept all these elements and convert correctly into the execution engine.

Analysis of the medication choice by physicians

For the 201 test cases, the LIGHT system made 537 medication recommendations with an average of 5.3 recommendations per test case (median 2, range 0-9). Physician A and B chose 279 hypertensive drug classes with an average of 2.8 for same test cases, respectively (physician A and B; median 1, range 0-4).

Among 279 drug classes, 164 classes selected from physician A and 176 selected classes from physician B came under the scope of the LIGHT system. The type of medication choice by physicians is shown in Table 2.

Table 2 – Type of prescription choice by physicians

	Type of Prescription			
	Add	**Maintain**	**Increase**	**Remove**
Physician A	30 (18.3%)	114 (69.5%)	17 (10.4%)	3 (1.8%)
	Subtotal		164(100.0%)	
Physician B	42 (23.9%)	116 (65.9%)	17 (9.6%)	1 (0.6%)
	Subtotal		176(100.0%)	

Result of comparison

In the case of compelling indication, correspondence rate for each physician was 85.1% respectively. In absolute contraindication, the rate was 100% respectively (Table 3). Two physicians were followed well by absolute contraindication from CPGs.

There were 27 test cases, when the medication recommendation discrepancies were classified by test case. These cases were characterized in three types; 1) A patient needed to increase the dose of a current medication or to add another medication, physicians did not choose a medication of compelling indication for ADD, INCREASE, 2) System recommended a medication of absolute contraindication, but physicians decided to ADD, MAINTAIN the medication or INCREASE dose, 3) The system recommended a medication of compelling indication, but physicians decided to remove the medication.

Table - 3 Correspondence rate of compelling indication

Classification	Physician A	Physician B
Correspondence	137 (85.1%)	149 (85.1%)
Discrepancy	24 (14.9%)	26 (14.9%)
Total	161 (100%)	175 (100%)

The reasons that led to discrepancies were analyzed through a review of the knowledge base and the opinion of an advanced physician. Medication recommendation discrepancies between physicians and the LIGHT system originated from the two reasons as follow; 1) The rule was on the document for semi-formal representation, however the rule was not encoded in the knowledge base. The relationship of a DHP-calcium channel blocker and angina was missed. The knowledge base was refined according to the results. 2) A physician did not recognize the condition of absolute contraindication. In this case, feedback was provided to the physician. 3) When blood pressure is controlled and the current medication is not absolute contraindication, physicians have a tendency not to change medications. This study did not regard as a discrepancy when the recommendation between them didn't correspond exactly.

Usefulness of recommendations of LIGHT

After physicians first chose recommendations were provided generated by the LIGHT system that gave the physicians a chance to change the selected medication. Physician A changed the choice in 14 cases and physician B did in 8 cases. In the evaluation of the usefulness of the recommendation given, physician A and B showed 96.1%, 77.4% respectively.

Physicians commented that the recommendation of the system would be very helpful for patients who required hypertension medication for the first time. However, in the case of a very complex patient, the LIGHT system did not consider all the parameters.

Discussion

It is difficult to make computer interpretable guideline in narrative CPGs when there are ambiguities and omissions [5, 7]. Newly developed software may contain errors [6]. The procedural testing method was conducted in order to search for errors in the knowledge base.

The EHR knowledge representation framework was used based on SAGE to make computer interpretable guidelines. The framework includes a knowledge converter that converts computer interpretable guidelines into knowledge execution engine. This study verified that the converter correctly all knowledge elements used in the SAGE framework with the converting knowledge base of HT management.

The validation of knowledge base is whether the content of the knowledge base accurately includes the knowledge of human experts [8], it is essential for human experts to participate. We could search one missing error and refined in the knowledge base through the testing process.

One of the limitations of this study is that the knowledge base didn't contain rules to cover all antihypertensive medications.

Conclusion

This study was conducted to verify and validate the knowledge base in every phase of developing CDSS. Through the verification and validation process, one omission in the knowledge base was found and refined to improved accuracy. The result showed that the testing process in every development phase contributed to an accurate and useful knowledge base and is useful for evaluating for other knowledge bases.

Acknowledgments

This work was supported by a grant of the Korea Health 21 R&D Project, Ministry of Health and Welfare in Republic of Korea (A050909).

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