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Creating hospital-specific customized clinical pathways by applying semantic reasoning to clinical data

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ABSTRACT

Objective: Clinical pathways (CPs) are widely studied methods to standardize clinical intervention and improve medical quality. However, standard care plans defined in current CPs are too general to execute in a practical healthcare environment. The purpose of this study was to create hospital-specific personalized CPs by explicitly expressing and replenishing the general knowledge of CPs by applying semantic analysis and reasoning to historical clinical data.

Methods: A semantic data model was constructed to semantically store clinical data. After querying semantic clinical data, treatment procedures were extracted. Four properties were self-defined for local ontology construction and semantic transformation, and three Jena rules were proposed to achieve error correction and pathway order recognition. Semantic reasoning was utilized to establish the relationship between data orders and pathway orders.

Results: A clinical pathway for deviated nasal septum was used as an example to illustrate how to combine standard care plans and practical treatment procedures. A group of 224 patients with 11,473 orders was transformed to a semantic data model, which was stored in RDF format. Long term order processing and error correction made the treatment procedures more consistent with clinical practice. The percentage of each pathway order with different probabilities was calculated to declare the commonality between the standard care plans and practical treatment procedures. Detailed treatment procedures with pathway orders, deduced pathway orders, and orders with probability greater than 80% were provided to efficiently customize the CPs.

Conclusions: This study contributes to the practical application of pathway specifications recommended by the Ministry of Health of China and provides a generic framework for the hospital-specific customization of standard care plans defined by CPs or clinical guidelines.

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1. Introduction

Clinical pathways (CPs), defined as structured multidisciplinary care plans [1], have been widely implemented as methods to standardize clinical intervention and potentially improve medical quality [2–5]. Extensive studies have evaluated the effectiveness of CPs for various diseases [6–10], though little information exists describing the use of CPs. Recent clinical practice in China has proven that the utility rate of CPs is unsatisfactory [11,12]. The European Pathway Association (EPA) performed an international survey on the practical implementation of CPs in 23 countries between 2004 and 2005 [11]. According to the statistical results reported by the EPA, in only three of the countries evaluated were approximately 21–40% of patients under pathway-based treatment, while in China and other participating countries, the number was less than 15%. Tao et al. [12] summarized the use of CPs based on 1051 literatures about CPs published in Chinese journals between 2003 and 2009. As reported, there were 162 hospitals in China that implemented electronic or paper CPs, accounting for only 0.82% of the total hospitals. And in 162 hospitals, 82.7% of the hospitals implemented CPs for less than 10 diseases.

There are two main reasons limiting the practicability of CPs. First, the standard care plans pre-determined in CPs are not universally adaptable for different patients in different hospitals. In addition to patient characteristics, which have been a key consideration in creating personalized care plans via pathway customization, hospital characteristics are also important for generating personalized CPs. Merging the treatment experience of current hospitals

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into patient-specific CPs is beneficial in improving the practicability of CPs. Second, care plans defined in current CPs are too general to execute. Standard care plans in the clinical pathway (CP) specifications recommended by the Ministry of Health of China cannot be directly implemented in hospitals due to the general description of medical interventions. For example, anesthesia, which is usually essential before a surgical operation in a practical clinical environment, is frequently ignored in standardized CPs. Additionally, antiseptic, anticoagulant, and anti-infective agents are commonly defined in CPs without detailed names and dosages. Addressing complicated clinical details has become a challenge for implementing CPs.

Taking into account the above two factors, this study proposes a data-driven, decision-making methodology to improve CP customization by applying semantic analysis and reasoning to historical clinical data. Through the analysis of historical clinical data in the hospital, we can generate disease-specific treatment procedures that are frequently used by physicians. These treatment procedures detail medical interventions of standard CPs and are helpful in creating hospital-specific customized implementation strategies.

However, the quality of medical data may be indefinite due to data inconsistency, incompleteness, and ambiguities. Pretreatment is indispensable before completing data statistics and analysis. Semantic web technologies provide a novel approach to address the problem of data complexity [13–17]. This study analyzes and processes the historical clinical data by semantic transformation and reasoning. Common treatment procedures are extracted from clinical data via probability and statistics. After calculating the probabilities of standard CP procedures that appear in historical data, we discuss the process of CP replenishing and detailing, which are realized with the guidance of the historical treatment experience from historical data.

In this paper, complete treatment procedures with pathway orders (standard interventions defined by CPs), deduced pathway orders (detailed interventions generated via semantic reasoning), and orders with high probability (supplementary interventions obtained from clinical data) are provided to efficiently customize CPs. Hospital-specific customized CPs are created by applying semantic reasoning to clinical data, which is beneficial for improving the practicability of standard CPs in hospitals.

2. Related work

2.1. Pathway customization

Numerous published studies have proposed methods of customizing CPs, most of which generate patient-specific care plans by individually analyzing patient characteristics based on patient information in the electronic healthcare records (EHR) [18–20]. The EHR, as integration of subset records of patient encounters in various care delivery settings, contains complete patient health information ranging from patient demographics and past medical history to laboratory and radiology data generated from medical devices and enables different organizations to easily share patients' medical information [21]. Wang et al. [20] proposed interaction between knowledge-based CPs and semantic EHR to improve the practicality of CPs. Serbanati et al. [22] proposed a virtually centralized, longitudinal patient record called the virtual healthcare record, which is a patient-centric model with a complete and authoritative representation of patient data for regional sharing. The virtual healthcare record was designed to have a native function to monitor clinical information and support CP customization. Although customized methods of analyzing patient characteristics are rational and valid for improving CP practicability, EHR systems are not widely implemented in most countries. Consequently, information about patient characteristics is difficult to capture, which constrains the generation of patient-specific CPs.

Compared to the EHR, the electronic medical record (EMR) is adopted by healthcare practitioners to document, monitor, and manage patients' medical process within a care delivery organization [21]. With the rapid increase in the adoption and implementation of EMR systems, hospital characteristics are comparatively convenient to capture from clinical data recorded by EMR systems.

2.2. Semantic transformation and mapping

A platform for accessing relational databases as virtual RDF graphs (D2RQ) [23] is commonly used to conveniently access relational databases as semantic RDF graphs [24–26]. However, it offers RDF-based access to the content of relational databases without replicating it into an RDF store, which confines the content of relational databases to semantic reasoning. CEM-OWL is a tool proposed for semantic transformation that provides authoring, reasoning, and querying tools [27]. It transforms the data stored in XML format in EHR systems to semantic data in OWL format. However, in Chinese clinical practice, the medical data recorded by EMR systems and stored in a database like Oracle, are mainly in the form of two-dimensional tables rather than in XML format, which limits the applicability of CEM-OWL. Therefore, instead of using the D2RQ platform and CEM-OWL, this study constructs and customizes a semantic data model according to data structure and practical requirements.

Some studies have adopted semantic similarity matching to address semantic mapping [28–30]. Similarity calculation could achieve more intelligent semantic mapping; however, the mapping process is complex and time-consuming, which will affect the performance of real-time decision support. To achieve data mapping, this study adopts the method of building local ontologies. A separate property is created for each hospital object recording hospital-specific clinical terms. On one hand, because the CP specifications recommended by the Ministry of Health of China describe the treatment procedures generally with "antibacterials" or "chest X-ray" rather than detailed drug names or instrument model numbers, the number of pathway orders for each CP is limited. On the other hand, except for periodic updates for new drugs, materials and instruments, the hospital-specific terms of pathway orders are relatively static, which make the hospital-specific terms easy to establish by the default local ontology. Additionally, even if a new instrument is not updated in local ontologies, the relevant information will be supplemented to treatment procedures from the clinical data if the new instrument has been used frequently. Consequently, the approach of default local ontology could efficiently achieve data mapping and greatly simplify the complexity of semantic reasoning.

3. Material and methods

3.1. Data collection

We performed our study using data from Navy General Hospital in Beijing, China. We compiled statistics on clinical data acquired between August 1, 2010 and July 31, 2011. Over this time period, the hospital had 1,114,693 outpatients, 28,775 inpatients, 163,707 diagnoses, and 2,646,572 executed orders that included laboratory tests, radiation, injections, operations and other order types.

Several types of diagnoses were considered, including: outpatient diagnoses, inpatient diagnoses, key diagnoses, operation complications and other diagnoses. These types of diagnoses were

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