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A decision support system for lower back pain diagnosis: Uncertainty management and clinical evaluations

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Abstract

Lower back pain (LBP) is a common medical problem that deprives many individuals of their normal lifestyles and keeps them from routine activities. Diagnosing LBP is challenging because it requires highly specialized knowledge involving a complex anatomical and physiological structure as well as diverse clinical considerations. Although a handful of studies have proposed or developed systems to support LBP diagnosis and improve knowledge sharing, these systems have limited scope, lack systematic evaluations, and/or ignore diagnoses that consist of multiple parts (i.e., decision outcomes), each of which corresponds to a particular medical condition, disease, or abnormality. In this study, we design, implement, and evaluate a Web-based decision support system that employs an intuitive and easy-to-use framework to assess the patient's information and recommend a diagnosis consisting of one or multiple parts. Our system design addresses the challenging characteristics of a LBP diagnosis and uses verbal probability estimation to represent and reason about the associated uncertainty. Our evaluations are systematic, including knowledge base verification, system validation using a modified Turing test, and clinical efficacy assessment involving 5 clinicians and 180 real-world cases collected from geographically dispersed clinics. Our evaluation design is more thorough than those used by most previous studies, and the proposed system is relatively ready for clinical deployment. Therefore, this study both contributes to decision support systems research and has advanced clinical support for LBP diagnosis. In light of some of the limitations of this study, we also identify and discuss several areas that need continued investigation.

Keywords: Low back pain diagnosis; Decision support system; Rule-based system; Consensus model; System evaluation; System verification and validation; Turing test; Diagnosis

1. Introduction

The use of decision support systems in clinical medicine has received considerable attention from information systems researchers and practitioners [2,6,17,23,38–40]. Of particular importance is diagnosis decision-making, a critical aspect of patient care and management by healthcare professionals. Broadly, diagnosis refers to a classification process through which the attending clinician, on the basis of information and symptoms collected, assigns a new patient to one or more pre-specified medical conditions (e.g., illness/disease, injury, abnormality) [36]. An inadequate or incorrect diagnosis can adversely affect subsequent patient treatment or management plan. When diagnosing a patient, a clinician often needs complex and highly specialized knowledge that may not be accessible in a convenient and timely manner. In this vein, the use of a decision support system that embraces pertinent diagnosis knowledge is desirable,

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particularly because it may improve service quality and diagnosis knowledge accessibility and dissemination.

Although clinical diagnosis decision-making support has been examined by previous research, several challenges remain, including the representation of the associated uncertainty, reasoning under uncertainty, the support of a non-exclusive multi-part diagnosis[1] (in which each part refers to a specific medical condition, illness, injury, or abnormality), and systematic clinical evaluation. Many clinical diagnosis tasks involve reasoning under uncertainty. Although different methods have been proposed to model such uncertainty, including certainty factor [6,7], Bayesian theory [1,30], belief functions [11,31], and fuzzy logic [42], these methods require significant probability estimation efforts by domain experts and thus often create bottlenecks in the already tedious and time-consuming knowledge acquisition process. The support of diagnosis that contains multiple non-exclusive medical conditions represents another challenge to the development of clinical decision support systems [36]. Conceivably, a patient may be diagnosed with multiple medical conditions simultaneously. Unfortunately, only few systems are able to support multiple-part diagnosis. In addition, a clinically viable system requires systematic and thorough evaluation. To be accepted and routinely used by targeted clinicians, a diagnosis support system must embrace verifiable domain knowledge, exhibit appropriate validity, and demonstrate sufficient clinical efficacy. A review of extant literature suggests that most previous research has addressed some but not all of these fundamental evaluation requirements.

In this research, we develop a system to support clinicians' diagnosis of lower back pain (LBP), a prevailing medical problem that requires appropriate responses to several challenging characteristics. Although LBP has been identified as a common cause of missed work and altered lifestyles among adults [40], its diagnosis is challenging and requires highly specialized knowledge that involves a complex anatomical and physiological structure, diverse clinical considerations, and nonstandard terminology [10]. As Jackson et al. [19] note, only approximately 15% of LBP patients surveyed had received accurate diagnoses with some degree of certainty. Clinicians usually acquire their diagnosis knowledge experientially in an intensive, time-consuming process. Therefore, a system-based approach for supporting their diagnosis of LBP patients is appealing and can improve both diagnosis quality and timely knowledge access.

We report the design, implementation, and evaluation of a diagnosis support system whose design addresses the challenging characteristics of LBP diagnosis. We used multiple complementary methods to acquire the targeted knowledge from two highly experienced domain experts who practice in different clinics in distant geographic regions. We used verbal probability estimation to capture and represent uncertainty, and we developed a voting scheme for knowledge inference on the basis of consensus-based modeling. Our system is Web based and architecturally consists of a knowledge base, an inference engine, a case repository, and two interfaces for convenient system access and knowledge update. To ensure the system's validity and clinical utility, we verified our knowledge base, examined the system's validity, and evaluated its efficacy using 180 cases collected from various clinics.

This study makes several contributions to decision support systems research. First, we propose an intuitive and easy-to-use framework for representing and reasoning about diagnosis knowledge that both involves uncertainty and may consist of multiple decision outcomes simultaneously (i.e., a multi-part diagnosis). This framework can alleviate the relentless probability-estimation requirements of domain experts and thereby facilitate the conventional knowledge-engineering process. We also demonstrate a systematic and thorough approach to developing and evaluating a clinical diagnosis support system using LBP diagnoses for illustration. Our system development attends to issues pertinent to problem analysis, system design, knowledge base verification, system validation, and clinical efficacy assessment. Clinically, this study responds to the need for a system-based approach to support clinicians' diagnoses of LBP. Our evaluations arguably are more systematic and thorough than those involved in most previous research [5,16]. In turn, our proposed system may be more ready for clinical deployment than were those reported by most previous studies.

The organization of the article is as follows. In Section 2, we provide an overview of LBP, together with the challenging characteristics that must be addressed during the development of a diagnosis support system. In Section 3, we review relevant previous research and highlight our motivation. We then describe our system design and implementation (including system architecture, knowledge acquisition, representation, and inference) in Section 4. In Section 5, we detail our verification, validation, and clinical evaluation designs and discuss some important results. Finally, we conclude in Section 6

[1] In this study, we use "non-exclusive multi-part diagnosis" to refer to a patient diagnosis that consists of one or more medical conditions (e.g., diseases or abnormalities) identified or suspected by the attending clinician.