Postprint of a Clinical Decision Support System for Primary Headache Based on International Headache Diagnostic Criteria

Authors: Ziming Yin, Dong Zhao, Kong Xiangyong

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Abstract

To address the problem of high incidence yet low diagnostic accuracy of primary headaches in China, this study proposes a clinical knowledge modeling and knowledge base construction method that transforms textual international headache diagnostic criteria into computer-executable reasoning. The method first converts diagnostic reasoning flowcharts based on the diagnostic criteria into standardized clinical knowledge expression models, which are then transformed into rules for computer-aided diagnostic reasoning through rule mapping technology, thereby forming a knowledge base. Based on this foundation, a primary headache clinical decision support system covering the complete headache diagnostic workflow was developed. Clinical evaluation demonstrates that the system correctly identifies 91.3% of migraine patients, 87.2% of tension-type headache patients, and 90.0% of cluster headache patients, achieving high diagnostic accuracy for common primary headaches.

Full Text

Preamble

Title: Assistant Decision-Making System Based on International Diagnostic Criteria for Primary Headache Disorders

Authors: Yin Ziming[1], Dong Zhao[2]†, Kong Xiangyong[1]
[1]School of Medical Instrument & Food Engineering, University of Shanghai for Science & Technology, Shanghai 200093, China
[2]Department of Neurology, Chinese PLA General Hospital, Beijing 100853, China

Abstract: To address the high incidence yet low diagnostic accuracy of primary headaches in China, this paper proposes a clinical knowledge modeling and

knowledge base construction method that transforms text-based international headache diagnostic criteria into computer-executable reasoning logic. The method first converts diagnostic criteria-based flowcharts of diagnostic reasoning into standardized clinical knowledge representation models, then translates these models into computer reasoning rules through rule-mapping techniques to form a knowledge base. Based on this approach, we developed a primary headache assistant decision-making system covering the complete headache diagnosis workflow. Clinical evaluation demonstrated that the system correctly identified 91.3% of migraine patients, 87.2% of tension-type headache patients, and 90.0% of cluster headache patients, achieving high diagnostic accuracy for common primary headaches.

Keywords: primary headache; assistant decision-making system; international diagnostic criteria for headache disorders; clinical knowledge modeling

0 Introduction

Headache represents one of the most common chief complaints in neurology outpatient clinics, with studies indicating that headache patients account for approximately 20% of all neurology outpatients. Among these patients, primary headaches constitute the vast majority of headache types. According to World Health Organization statistics, the prevalence of primary headaches in China has reached 23.8%, including 9.3% for migraine and 10.8% for tension-type headache. Given China' s large population base, even moderate prevalence rates translate into substantial absolute numbers of patients. Furthermore, Chinese patients spend approximately 672.7 billion RMB annually on primary headaches, representing 2.24% of China' s GDP and imposing a heavy burden on both families and the national economy.

Despite the large patient population, headache diagnosis in China remains relatively chaotic, with extremely low rates of correct diagnosis and treatment. For example, among the two most prevalent headache types, migraine diagnosis accuracy is only 13.8% and tension-type headache only 5.6%. Many hospitals still use non-standard or fabricated headache diagnoses such as “vascular headache”or “neural headache.”Such 不规范 diagnoses lead to inappropriate treatments, missed optimal treatment windows, progression from acute to chronic daily headache, and development of intractable headaches that severely impair patients' quality of life and work capacity. When headaches worsen, patients often seek treatment at major tertiary hospitals, consuming substantial medical resources and significantly increasing healthcare costs. Therefore, improving headache diagnostic accuracy at all hospital levels is critically important.

The current international standard for headache diagnosis is the International Classification of Headache Disorders (ICHD) developed by the International Headache Society. This standard classifies all headache disorders into primary and secondary headaches. Secondary headaches, caused by external factors, can be reliably diagnosed through instrumental examinations. The diagnostic chal-

lenge lies in primary headaches, which include migraine, tension-type headache, trigeminal autonomic cephalalgias, and other primary headaches. These patients typically show no abnormalities on routine imaging or other auxiliary tests, requiring physicians to diagnose based primarily on patients' recall of clinical symptoms such as attack frequency, location, pain type, duration, accompanying symptoms, and medication usage. Several factors contribute to diagnostic errors in primary headaches: first, many non-specialist physicians lack familiarity with ICHD due to limited specialized training and thus do not follow ICHD criteria in clinical practice; second, ICHD contains numerous primary headache categories with highly similar diagnostic criteria that are easily confused; third, unfamiliarity with diagnostic standards often leads physicians to forget to inquire about certain diagnostic indicators or 不知道如何 ask about specific indicators. Additionally, many patients cannot accurately recall headache symptoms during visits (for instance, forgetting whether headache duration exceeds or falls short of four hours, a critical diagnostic criterion), further complicating diagnosis.

If diagnostic criteria could be 固化 into computer-based knowledge libraries to form an assistant decision-making system for consultation, diagnosis, and treatment, combined with a mobile APP-based electronic headache diary system for patients, it would help physicians obtain accurate symptom information, understand and memorize diagnostic standards, and improve diagnostic accuracy. Current international research on primary headache assistant decision-making systems remains in its infancy, while domestic research is virtually nonexistent. Khayamnia et al. developed a fuzzy logic-based headache expert system, but this tool can only diagnose migraine with limited applicability. Hasan et al. developed a tree diagram-based headache diagnosis expert system that obtains diagnostic conclusions through a series of questions, but this method does not fully cover headache diagnostic criteria. Krawczyk et al. employed machine learning methods for headache diagnosis, comparing multiple algorithms and concluding that random forest performed best, but such computer algorithms represent "black boxes" to physicians and are difficult to gain clinical acceptance. According to our investigation, existing headache systems have remained limited to laboratory settings and have not been widely applied in clinical practice.

To popularize headache diagnostic standards across hospitals, this paper utilizes network technology and knowledge base modeling techniques from artificial intelligence to develop a primary headache assistant decision-making system based on the latest International Headache Diagnostic Criteria (ICHD-III beta). The system comprises a physician-oriented assistant decision-making system and a mobile APP-based patient electronic headache diary system. We expect this system to promote headache diagnostic standards, enable knowledge sharing, help non-specialist physicians improve adherence to diagnostic criteria, standardize diagnoses, and ultimately improve diagnostic accuracy.

1.1 System Architecture

As shown in [Figure 1: see original paper], this system adopts a Browser/Server (B/S) architecture, which offers several advantages: (a) convenient access, requiring only a standard browser without additional software installation; (b) cross-platform compatibility, accessible from both PCs and mobile devices; (c) simplified maintenance and upgrades, as updates to system functions or knowledge bases only require server-side modifications; and (d) ease of promotion and application across multiple hospitals, usable anywhere with network connectivity.

The system employs the Model-View-Controller (MVC) pattern for framework development, reducing coupling between data description and application operations while ensuring clear system structure and component reusability. The Model layer handles data logic, comprising two components: (1) the inference engine interface, inference engine, and knowledge base for knowledge processing, and (2) the database and data access interface. The Controller layer includes clinical business logic, in-hospital information management, consultation workflow management, and diary data management. The View layer handles data display, including interface configuration files, input/display components, and data interaction modules. This separation significantly enhances system maintainability and scalability. Running the entire system on cloud servers facilitates sharing of clinical data and knowledge across hospitals. Additionally, the system assigns different permissions based on physician user roles and provides data export and management functions to facilitate retrospective clinical research.

1.2 Key Technologies

1.2.1 Clinical Knowledge Modeling and Knowledge Base Construction

The knowledge base represents the core of computer-assisted decision-making systems, yet knowledge acquisition remains a major challenge in clinical knowledge base development. This difficulty arises because clinical knowledge base construction requires close collaboration between clinical experts and knowledge engineers, who often struggle to understand each other' s perspectives due to differing professional backgrounds. This paper designs a clinical knowledge transformation method that converts text-based headache diagnostic criteria into computer-executable reasoning knowledge, with the overall process illustrated in [Figure 2: see original paper].

First, clinical experts convert international headache diagnostic criteria into diagnostic reasoning flowcharts. The diagnostic workflow proceeds as follows: headaches are classified as chronic or non-chronic based on disease course. Chronic headache has relatively clear diagnostic criteria, so diagnosis begins by determining whether the condition meets chronic headache criteria based on onset time and frequency. Among non-chronic headaches, cluster headache and other trigeminal autonomic headaches exhibit distinct autonomic symptoms that are clinically observable, so these conditions are diagnosed first. Within

this category, exclusion proceeds according to disease prevalence rates. After excluding cluster headache and other trigeminal autonomic headaches, the system determines whether the condition is migraine or tension-type headache. Clinically, these two conditions share similar diagnostic indicators but differ in diagnostic criteria. Since migraine is more specific than tension-type headache, migraine is assessed first, followed by tension-type headache. Finally, headaches that cannot be classified are categorized as other primary headaches.

Flowcharts cannot be directly understood by computers and require further processing. After comprehending the flowchart, engineering technicians extract headache concept ontologies and convert the flowchart into a clinical knowledge representation model. This paper selects the internationally latest SAGE model as the clinical knowledge representation model. The SAGE model consists of numerous predefined clinical information classes, with the most important being the recommendation set, which comprises directed activity graphs. SAGE utilizes the Workflow Process Definition Language (WPDL) defined by the Workflow Management Coalition as the foundation for directed activity graph semantic expression. A directed activity graph is an instantiation of a WPDL process composed of four node types: Action, Decision, Context, and Route. The Context node serves as the process entry point, with the triggering event class specifying the clinical context for execution. This can be set to initiate diagnostic reasoning when a physician requests assistance. The Decision node represents choice points requiring selection among several options with defined conditions. Decisions must select exactly one option from the listed choices, with conditions expressed as simple logical conditions (e.g., and, or), comparison conditions (e.g., $>$, $<$, $=$), or complex compound conditions. For example, migraine diagnostic criteria require satisfaction of one of two conditions: nausea and/or vomiting; or photophobia and phonophobia. Such judgments cannot be directly expressed in the SAGE model and must be decomposed. Analysis of this diagnostic criterion reveals seven possible scenarios, which are expressed as primary sub-condition expressions in the Decision node using "OR" relationships, with some sub-conditions further decomposed into secondary sub-condition expressions. The Action node represents the leaf node of the recommendation process, specifying actions such as medication reminders. In this paper, Action represents the diagnostic conclusion as an instance of the Observation class.

Through expression using these nodes, the overall diagnostic process forms a diagnostic flow model based on headache concept ontologies. However, this knowledge representation model cannot be directly used for computer reasoning. Since headaches are diseases with clear diagnostic criteria that can be easily expressed in "if···then···" rule format, this paper employs rule-mapping methods to convert the diagnostic model into rule sets, which constitute the knowledge base usable by computer inference engines.

A significant advantage of this knowledge base construction method is that knowledge can be updated independently from computer code. When the system requires knowledge updates (e.g., when international headache diagnostic

criteria upgrade from ICHD-II published in 2004 to ICHD-III beta published in 2013), the corresponding knowledge in the assistant decision-making system should also be updated. Using this method, knowledge base content can be directly updated without modifying system code, enabling knowledge update capability.

1.2.2 Web Service-Based Inference Engine Technology

The inference engine is the primary component providing diagnostic conclusions in computer-assisted decision-making systems. It utilizes knowledge base content according to specific reasoning strategies to derive answers based on system input data. Most existing clinical decision support systems build inference engines directly into the system, where updates or replacements of the inference engine may require repetitive development work.

This paper encapsulates the inference engine as a software service deployed on servers using Web Service technology, providing reasoning functionality to upper-layer systems in the form of web services. The upper layer only needs to provide patient data according to interface standards and transmit it through the network to the server-side inference engine, which returns diagnostic conclusions to the upper layer after reasoning, as illustrated in [Figure 3: see original paper].

Web Service-based inference engines offer several advantages: (a) low coupling between the system and inference engine, allowing inference engine upgrades without modifying system calling code as long as interface formats remain unchanged; (b) platform independence, as Web services use universal Internet protocols such as HTTP and SOAP, enabling any Internet-connected platform to access the service from PCs or mobile devices; and (c) good concurrency performance to meet simultaneous access demands from multiple terminals across multiple hospitals.

1.3 System Main Functions

In addition to developing the ICHD-based knowledge base and inference technology, this system provides a physician-oriented primary headache assistant decision-making system and a complementary mobile APP-based patient electronic headache diary system. These two systems work together to improve diagnostic accuracy through various assistant decision-making functions. The physician-oriented primary headache assistant decision-making system covers the complete headache diagnosis workflow according to physicians'clinical habits, including assisted inquiry, assisted diagnosis, medication reference, automatic headache report generation, and headache diary data analysis. The electronic headache diary system helps patients record headache symptoms, evaluates treatment outcomes through attack severity and frequency, and forms personal electronic headache health records.

1.3.1 Physician-Oriented Primary Headache Assistant Decision-Making System

a) Assisted Inquiry. The assisted inquiry function addresses two problems during consultation: (1) Which headache symptoms should be asked about according to diagnostic criteria? (2) How to phrase questions so patients can most easily understand without misinterpretation? All system input items originate from ICHD and represent essential diagnostic information. During system use, physicians can follow interface prompts to inquire about patient conditions item by item, reducing inquiry omissions. If uncertain about how to ask about a particular symptom, physicians can click the "?" button next to the input item, and the system will display a dialog box with inquiry prompts, as shown in [Figure 4: see original paper], helping physicians describe questions accurately and facilitating patient understanding and cooperation.

b) Assisted Diagnosis. Assisted diagnosis is the core system function, helping physicians determine headache type while also serving an educational and promotional role for international headache diagnostic standards. After physicians complete information input during the inquiry step, the system provides diagnostic suggestions for reference. Physicians must decide whether to adopt the system' s recommendation; if not adopted, they must provide their diagnostic conclusion, as shown in [Figure 5: see original paper]. If physicians are unclear about the reasoning behind a diagnostic conclusion, they can click the "Diagnostic Basis" button to view the diagnostic criteria for a particular headache type, enabling them to review the latest International Headache Society diagnostic standards and enhance familiarity and understanding.

c) Medication Reference. For physicians unfamiliar with primary headache disorders, the system provides reference medications for specific headache types based on diagnostic conclusions. Reference medications are categorized as acute-phase or preventive-phase treatments, with acute-phase drugs further divided into specific and non-specific medications. [Figure 6: see original paper] lists reference medications for migraine without aura. Physicians can also write prescriptions based on their hospital pharmacy' s actual availability.

d) Automatic Medical Record Generation. Outpatient clinics typically have high patient volumes and heavy workloads, making manual medical record writing time-consuming. This system can automatically generate patient medical records based on previously entered headache symptoms, diagnostic conclusions, and medical orders. Physicians can modify the records, and the system provides printing functionality for patients to take home. Each headache medical record includes the physician' s electronic signature.

e) Headache Diary Data Analysis. Headache patients often forget their headache characteristics during visits, complicating diagnosis. If patients use the mobile APP-based electronic headache diary during headache attacks to record accurate symptoms and upload data to the server, physicians can access and analyze these headache diaries during subsequent visits, as shown in [Figure

7: see original paper]. For example, physicians can evaluate whether headache attack frequency and severity have decreased after medication. This function requires integration with the patient-oriented electronic headache diary system.

1.3.2 Mobile APP-Based Patient Electronic Headache Diary System

To address patients' difficulty recalling headache characteristics during visits, this paper developed a patient-oriented electronic headache diary system. Patients can record headache symptoms at onset and conclusion, including start/end time, location, pain quality, severity, accompanying symptoms, and whether daily activities aggravate the condition, as shown in Figure 8: see original paper. This information is critical for primary headache diagnosis. The system generates analysis reports based on patient-inputted headache diaries Figure 8: see original paper, which can be presented to physicians during subsequent visits. This approach provides more accurate information than patient recall alone, facilitating more precise diagnoses.

2.2 System Function Evaluation

This study employed questionnaire assessment for physicians who used the system for over one year. Eight physicians participated, divided into two categories: four headache specialists and four non-specialist trainees. Anonymous questionnaire evaluation was conducted, with physicians scoring each item from 0-5: 0= "no opinion," 1= "very unimportant," 2= "not very important," 3= "moderately important," 4= "important," 5= "very important." Statistical analysis of the eight responses is presented in .

The system was clinically evaluated at a tertiary hospital' s International Headache Center in Beijing for four months, collecting data from 543 patients. The evaluation procedure was as follows: After entering the headache clinic, trainee physicians unfamiliar with headache diagnostic criteria recorded patient headache symptoms (location, duration, frequency, severity, accompanying symptoms, aura, etc.), and the headache assistant decision-making system provided diagnoses. A panel of three headache experts then reviewed the medical records to provide final diagnoses as the gold standard. System diagnoses were compared against expert diagnoses for each case, with Cohen' s kappa ( ) calculated to assess diagnostic agreement. Guidelines suggest >75% indicates excellent agreement, 40-75% indicates fair to good agreement, and <40% indicates poor agreement, using a 5% significance level and 95% confidence interval.

The system correctly identified 159/160 (99.4%) cases of migraine without aura, 36/36 (100%) cases of migraine with aura, 20/21 (95.2%) cases of chronic migraine, and 37/59 (62.7%) cases of probable migraine. The system also correctly identified 157/180 (87.2%) cases of tension-type headache, including 12/13 (92.3%) episodic tension-type headaches, 99/101 (98.0%) frequent tension-type headaches, 18/20 (90.9%) chronic tension-type headaches, and

28/46 (60.9%) probable tension-type headaches. Correct identification rates for cluster headache and new daily persistent headache were 90.0% and 100%, respectively.

System diagnostic sensitivity, specificity, and kappa values are shown in . These results demonstrate that the method is accurate and reliable for diagnosing migraine without aura, migraine with aura, chronic migraine, episodic tension-type headache, frequent tension-type headache, chronic tension-type headache, cluster headache, and new daily persistent headache. For probable migraine and probable tension-type headache, although specificity was high (98.76% for migraine, 97.99% for tension-type headache), sensitivity was relatively low (62.71% for migraine, 60.87% for tension-type headache). Kappa values indicated fair to good agreement: 0.6978 for migraine and 0.639 for tension-type headache.

As shown in , physicians rated the system favorably, with non-specialist physicians providing higher ratings than specialists. Non-specialist physicians scored all system functions higher than specialists, likely because their limited knowledge in the headache domain made them perceive greater value in such a system.

3 Discussion

This system focuses on primary headaches but must first exclude secondary headaches before primary headache diagnosis. This study screens for secondary headaches using 10 commonly employed "red flag symptoms" in Chinese neurology departments: sudden-onset headache; progressively worsening headache; headache with systemic disease signs (fever, neck stiffness, rash); focal neurological symptoms and signs (except typical visual/sensory aura); headache with cognitive impairment; papilledema; headache triggered by coughing or exertion; headache during pregnancy or postpartum; new headache in cancer or AIDS patients; and new headache after age 50. According to the system workflow, physicians must inquire about these features, considering secondary headache if any are present and proceeding to primary headache inquiry if absent.

While designed for primary headaches, many primary headaches are not clearly distinct, with some scholars suggesting overlap between different primary headache types—where patients exhibit symptoms of one headache type accompanied by symptoms of another without fully meeting diagnostic criteria for either. The most common overlap occurs between migraine and tension-type headache, though migraine and cluster headache symptoms may also overlap. Clinicians frequently encounter patients with overlapping symptoms, and since each headache type requires different treatment, physicians must determine which headache type the patient more likely has to provide targeted therapy. Such atypical presentations challenge both clinical diagnosis and computer-assisted diagnosis, explaining the system' s relatively lower accuracy for probable migraine and probable tension-type headache. As our knowledge modeling and reasoning approach is knowledge-based, future work could integrate case-based reasoning or other data-driven reasoning methods to

create a hybrid reasoning model capable of handling uncertainty and improving diagnostic accuracy for these complex cases.

4 Conclusion

Primary headaches are highly prevalent yet frequently misdiagnosed diseases. This paper proposes a clinical knowledge modeling and knowledge base construction technique that transforms text-based international headache diagnostic criteria into computer-executable reasoning logic, enabling automated inference diagnosis of primary headaches through rule-based reasoning engines. Based on this technology, we designed and developed a primary headache assistant decision-making system for non-specialist physicians that covers the complete headache diagnosis and treatment workflow. Evaluation experiments demonstrate that the system achieves high diagnostic accuracy for most common primary headaches and can improve diagnostic capabilities among non-specialist physicians. However, diagnostic accuracy for complex headaches with overlapping symptoms could be further optimized, representing a future research direction.

References

[1] Dong Zhao, Yu Shengyuan. Neuropathic pain and head-facial pain [J]. Chinese Journal of Contemporary Neurology and Neurosurgery, 2013, 13(9): 752-754.

[2] Guerrero Á L, Rojo E, Herrero S, et al. Characteristics of the first 1000 headaches in an outpatient headache clinic registry [J]. Headache: the Journal of Head and Face Pain, 2011, 51(2): 226–231.

[3] Yu Shengyuan. Overview of key points in headache diagnosis and treatment [J]. Chinese Journal of Practical Internal Medicine, 2010, 30(6): 493-495.

[4] Liu Ruozhuo, Yu Shengyuan, He Mianwang, et al. Health-care utilization for primary headache disorders in China: a population-based door-to-door survey [J]. Journal of Headache and Pain, 2013, 14(1): 1-8.

[5] Wu Xinwei, Yang Xiaosu. Research progress on chronic daily headache [J]. Chinese General Practice, 2014, 17(34): 4133-4136.

[6] Headache Classification Committee of the International Headache Society. The international classification of headache disorders, 3rd edition (beta version) [J]. Cephalalgia, 2013, 33(9): 629-808.

[7] Khayamnia M, Yazdchi M, Vahidiankamyad A, et al. The recognition of migraine headache by designation of fuzzy expert system and usage of LFE learning algorithm [C]// Proc of the 5th Iranian Joint Congress on Fuzzy and Intelligent Systems. 2017: 50-53.

[8] Hasan M R, Hasan M S, Siraj F. An expert system based headache solution [C]// Proc of IEEE Symposium on Computer Applications and Industrial Electronics. 2013: 287-292.

[9] Krawczyk B, Simić D, Simić S, et al. Automatic diagnosis of primary headaches by machine learning methods [J]. Central European Journal of Medicine, 2013, 8(2): 157-165.

[10] Tian Chenyu, Tang Dan, Zhao Wu. Research and development of an intelligent expert system for CT contrast agent application [J]. Application Research of Computers, 2017, 34(07): 2088-2089.

[11] Tu S W, Campbell J R, Glasgow J, et al. The SAGE Guideline Model: achievements and overview [J]. Journal of the American Medical Informatics Association, 2007, 14(5): 589-598.

[12] Kaniecki R G. Migraine and tension-type headache: An assessment of challenges in diagnosis [J]. Neurology, 2002, 58(6): 15-20.

Note: Figure translations are in progress. See original paper for figures.