Iranian Journal of Medical Physics
Vol. 12, No. 1, Winter 2015, 1-6
Received: June 24, 2014; Accepted: December 4, 2014

IJMP

Original Article

A Fuzzy Expert System for Distinguishing between Bacterial and Aseptic Meningitis

Mostafa Langarizadeh[1], Esmat Khajehpour[1*], Hassan Khajehpour[3], Mehrdad Farokhnia[4], Mahdi Eftekhari[5]

Abstract

Introduction
Bacterial meningitis is a known infectious disease which occurs at early ages and should be promptly diagnosed and treated. Bacterial and aseptic meningitis are hard to be distinguished. Therefore, physicians should be highly informed and experienced in this area. The main aim of this study was to suggest a system for distinguishing between bacterial and aseptic meningitis, using fuzzy logic.

Materials and Methods
In the first step, proper attributes were selected using Weka 3.6.7 software. Six attributes were selected using Attribute Evaluator, InfoGainAttributeEval, and Ranker search method items. Then, a fuzzy inference engine was designed using MATLAB software, based on Mamdani's fuzzy logic method with max-min composition, prod-probor, and centroid defuzzification. The rule base consisted of eight rules, based on the experience of three specialists and information extracted from textbooks.

Results
Data were extracted from 106 records of patients with meningitis (42 cases with bacterial meningitis) in order to evaluate the proposed system. The system accuracy, specificity, and sensitivity were 89%, 92 %, and 97%, respectively. The area under the ROC curve was 0.93, and Kappa test revealed a good level of agreement (k=0.84, P<0.0005).

Conclusion
According to the results, the suggested fuzzy system showed a good agreement and high efficiency in terms of distinguishing between bacterial and aseptic meningitis. To avoid unnecessary antibiotic treatments, patient hospitalization, and misdiagnosis of bacterial meningitis, such systems are useful and highly recommended. However, no system has been yet introduced with 100% correct output and further research is required to improve the results.

Keywords: Aseptic Meningitis; Bacterial Meningitis; Expert System; Fuzzy Logic; Meningitis

---

1- Medical Informatics Dept., Faculty of Health Management and Information Sciences, Iran University of Medical Sciences, Tehran, Iran
2- Medical Informatics Dept., Tehran University of Medical Sciences, Tehran, Iran
*Corresponding author: Tel: 09133907047; E-mail: e_khajehpoor@yahoo.com

3- Biomedical Engineering Dept., Tehran University of Medical Sciences, Tehran, Iran
4- Infectious Diseases Specialist, Kerman University of Medical Sciences, Kerman, Iran
5- Artificial Intelligence, Department of Computer Engineering, Shahid Bahonar University, Kerman, Iran

1. Introduction

Meningitis is an acute inflammatory disease which impacts the brain and spinal cord and leads to mortality and morbidity among children [1-3]. Meningitis is generally classified into bacterial and aseptic meningitis. Aseptic meningitis is rarely life-threatening and full recovery is achieved quickly. On the other hand, bacterial meningitis is considered a potential medical emergency since it could result in death or serious complications. Given the rapid progress of bacterial meningitis, diagnosis and antibiotic treatment are of high priority [4-8].

Children with meningitis are hospitalized and administered antibiotics, depending on the culture results. Since laboratory results are normally prepared within 24 to 72 hours, distinguishing bacterial from aseptic meningitis is often difficult [4, 6, 9].

World Health Organization (WHO) predicted that more than one million individuals will be infected with meningitis per year, mostly in poverty-stricken and developing countries [10]. In these countries, excessive use of antibiotics and poor health care provision have resulted in bacterial resistance to antibiotics [11]. On the other hand, distinguishing between bacterial meningitis and viral meningitis is intricate bacterial meningitis has an intricate distinction because of its misdiagnosis as viral meningitis [12].

Considering the increasing demand for health care services, artificial intelligent systems are used to help health care workers and patients [13]. Studies have shown that a properly designed expert system is beneficial for medical decision-making [14]. In this regard, different systems have been designed to diagnose and distinguish bacterial meningitis from other types of meningitis and similar diseases.

Francoise et al. introduced a medical consulting system, known as MENINGE, using numerical scores and threshold values, based on the statistical analysis of 329 clinical cases. MENINGE was properly designed to diagnose and treat acute meningitis in children. However, the obtained scores were dependent on 329 clinical cases which selected as statistical population [14].

Additionally, Ahmad introduced a rule-based expert system for diagnosing neurological disorders (e.g., Alzheimer, Parkinson, Huntington's disease, cerebral palsy, epilepsy, multiple sclerosis, stroke, meningitis, and cluster headache); however, no evidence was provided indicating the system's efficiency [15].

Ocampo et al. introduced a clinical decision support system by integrating case-based reasoning and rule-based expert systems in order to distinguish bacterial meningitis from acute viral meningitis, tuberculous meningitis, encephalitis, brain abscess, meningism, meningeal inflammatory response, meningeal hemorrhage, and brain tumor. This system was highly efficient, although it was dependent on users' experiences [16].

In 2011, Ocampo et al. published a study entitled, "Comparing Bayesian inference and case-based reasoning as support techniques in the diagnosis of acute bacterial meningitis". In their study, Acute Bacterial Meningitis Case-Based Diagnosis (ABMCBDS) and ABMCBDS-Adapt expert systems were compared with Bayesian expert system in terms of distinguishing bacterial meningitis from similar diseases. The obtained results showed that all systems were suitable, while case-based reasoning-based systems were more capable than Bayesian system [17].

In artificial intelligence, an expert system is a computer-based system that emulates the decision-making ability of a human expert [18]. The most important point is translating uncertain terms of medicine for computerized systems. Establishment of a method to translate these terms for the system could be useful and prosperous. These terms are translated by fuzzy sets and their membership functions are determined for computerized systems [19, 20].

The main aim of this study was to suggest and evaluate a fuzzy logic system for distinguishing bacterial and aseptic meningitis. Hence, proper attributes were identified using Waikato Environment for Knowledge Analysis (WEKA) 3.6.7 software. Then, a fuzzy logic expert system was designed to distinguish bacterial from aseptic meningitis. Finally, the system's efficiency was evaluated using the data obtained from 106 meningitis patients.

2. Materials and Methods

In this study, three experts with at least 5 years of experience in the diagnosis and treatment of meningitis were consulted. A total of 9 attributes were selected under expert supervision including gram stain, white blood cell (WBC) count in cerebrospinal fluid (CSF), percentage of polymorphonucleocytes in CSF, CSF protein, CSF/serum glucose ratio, WBC count in blood, percentage of blood neutrophils, blood C-reactive protein (CRP), and platelet (Plt) count.

The data were collected from 106 meningitis patients (3 months to 13 years old) from Children's Medical Center affiliated to Tehran University of Medical Sciences (Table 1). Missing records were removed from our database, thus, no such values were encountered. Then, the data were entered to WEKA software in order to select the best attributes.

Table 1. Demographic variables

	Bacterial meningitis		Aseptic meningitis	
	Number	Age	Number	Age
Female	11	4.01±4.1	37	3.6±2.28
Male	31	2.8±2.03	27	3.8±2.4
Total	42	3.13±1.86	64	3.6±1.7

A number was dedicated to each attribute in WEKA, using InfoGainAttributeEval, which evaluates the value of an attribute by measuring the information gain with respect to the class and Ranker search method, which ranks the attributes by individual evaluations [21]. Six important attributes were selected with maximum effect to distinguish bacterial meningitis.

Since the signs and symptoms of the disease were defined by uncertain linguistic terms, they were translated to fuzzy sets in order to design computerized systems [19, 20]. For instance, CSF WBC count in patients, who were affected by meningitis, was defined by two uncertainty terms of normal and high. Each term was translated to a value between 0 and 1, using membership functions as follows:

"High" fuzzy set of CSF WBC count= $\{(x, \mathrm{smf}(10{,}2500))\,|\,x\epsilon M\}$ (1)

$$\mathrm{Smf}(10{,}2500)\begin{cases} 0 & x < 10 \\ 2[\frac{x-900}{900}]^2 & 10 < x < 1255 \\ 1-2\left[\frac{x-2100}{900}\right]^2 & 1255 < x < 2100 \\ 1 & 2100 < x \end{cases}$$

Where M is the parent set, x is CSF WBC count, and smf (10, 2500) is membership function.

An expert system includes three parts: knowledge base, inference engine, and user interface [22, 23]. The fuzzy inference engine is the main part of the fuzzy expert system which is defined based on fuzzy sets, if-then rules, and fuzzy reasoning. Fuzzy sets translate terms, if-then rules define human knowledge, and either fuzzy reasoning or inference mechanism is used to help the system archive reasonable results using fuzzy sets, if-then rules, and patients' clinical attributes [24].

In this system, the rule base consisted of eight rules with 0.8 and 1 weights, based on the experience of three specialists and textbook information. Finally, max-min method as or-and operators, prod-probor method as implication-aggregation strategy, and centroid method of defuzzification were employed.

3. Results

According to table 2, the system's accuracy ((Number of correct assessments)/Number of all assessments)), specificity((Number of true negative assessment)/(Number of all negative assessment)) ,and sensitivity((Number of true positive assessment)/(Number of all positive assessment))were 89%, 92%, and 97%, respectively.

Table 2. Diagnosis of bacterial meningitis

Count		Truth: Other types of meningitis	Truth: Bacterial meningitis	Total
System	Negative	57	1	58
	positive	7	41	48
Total		64	42	106

Kappa statistics were calculated to evaluate agreement between the system and expert diagnosis (0.84, P<0.0005). The results indicated a highly acceptable agreement according to Landis-Koch criteria [25]. Finally, receiver operating characteristic (ROC) curve was depicted to illustrate system performance. The area under the curve was 0.93 which is very close to 1 (indicating higher system performance) (Figure 1).

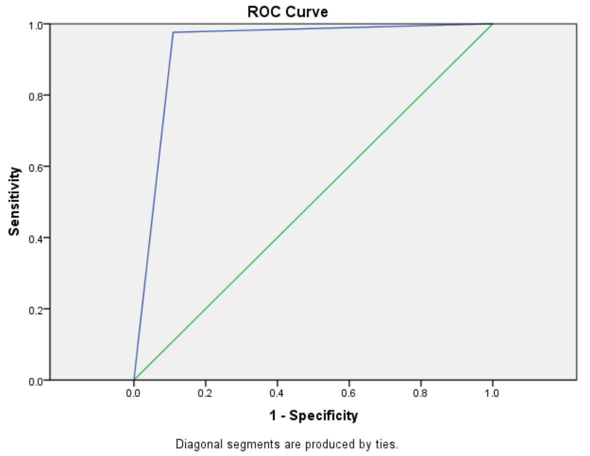

Figure 1. ROC curve

4. Discussion

Late diagnosis of bacterial meningitis and prescription of unnecessary antibiotics have been reported in the treatment of meningitis, given the similarity between bacterial and aseptic meningitis [4]. A system which can specifically prevent the late diagnosis of bacterial meningitis, prescription of unnecessary antibiotics, and unnecessary hospitalization will be useful in medicine.

In this study, Weka software was used to decrease the number of attributes until the system rules were suitable and proper for discrimination. Since the late diagnosis of bacterial meningitis can be accompanied by severe consequences, a diagnostic tool must aim for 100% sensitivity in distinguishing bacterial meningitis from aseptic meningitis [4, 26].

The results of system evaluation displayed high accuracy and specificity either sensitivity of system announced the slender probability of missing patients with bacterial meningitis Because the sensitivity of system is 97% . In this study, the system missed a patient with bacterial meningitis and negative CSF culture. On the other hand, Francois's system missed 2 patients with bacterial meningitis among 212 patients [14]. Ocampo's systems had high accuracy dependent on users' experiences. These systems were used to diagnose and treat many diseases, although no specific results were obtained regarding bacterial meningitis [16,17].

Ahmad's study did not report any results about the system evaluation (Table 3).

Table 3. Reports of systems

systems		accuracy	sensitivity	specificity	Kappa statistics	area under the ROC
Fuzzy system		89	97	92	k=0.84, P<0.0005	.93
Francoise system		98.2	No reported	No reported	No reported	No reported
Ocampo's systems	CBR & RBR	97	No reported	No reported	No reported	No reported
	ABMCBDS	90	No reported	No reported	No reported	No reported
	ABMCBDS_adapt	93	No reported	No reported	No reported	No reported
Ahmad's system		No reported	No reported	No reported	No reported	No reported

5. Conclusion

In the current study, capability of fuzzy method in distinguishing bacterial meningitis from aseptic meningitis was shown, and fuzzy expert system was proper for this propose. However, more comprehensive research is necessary to achieve 100% sensitivity.

Since in many cases, early signs of meningitis are highly similar to flu, the possibility of misdiagnosis increases [17, 27] and system development is limited. In addition, meningitis is classified into different similar types, which was in fact another limitation of this study, given the limited sample size for each type, which should be considered in future studies.

Acknowledgement:

We would like to appreciate staff of Children's Medical Center Hospital.

References

1. Richard B, Kligman R, Jaysin H. Infection disease nelson 2004. 17th edit. Tehran:Teymorzadeh.
2. Meningitis Research Foundation. What are meningitis and septicemia? [Internet]. Bristol :Meningitis Research Foundation; Nodate[cited 8/11/2013] available from: http://www.meningitis.org/disease-info/what-are-meningitis-septicaemia.page
3. Fauci A, Braunwald E, Kasper D, Hauser S, Longo D, Jameson J, et al. Harrison's Principles of Internal Medicine, 17th Edition: Mcgraw-hill; 2008.
4. Dubos F, Lamotte B, Bibi-Triki F, Moulin F, Raymond J, Gendrel D, et al. Clinical decision rules to distinguish between bacterial and aseptic meningitis. Arch Dis Child. 2006;91(8):647-50.
5. Sigurdardottir B, Björnsson ÓM, Jonsdottir KE, Erlendsdottir H, Gudmundsson S. Acute bacterial meningitis in adults: a 20-year overview. Arch Intern Med. 1997;157(4):425-30.
6. Nigrovic LE, Kuppermann N, Malley R. Children with bacterial meningitis presenting to the emergency department during the pneumococcal conjugate vaccine era. Acad Emerg Med. 2008;15(6):522-8.
7. Ross D, Rosegay H, Pons V. Differentiation of aseptic and bacterial meningitis in postoperative neurosurgical patients. J Neurosurg. 1988;69(5):669-74.
8. Tunkel AR, Hartman BJ, Kaplan SL, Kaufman BA, Roos KL, Scheld WM, et al. Practice guidelines for the management of bacterial meningitis. Clin Infect Dis. 2004;39(9):1267-84.
9. Wood AJ, Quagliarello VJ, Scheld WM. Treatment of bacterial meningitis. New England Journal of Medicine. 1997;336(10):708-16.
10. Tehran University of Medical Science .Guideline of meningitis surveillance.Tehran:Tehran University of Medical Science;2010 [updated 1/11/2011;cited 8/22/2013];Available from: http://health.tums.ac.ir/fa/620.aspx.
11. Wright JP, Ford HL. Bacterial meningitis in developing countries. Trop Doct. 1995;25(1):5-8.
12. Dubos F, Martinot A, Gendrel D, Breart G, Chalumeau M. Clinical decision rules for evaluating meningitis in children. Curr Opin Neurol. 2009;22(3):288-93.
13. Karami M .Artifical intelligence in medicine. Medical Record. 2/2010;6(3):47-50.
14. Francois P, Robert C, Astruc J, Begue P, Borderon JC, Floret D, et al. Comparative study of human expertise and an expert system:application to the diagnosis of child's meningitis . Computt Biomed Res.1993;26(4):383-38.
15. Ahmad A, Al_Hajji. Rule-based expert system for diagnosis and symptom of neurological disorders “neurologist expert system (NES)”. In: Chitaggon Uo, editor. 15th international conference on computer and information technology; Bangladesh.
16. Ocampo E, Cabrera MM. Integration of rule based expert systems and case based reasoning in an acute bacterial meningitis clinical decision support system. IJCSIS. 2010;7(2):112-8.
17. Ocampo E, Maceiras M, Herrera S, Maurente C, Rodríguez D, Sicilia MA. Comparing Bayesian inference and case-based reasoning as support techniques in the diagnosis of Acute Bacterial Meningitis. Expert Syst Appl. 2011;38(8):10343-54.
18. Shortliffe E. Medical expert systems-knowledge tools for physicians. Medical informatic.1986;145(6):830_9.
19. Torres A, Nieto JJ. Fuzzy logic in medicine and bioinformatics. J Biomed Biotechnol. [Review Article].12/21/2005;2006:1_7.
20. Phuong NH, Kreinovich V. Fuzzy logic and its applications in medicine. Int J Med Inform. 2001 Jul;62(2-3):165-73.

21. Machine Learning Group at the University of Waikato. Package weka.attributeSelection [internet]. Waikato: the University of Vikato;Nodate[cited 8/11/2014]. available from:http://weka.sourceforge.net/doc.dev/weka/attributeSelection/package-summary.html
22. Aziz AA. Expert system: PDAMum[internet].Generation5 JDK;2005 [cited 8/11/2013]; Available from: http://www.generation5.org/content/2005/pdamum.asp.
23. Nwigbo Stella N, Chuks AO. Expert System: A Catalyst in Educational Development in Nigeria. In: proceeding of the 1st International Technology, Educationand Environment Conference; 2011; Nigeria: Human Resource Management Academic Research Society;2011. p.566-71.
24. Kia m. Fuzzy logic using MATLAB.Tehran:Kiyan rayane;2010. (in persian)
25. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159-74.
26. Haruda FD. Meningitis—viral versus bacterial. Pediatrics 2003;112:447–8.
27. Rechard B, Gelemgen R, Bijensen H. Nervous system diseases (N)elson 2004: Teymorzadeh; 2004.