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Activities of daily living and lesion position among multiple sclerosis patients by Bayes network☆

Zhifang Pan[1, 2], Hongtao Lu[1], Qi Cheng[3, 4]

1 *Department of Computer Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China*
2 *School of Information & Engineering, Wenzhou Medical College, Wenzhou 325035, Zhejiang Province, China*
3 *School of Public Health, Shanghai Jiao Tong University, Shanghai 200025, China*
4 *Department of Neurology, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai 200025, China*

Abstract
Magnetic resonance imaging is a highly sensitive approach for diagnosis of multiple sclerosis, and T2-weighted images can reveal lesions in the cerebral white matter, gray matter, and spinal cord. However, the lesions have a poor correlation with measurable clinical disability. In this study, we performed a large-scale epidemiological survey of 238 patients with multiple sclerosis in eleven districts by network member hospitals in Shanghai, China within 1 year. The involved patients were scanned for position and size of lesions by MRI. Results showed that lesions in the cerebrum, spinal cord, or supratentorial position had an impact on the activities of daily living in multiple sclerosis patients, as assessed by the Bayes network. On the other hand, brainstem lesions were very unlikely to influence the activities of daily living, and were not associated with the position of lesion, patient's gender, and patient's living place.

Key Words
neural regeneration; neurodegenerative diseases; multiple sclerosis; magnetic resonance imaging; Bayes network; activities of daily living; epidemiological survey; grants-supported paper; neuroregeneration

Research Highlights
(1) All cases with multiple sclerosis in eleven districts of Shanghai, China, were analyzed within 1 year for a large epidemiological survey.
(2) When the cerebrum was intact with no lesion, the probability of supratentorial lesion was very small, despite the grade of daily living activity. When the cerebrum was lesioned, the probability of supratentorial lesion increased. When the cerebrum was lesioned and the activities of daily living were basically normal, only help in bathing is needed, and the probability of supratentorial lesion peaked (96.4%). We speculate that the cerebral lesion mainly occurs in the supratentorial site.
(3) When the cerebrum presents no lesions and the patients need for help in daily living, we speculate the presence of spinal cord injury. Limitations of daily living activities indicate a greater probability of spinal cord injury. The probability is 100% when the activities are completely lost and the patients depend on a wheel-chair/bedridden.
(4) The activities of daily living are associated with the lesions of the cerebrum. When the activities of daily living are completely disabled and patients depend on wheel-chair/bedridden, the probability of cerebral lesion is 66.6%.
(5) Brainstem lesions did not have an influence on the activities of daily living.

Corresponding author: Zhifang Pan☆, Studying for doctorate, Associate professor, Department of Computer Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; School of Information & Engineering, Wenzhou Medical College, Wenzhou 325035, Zhejiang Province, China, panzhifang@hotmail.com. Qi Cheng, M.D., Ph.D., Professor, School of Public Health, Shanghai Jiao Tong University, Shanghai 200025, China; Department of Neurology, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai 200025, China, qicheng8@yahoo.com.cn.

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INTRODUCTION

Multiple sclerosis is a central nervous system autoimmune disease, and is also associated with cognitive impairment in 40–70% of patients[1]. Its cause and pathogenesis remain unclear. Multiple sclerosis is associated with various systemic symptoms following abnormal activation of T lymphocytes through the blood-brain barrier. The main symptoms are motor, visual and sensory disturbances, and other symptoms of the rectum (solution stool), bladder (urine solution) disorder, affective disorder, and mental deterioration. There are many important questions regarding multiple sclerosis. For example, what is associated with physical recovery in multiple sclerosis patients, what is its relationship to gender, age, early age at onset, type of multiple sclerosis, and the first symptom, what is the lesion region and lesion size, and which standard reflects the influence of these factors on recovery of the body? The chance of recovery from multiple sclerosis depends on the length of recurrence as well as the types of symptoms. Establishing an accurate prognosis is impossible, although some characteristics seem to affect prognosis. There is supporting evidence that multiple sclerosis is related to age, early age at onset, lesion region, and the type of multiple sclerosis. However, the correlation with gender and human leucocyte antigen remain controversial[2-21]. Interestingly, a recent study suggests that optic neuritis presentations may have a better prognosis[2].

Multiple sclerosis is a debilitating disease, which can result in chronic disability over many years[3]. Naci *et al* [4] reviewed eighteen studies and reported utilities associated with health states of multiple sclerosis measured by the Expanded Disability Status Scale. They concluded that utilities decreased considerably with increasing neurological disability. The majority of these reviewed studies were from Europe, with only four from North America. A number of studies have examined the severity of impairment expressed by multiple sclerosis patients, and found that multiple sclerosis had a significant impact on the health utility of patients[5-21].

An alternative model that combined the Expanded Disability Status Scale and multimodal sensory evoked potential using regression algorithm was shown to accurately predict short-term disability in multiple sclerosis patients, and was used to optimize decisions concerning treatment[5]. Most multiple sclerosis patients eventually experience walking disability. A shorter timed walking test over a 25-foot walk is the best characteristic objective measure of walking disability[7]. However, further studies are required to fully characterize the other objective walking assessments in multiple sclerosis. In one study, data from 104 multiple sclerosis patients were collected with patient information form, disability questionnaire, and the Barthel Index of Activities of Daily Living[9]. The working status, education level, and having a child were found to be common factors that affected both the disability and the level of independence in maintaining activities of daily living. In addition, a negative correlation was found between the scores of Brief Disability Questionnaire and Barthel Index of Activities of Daily Living in multiple sclerosis patients[9]. Brain atrophy was also reported to be correlated with both physical disability and cognitive impairment in multiple sclerosis patients[11]. Llufriu *et al* [11] recently examined the volumes of white matter lesions, cortical gray matter, cerebral white matter, caudate nucleus, putamen, thalamus, ventricles, and brainstem of sixty multiple sclerosis patients and thirty-seven healthy volunteers were measured by magnetic resonance imaging (MRI). In that study, the gray matter was atrophic in multiple sclerosis cases, while white matter lesion volume was in the normal range. Corpus callosum damage affects cognitive dysfunction and physical disability through a disconnection mechanism[12]. Atrophy of the cervical spinal cord, including the thoracic or whole spinal cord volume, and of the cerebral gray, white, or whole brain volume, is strongly correlated with physical disability in multiple sclerosis patients, while a weak relationship was found between spinal cord and brain lesions and atrophy[17].

Langer-Gould *et al* [22] identified that clinical and demographic factors were associated with long-term disability in patients with relapsing-remitting multiple sclerosis by searching the Medline (from January 1966 to May 2005), EMBASE, CINAHL, Cochrane, and PsycINFO databases, and reference lists of retrieved articles were reviewed. The sex and age of onset are commonly believed to be risk factors for poor prognosis in relapsing-remitting multiple sclerosis. Except for sphincter involvement, there were mixed, weak, or no effect of different types of symptoms at onset on the prognosis[22]. By contrast, optic neuritis presentations have a better prognosis[2]. In children, the risk of second attack of central nervous system demyelination was higher than that in older patients and lower than that in patients with mental status change, while the risk of disability was higher than that in polysymptomatic and relapsing patients[23]. Multiple sclerosis also results in

asystematic central nervous system damage due to involvement of both the cerebral white matter and gray matter. Although gray matter lesions were originally considered to be evident in advanced stage multiple sclerosis, we have confirmed that early stage multiple sclerosis patients can exhibit affective disorders, cognitive function impairment, and symptoms of gray matter involvement of brainstem neurons and nerve cells[24].

The incidence of spinal cord lesion is 70–90% in multiple sclerosis patients, which is the main cause of disability[25]. MRI, which is the most sensitive imaging method, can dynamically display the evolution of multiple sclerosis lesions including lesion duration, position, number, size, and distribution. Approximately 90% of spinal cord lesions can be scanned by routine MRI. Spinal cord lesions are predominantly located in the perimedullary vein to the white matter, while interstitial edema and perivascular inflammatory cell infiltration are increased during the demyelinating process, followed by oligodendrocyte and phospholipid cell death. As spinal cord lesions in multiple sclerosis usually involve motor and sensory transduction pathways, patients typically present symptoms including sensory disorder, amyotrophy, and fibrillation, and often visit the doctor for limb numbness and dyskinesia.

MRI can provide clinical evidence of multiple lesions with high sensitivity and specificity[26], and is an established tool to diagnose multiple sclerosis and track its evolution[27]. MRI has also revealed a profound heterogeneity in multiple sclerosis[28]. The presentation of multiple sclerosis lesions is mainly hyper-intense on T2-weighted images[29]. The lesions are predominantly found in the white matter, although are occasionally detected in gray matter[30]. Approximately 80% of contrast-enhancing lesions appear hypo-intense on the corresponding unenhanced T1-weighted images[31]. Multiple sclerosis lesions may also be observed in the spinal cord[32-34]. Furthermore, over the past few years, MRI has been used to investigate the features of pediatric multiple sclerosis patients[35-36].

Although the high sensitivity of MRI allows timely detection of lesions, the lesions have a poor correlation with measurable clinical disability[37-38]. Patients typically present with multiple disabilities, with a high impact on quality of life. Thus, development of a prognostic indicator of multiple sclerosis is important. The Kurtzke Disability Status Scale and the Expanded Disability Status Scale scores are the most common assessment criteria of disease progression and physical disability[39]. A novel approach, which uses composite endpoints, patient-reported outcomes, and measurement of biomarkers is a promising adjunct to the current disability measures, but insufficiently substitutes the Expanded Disability Status Scale. A collaborative approach including academic experts, regulators, industry representatives, and funding agencies is needed to measure disability[15].

In 1997, Friedman and Goldszmidt[40] proposed the Tree Augmented Naive (TAN) Bayes classifier based on Cow and Liu's dependence trees in 1968. The TAN network extends the naive Bayesian network by relaxing the input variables conditional independence assumption. It can effectively use dependent information between attribute variables. When the most complex dependence is found between attribute variables and class variables with respect to the star structure, the classification effect improves. The TAN classifier has the advantages of using a simple fixed algorithm and does not require a large number of training samples, and is thus a widely used classifier.

In summary, multiple sclerosis lesions can be found in the spinal cord or brain. However, there are no data available with regard to the specific relationship between lesions and disability. Thus, in the present study we analyzed 238 multiple sclerosis subjects from Shanghai in China using MRI by the TAN Bayes network, in a broader attempt to further explore the relationship between activities of daily living and different lesion positions such as cerebrum, spinal cord, brainstem, supratentorium.

RESULTS

Quantitative analysis and clinical information of subjects

A large epidemiological survey was conducted to identify and investigate all prevalent patients with multiple sclerosis by network member hospitals in 11 districts in Shanghai, China[41-42]. All multiple sclerosis patients were scanned by brain MRI, and 55% of the scanned patients had periventricular lesions, 23% had both periventricular and infratentorial lesions, 15% had infratentorial lesions, and 7% had other various combinations of lesion locations. A total of 240 patients were scanned, and 238 were involved in the final analysis, including 99 males and 139 females,

while two patients were excluded because of missing data of activities of daily living. There were 118 permanent residences in the study area, and 120 non-permanent residences.

Lesion positions by MRI included the optic nerve, cerebrum, cerebellum, spinal cord, brainstem, other positions, supratentorium, subtentorium, cervical vertebra, upper cervical vertebra, thoracic vertebra, upper thoracic vertebra, lumbar vertebra, C_{1-7}, T_{1-12}, and L_{1-5}. Other factors such as the size of lesion, gender, age, duration of illness, number of recurrence, study area, fatigue, and sense are shown in Table 1.

Table 1 Number of multiple sclerosis patients in different lesion positions

Position	Lesion (*n*)	Non-lesion (*n*)
Optic nerve	94	144
Cerebrum	132	106
Cerebellum	35	203
Spinal cord	136	102
Brainstem	9	229
Other positions	26	212
Supratentorium	139	99
Subtentorium	66	172
Cervical vertebra	61	177
Upper cervical vertebra	3	235
Thoracic vertebra	42	196
Upper thoracic vertebra	3	235
Lumbar vertebra	2	236

Total number = 238.

Selection of multiple sclerosis-related factors

We initially performed feature selection and obtained an importance index 0.95. The rest factors included fatigue, sense, duration of illness, number of recurrence, cerebrum, age, brainstem, spinal cord, and supratentorium. The activities of daily living were unrelated to study area and size of lesion. Table 2 shows the importance of several fields, including fatigue, sense, cerebrum, age, brainstem, duration of illness, spinal cord, TIMEDISE, and supratentorium. In particular, the size of the lesion, gender, and study area were not related to activities of daily living.

Bayes network showed a correlation between lesion position and activities of daily living

After feature selection, we used the Bayes network as an analysis model (Figures 1, 2). The most important factor was the cerebrum, followed by the spinal cord, brainstem and the supratentorium. The cerebrum position depended on the spinal cord, brainstem, and supratentorium. The brainstem lesion had a low probability relationship with activities of daily living.

Table 2 The importance values of multiple sclerosis patients in different fields

Rank	Field	Importance value
1	Fatigue	1.0
2	Sense	0.994
3	Cerebrum	0.99
4	Age	0.989
5	Brainstem	0.977
6	Duration of illness	0.974
7	Spinal cord	0.962
8	TIMEDISE	0.952
9	Supratentorial position	0.95

The field is ranked according to importance value. Fatigue exhibited the largest value of all fields. TIMEDISE represents the incidence number.

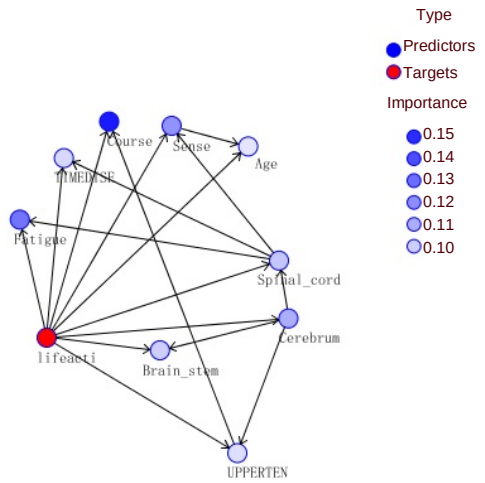

Figure 1 The Bayes network of multiple sclerosis reflects the relationship between activities of daily living and various factors.

The nodes of the outgoing arrows represent patient nodes, while the nodes of the ingoing arrows represent children nodes. The patient nodes are dependent on the children nodes, and are affected by children nodes. Importance = 1–*P*; *P* represents the *P* value in the hypothesis test. The *P* value is based on the *F* statistic of the factors for the continuous data, and on the Pearson chi-square for the discrete data.

Course: Duration of illness; UPPERTEN: supratentorium.

As shown in Tables 3–7, conditional probabilities of activities of daily living[42], brainstem, supratentorium, spinal cord, and cerebrum were observed. Restricted activities of daily living were associated with cerebrum lesion. When the activities of daily living were complete disability, wheel-chair/bedridden (lifeacti = 4), the highest probability of cerebrum lesion was 0.666 (Table 7). When the cerebrum was not lesioned and the patients need help in daily living, the spinal cord is very likely to be lesioned. The probability of self-care, need for help in bathing (lifeacti = 2) was 0.903, the probability of severe disability, need help for many activities (lifeacti = 3) was

0.944, and the probability of complete disability, wheel-chair/bedridden (lifeacti = 4) was 1. The worse the activities of daily living, the more increased the probability of spinal cord lesion (Table 6). When the cerebrum was not lesioned, the probability of supratentorial lesion was low, despite the activities of daily living score. When the cerebrum was lesioned, the probability of supratentorial lesion was greater. When the cerebrum was lesioned and the activities of daily living were self-care, need for help in bathing (lifeacti = 2), the probability of supratentorial lesion was the greatest (0.964), as the supratentorium is a part of the cerebrum (Table 5). Brainstem lesion had little relationship with activities of daily living (Table 4).

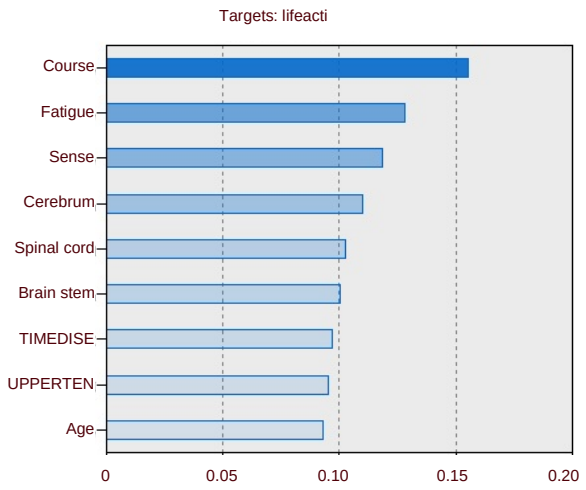

Figure 2 The importance of all variables in the Bayes network of multiple sclerosis reflects the relationship between activities of daily living and various factors.

The importance of all variables in Figure 1 is shown in descending order. When lifeacti is the target, the descending order of the predicted variable is course (duration of illness), fatigue, sense, cerebrum, spinal cord, brainstem, TIMEDISE (incidence number), UPPERTEN (supratentorium), and age. Lifeacti represents the activities of daily living.

Table 3 Headcounts and probabilities of different classes in the activities of daily living

Item	Not affected & no disability	Self-care basically, need for help in bathing	Severe disability, need help for many activities	Complete disability, wheel-chair/ bedridden
Headcount	147	59	26	6
Probability	0.617	0.247	0.109	0.025

Not affected & no disability represents complete rehabilitation. Self-care basically/need for help in bathing represents a minor disability. Severe disability/need help for many activities represents a severe disability. Complete disability/wheel-chair/bedridden is the worst living condition.

In brief, lesions in the cerebrum, spinal cord, and supratentorial position are likely to have an influence on activities of daily living. On the other hand, brainstem lesion is very unlikely to influence the activities of daily living. Nevertheless, while the activities of daily living of a given new lesion may be difficult to ascertain, the presence of MRI lesions is favorable for the diagnosis and the determination of which new lesions are prevented by various treatment measures. Conversely, the potential for change of activities of daily living may be predicted to a certain extent by the properties of the lesion.

Table 4 Probabilities of the brainstem with or without cerebrum lesion

Cerebrum	Activities of daily living	Probability	
		Non-lesion	Lesion
Non-lesion	Not affected & no disability	0.8	0.2
Non-lesion	Self-care basically, need for help in bathing	1	0
Non-lesion	Severe disability, need help for many activities	0.888	0.111
Non-lesion	Complete disability, wheel-chair/bedridden	1	0
Lesion	Not affected & no disability	0.869	0.130
Lesion	Self-care basically, need for help in bathing	0.964	0.035
Lesion	Severe disability, need help for many activities	1	0
Lesion	Complete disability, wheel-chair/bedridden	1	0

Not affected & no disability represents complete rehabilitation. Self-care basically/need for help in bathing represents a minor disability. Severe disability/need help for many activities represents a severe disability. Complete disability/wheel-chair/bedridden is the worst living condition.

Table 5 Probabilities of the supratentorium with or without cerebrum lesion

Cerebrum	Activities of daily living	Probability	
		Non-lesion	Lesion
Non-lesion	Not affected & no disability	0.800	0.200
Non-lesion	Self-care basically, need for help in bathing	0.806	0.193
Non-lesion	Severe disability, need help for many activities	0.833	0.166
Non-lesion	Complete disability, wheel-chair/bedridden	0.500	0.500
Lesion	Not affected & no disability	0.108	0.891
Lesion	Self-care basically, need for help in bathing	0.035	0.964
Lesion	Severe disability, need help for many activities	0.250	0.750
Lesion	Complete disability, wheel-chair/bedridden	0.250	0.750

Not affected & no disability represents complete rehabilitation. Self-care basically/need for help in bathing represents a minor disability. Severe disability/need help for many activities represents a severe disability. Complete disability/wheel-chair/bedridden is the worst living condition.

Table 6 Probabilities of the spinal cord with or without cerebrum lesion

Cerebrum	Activities of daily living	Probability	
		Non-lesion	Lesion
Non-lesion	Not affected & no disability	0.145	0.854
Non-lesion	Self-care basically, need for help in bathing	0.096	0.903
Non-lesion	Severe disability, need help for many activities	0.055	0.944
Non-lesion	Complete disability, wheel-chair/bedridden	0	1
Lesion	Not affected & no disability	0.706	0.293
Lesion	Self-care basically, need for help in bathing	0.642	0.357
Lesion	Severe disability, need help for many activities	0.625	0.375
Lesion	Complete disability, wheel-chair/bedridden	0.500	0.500

Not affected & no disability represents complete rehabilitation. Self-care basically/need for help in bathing represents a minor disability. Severe disability/need help for many activities represents a severe disability. Complete disability/wheel-chair/bedridden is the worst living condition.

Table 7 Probabilities of the cerebrum with or without cerebrum lesion

Activities of daily living	Probability	
	Non-lesion	Lesion
Not affected & no disability	0.374	0.625
Self-care basically, need for help in bathing	0.525	0.474
Severe disability, need help for many activities	0.692	0.307
Complete disability, wheel-chair/bedridden	0.333	0.666

The cerebrum is a lesion in which the activities of daily living is complete disability, wheel-chair/bedridden (lifeacti = 4). Not affected & no disability represents complete rehabilitation. Self-care basically/need for help in bathing represents a minor disability. Severe disability/need help for many activities represents a severe disability. Complete disability/wheel-chair/bedridden is the worst living condition.

DISCUSSION

Multiple sclerosis patients can present with cognitive impairment, fatigue, urinary incontinence, disability, impairment of activities of daily living, and other complications[43-48]. Subtentorial lesion[49] (including the cerebellum, brainstem, upper cervical vertebra), spinal cord lesion, and clinical subtype are related to disability status[50]. There is also some evidence that cognitive impairment in multiple sclerosis patients is related to heredity, gender, intelligence, and duration of illness (course)[51].

Cohen *et al* [15] demonstrated that the Expanded Disability Status Scale is insufficient to classify multiple sclerosis patients. MRI is an important method for examining spinal cord lesions in multiple sclerosis patients, but it has an obvious limitation in showing pathological characteristics and estimating focus quantification. Previous studies have reported a correlation between the Expanded Disability Status Scale and lesion positions. However, there are few data on the correlation between activities of daily living and lesion positions, and there are no fuzzy quantified studies for probability using the Bayes network. MRI is the most important clinical diagnosis method for multiple sclerosis, and it is the most sensitive neuroimaging method to reveal multiple lesions. Nevertheless, the pathology of the lesion cannot be determined by MRI. When clinical conditions of multiple sclerosis are met, MRI can support diagnosis and use for antidiastole[52]. The correlation between disability and brain lesion by MRI has been previously examined[53-55]. For example, a correlation between brain/spinal cord lesions and disability demonstrated by Z-score of central motor conduction time (Spearman correlation coefficients ranged from 0.29 to 0.53; $P < 0.05$) was reported[56]. Lin and colleagues[57] also investigated the correlation of brain and cervical cord volume to disability in clinical subtypes of multiple sclerosis. Furthermore, Colorado *et al* [58] reported that relapsing-remitting multiple sclerosis patients with an Expanded Disability Status Scale score of ≤ 1.5 exhibited increased activation of the right dorsolateral prefrontal cortex and anterior cingulate cortex during the performance of working memory task using functional MRI. In addition, limb apraxia in multiple sclerosis was reported to impact on manual dexterity and activities of daily living[59]. Friedman and Goldszmidt[40] also reported that dependence on the activities of daily livings increases using the Barthel Index along with the disability in multiple sclerosis patients.

Bayes is a decision method for studying uncertain problems and reasoned uncertain problems by Bayesian probability. The original Bayes network was used for knowledge representation of expert systems in artificial intelligence. More recently, the Bayes network has been applied to data analysis. The main focus of our Bayes network research is to determine how to search for dependency between input variables in large masses of data, what influence do different combinations of input variables have on output variables, and how to show this dependency intuitively by appropriate network configuration[40].

In summary, multiple sclerosis may result in lesions of the brain and spinal cord, although no obvious probability is observed, which is important for clinical application.

Shanghai is an international city of China, and citizens in Shanghai can obtain high-level medical service. However, people living in Shanghai will not usually look for medical treatment as some medical insurance in Shanghai is arranged and provided by the government. Thus, this research network aimed to collect all the data of patients in Shanghai, from which we used 238 multiple sclerosis patients. After correlation analysis by TAN network, we found the probability and correlation between different lesion positions and activities of daily living.

Our research has differences from other studies. In one-years time, all multiple sclerosis patients will be gathered if they seek medical advice to the cooperative network hospital in Shanghai, China. This is the largest case series of multiple sclerosis patients in China based on information from an epidemiological survey in a well-defined study area. Furthermore, all patients we analyzed have corresponding MRI data. During the whole study period, the multiple sclerosis diagnoses were supported by senior neurologists who always took part in each step of the investigation, including identification of cases, completion of protocols, and validation of data. The high proportion of patients receiving MRI scans in our study is a strong indicator for the validity of multiple sclerosis diagnosis. Because of folk custom and local characteristics in Shanghai, patients who suffer from an illness are not willing to go hospitals in other cities. Once multiple sclerosis patients experience their first attack, they will be collected by the multiple sclerosis hospital network. In general, most inhabitants of cities like Shanghai in China have some kind of medical insurance provided by the local government or organization, covering part of their medical bills. Because of these conditions, we first used a *P*-value test to select feature variables that contributed to changes of activities of daily living. Next, we applied the TAN network to compute lesion probability according to activities of daily living.

The retrospective nature of this study is a potential limitation. Furthermore, in the majority of the included studies, the study samples come from correlation hospitals, which are unlikely to be fully representative of the general patient population. Furthermore, the MRI checks performed are not unified among hospitals. Indeed, most hospitals acknowledged that there is a slight over-representation of patients with moderate and severe disease with life activity grade, not affected and no disability, and self-care, need for help in bathing. However, it is important to note that the research was unlikely to be biased by the grade since, where possible, health utilities are reported by life activity grade instead of Expanded Disability Status Scale for each study.

SUBJECTS AND METHODS

Design

A correlation analysis utilizing clinical medical imaging.

Time and setting

From September 2004 to August 2005, a large epidemiological survey was conducted to identify and investigate all prevalent patients with multiple sclerosis in 11 districts in Shanghai[41-42].

Subjects

Multiple sclerosis patients that had gone to a network hospital and were diagnosed according to McDonald's criteria were included in this study. A total of 240 patients were scanned for position and size of lesion by MRI, including 201 patients with brain MRI and 143 patients with spinal cord MRI. Among the multiple sclerosis patients that were scanned for brain MRI, 55% had periventricular lesions, 23% had both periventricular and infratentorial lesions, 15% had infratentorial lesions, and 7% had other various combinations of lesion locations. Two patients were excluded because of missing data of activities of daily living.

Methods

Normal values completed MRI missing values

All patients were diagnosed and MRI scan was required by senior physician according to the patient's condition. MRI was not performed if the physician diagnosed the patient as normal. The missing values were replaced by normal values.

Feature selection of obtained importance values in multiple sclerosis patients

Feature selection was applied to investigate the importance values for each predictor to target variables using the importance index. The analysis between predictors and target was based on *P* value of hypothesis testing. In our hypothesis test, H0 was the various factors that were unrelated to the activities of daily living. We refused H0 (the difference is not caused by sampling error) if $P < 0.05$ for the relevant factors, and

then considered the factor to be relevant to the activities of daily living. The larger the *P* value, the more independent the variables were. The importance index was equal to 1–*P*, and was assessed by Pearson's chi-square for discrete predictors and F-statistics for continuity. We examined a relationship between lesion positions and activities of daily living. According to the activities of daily living, physical disability was divided into four classes, since the Expanded Disability Status Scale was unrelated to the position of lesions. The first class was "Not affected & no disability", the second class was "Self-care basically, need for help in bathing", the third class was "Severe disability, need help for many activities", and the fourth class was "Complete disability, wheel-chair/bedridden"[60].

TAN Bayes model detected important lesion positions for activities of daily living

After selecting the feature, a TAN Bayes network was constructed to find the relationship between target and predictors. Data were analyzed using Clementine12.0 software (IBM; Armonk, NY, USA). A value of $P < 0.05$ was considered statistically significant.

The network structure and parameter estimation used for construction of the Bayes network were adjusted repeatedly to examine conditional independence between variables and in the process of learning to train samples based on the original network structure. If network structure was restrained before construction, we would obtain better performance. TAN[40] was used to expand the naive Bayes network by easing the hypothesis of independence conditional to the input variables.

The construction of the TAN network involved learning of the network concrete structure and estimation of the node parameter set. The core task of the learning structure was used to determine which input variable would become the parent of the other input variables. The core task of parameter estimation was used to computer conditional probability. However, there were problems with the TAN network. For example, it did not give expression to all input variables that contributed to predict classification, despite predicting that classification was based on total input variables. Thus, the input variables significantly influenced the output variables and an ideal solution was achieved only when these variables were used to predict classification. The Markov blanket was one of the ideal solutions[61]. In this kind of network, input and output variables have the same rank. Our method initially used Pearson's chi-square to obtain input variables that had a *P*-value greater than 0.05, which were then input into the TAN network to determine network structure and parameter.

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