Multivariate Analysis of Patients with Head Injury Using Quantification Theory Type II

—With Special Reference to Prediction of Patient Outcome—

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Abstract

Quantification theory type II was used to predict the outcome of 63 patients with head injury. Age, sex, two factors based on neurological examination, and seven factors based on findings of skull radiography and computed tomography of the head were selected as predictors. Patient outcome was evaluated 6 months after injury and assigned to good recovery, severe disability, or death. Discriminant analysis of patient outcomes was performed using the 11 factors. Two category scores were obtained for each category, since the highest correlation ratios were 0.869 and 0.252, and others were less than 10^{-15} . For each patient, a pair of sample scores was then obtained by simple summation of the 11 category scores. Pairs of sample scores were plotted, and the three groups of patient outcomes were clearly distinguishable without exception. These findings show that the outcome of patients with head injury can be accurately discriminated by quantitative analysis of qualitative data.

Key words: discriminant analysis, head injury, multivariate analysis, patient outcome, quantification

Introduction

Neurosurgeons and neurologists should make a correct prognosis for patients with head injury early after admission to hospital. Correlations between patient outcome and various factors such as neurological findings and abnormalities on computed tomography (CT) have been determined to identify significant predictive factors and more accurately predict patient outcome.^{5,11,12)} However, these factors were usually assumed to be statistically independent. Correlations between patient outcome and just one factor, or a simple combination of several factors, have been determined,^{1,2)} even though such factors are not independent. Analysis of data from 115 patients with severe head injury by a logistic regression model not requiring independence of factors for calculating the probability of a given outcome could predict patient outcome

based on 12 factors, and the correct prediction was made in 105 cases (91%).¹⁰⁾ Although this rate of correct prediction is quite high, inclusion of only two classes of patient outcome may be insufficient. Moreover, these factors are qualitative, not quantitative, and even the Glasgow Coma Scale scores are only rankings. Both multivariate and quantitative analyses are required to obtain a formula permitting better prediction of patient outcome. Discriminant analysis performed using quantification theory type II⁵⁾ is an established method in mathematics, and should be used especially in the field of medicine.

The present study used this theory for the analysis of data from 63 patients with head injury in our hospital.

Clinical Materials and Methods

Sixty-three patients with head injury, 47 males and 16 females, were admitted to Tottori Prefectural Central Hospital within one hour after injury be-

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tween January 1989 and April 1991. Immediately after admission, patients were examined neurologically, and skull radiography and head CT were performed to determine clinical condition. All 63 patients demonstrated at least one of the nine abnormalities described below.

Nine clinical factors and sex and age in years were selected as predictors (Table 1). Two clinical factors were obtained from neurological signs and symptoms on admission, and seven factors from skull radiography and head CT. Level of consciousness was divided into three categories: Eyes were open without stimuli; eyes open to stimuli such as words or pain; and eyes always closed. Pupil dilation, skull fracture on radiographs, and epidural hematoma, subdural hematoma, traumatic subarachnoid hemorrhage, intracerebral hematoma, cerebral contusion, and midline shift on CT had two categories based on the presence or absence of the factors. Patient outcomes were verified 6 months after injury and assigned to good recovery, severe disability, or death. Good recovery indicates that the patient was capable of independent life. Severe disability meant

that the patient was dependent on others or vegetative. The numbers of patients with good recovery, severe disability, and death were 41, 9, and 13, respectively.

Discriminant analysis for the three types of outcome was performed with the 11 factors using quantification theory type II. This analysis yields the following four parameters. The partial correlation coefficient indicates how strongly each factor contributes to patient outcome. The category score is a value given to each category when one specific patient datum reacted to the category. The sample score was assigned to each patient and was the sum of all category scores. The correlation ratio expresses the degree of discrimination of each group, and a number of correlation ratios should be derived from the analysis. Each correlation ratio has a set of partial correlation coefficients, category scores, and sample scores.

Results

The highest correlation ratios were 0.869 and 0.252. The others were less than 10^{-15} , indicating that they were far less meaningful for discrimination of outcome. Therefore, only two correlation ratios were employed for further evaluation. Each ratio had 11 partial correlation coefficients and a set of category scores as shown in Table 2. Two sample scores were assigned to each patient based on the two sets of data. The results of these calculations for a 12-year-

Table 1 Factors and categories for multivariate analysis

Factor	Category	Number of patients
Sex	male	47
	female	16
Age (yrs)	0- 9	8
	10-19	9
	20-29	2
	30-39	3
	40-49	3
	50-59	14
	60-69	13
	70-79	7
Level of consciousness	80-89	4
	eyes open without stimuli	22
	eyes open with stimuli	12
Pupil dilation	eyes closed	29
	-	44
Skull fracture	+	19
	-	27
Epidural hematoma	+	36
	-	53
Subdural hematoma	+	10
	-	44
Subarachnoid hemorrhage	+	19
	-	32
Intracerebral hematoma	+	31
	-	47
Cerebral contusion	+	16
	-	31
Midline shift	+	32
	-	42
	+	21

Fig. 1 Plot of the pairs of sample scores for each patient. The sample score obtained from the maximum correlation ratio group is plotted on the abscissa, and the value from the second highest correlation ratio on the ordinate. Open circles indicate good recovery, closed circles show severe disability, and open squares show death. The arrow indicates the sample scores of the example case of a 12-year-old boy.

Table 2 Partial correlation coefficients and category scores for the maximum and second highest correlation ratios

Category		Maximum correlation ratio (0.869)		Second highest correlation ratio (0.252)	
		Partial correlation coefficient	Category score	Partial correlation coefficient	Category score
Sex		0.488		0.114	
	male		<u>0.018</u>		<u>- 0.016</u>
	female		- 0.052		0.047
Age (yrs)		0.458		0.226	
	0- 9		- 0.003		- 0.008
	10-19		<u>- 0.053</u>		<u>0.030</u>
	20-29		0.032		- 0.259
	30-39		0.063		- 0.110
	40-49		- 0.031		- 0.052
	50-59		0.004		0.026
	60-69		0.034		0.055
	70-79		- 0.001		- 0.018
	80-89		- 0.036		- 0.039
Level of consciousness		0.613		0.202	
	eyes open without stimuli		<u>0.024</u>		<u>0.079</u>
	eyes open with stimuli		- 0.074		- 0.008
	eyes closed		0.049		- 0.057
Pupil dilation		0.588		0.018	
	-		- 0.035		<u>0.004</u>
	+		0.081		- 0.008
Skull fracture		0.299		0.016	
	-		<u>0.022</u>		<u>- 0.004</u>
	+		- 0.016		0.003
Epidural hematoma		0.003		0.045	
	-		- 0.001		<u>0.006</u>
	+		0.005		- 0.029
Subdural hematoma		0.607		0.233	
	-		- 0.034		<u>- 0.048</u>
	+		0.078		0.111
Subarachnoid hemorrhage		0.250		0.003	
	-		0.016		0.008
	+		- 0.016		- 0.009
Intracerebral hematoma		0.161		0.025	
	-		<u>0.006</u>		<u>0.004</u>
	+		- 0.018		- 0.011
Cerebral contusion		0.383		0.162	
	-		- 0.030		<u>0.050</u>
	+		0.029		- 0.048
Midline shift		0.275		0.086	
	-		<u>0.013</u>		<u>- 0.018</u>
	+		- 0.027		0.035

Two sets of partial correlation coefficients and category scores were obtained using the two correlation ratios. The underlined category scores are those for the example case of a 12-year-old boy.

old boy are presented as an example. He was hit by a car and brought immediately to the hospital by ambulance. On admission, his eyes were open without stimuli and his pupils were not dilated. Radiography showed no fractures and CT demonstrated no abnormal findings other than subarachnoid hemorrhage. He was assigned two sets of 11 category scores shown as underlined numbers in Table 2, summations of which yielded two sample scores, -0.134 and 0.077. Each of the 63

patients was assigned a pair of sample scores in the same way. Each pair of numbers was plotted two-dimensionally as a symbol determined by outcome, with open circles, close circles, and open squares representing good recovery, severe disability, and death, respectively (Fig. 1). The 12-year-old boy obtained a good recovery, and is represented by an open circle (arrow, Fig. 1). The three groups of outcomes were clearly distinguished from each other, because there were no areas in which more than two

types of symbols were present together on the graph.

Discussion

This study included patients admitted within one hour of severe or mild head injury, and excluded patients with mild head injury admitted more than one hour later. Such investigation of severe head injury should be useful for both neurosurgeons and general physicians. Prediction of the outcome of a patient with head trauma can be based on various findings, including the specifics of the accident, epidemiological factors, results of neurological examination, CT findings, laboratory data, and other factors. The numbers of such factors may increase over the clinical course. After initial care, the patient may undergo surgery, and then neurological examination, CT, magnetic resonance imaging, intracranial pressure monitoring, various forms of evoked potential monitoring such as auditory brainstem responses, cerebral blood flow measurement, and other studies.⁷⁾ The prediction of patient outcome at 24 hours after the injury may be based on hundreds of factors and should theoretically be more reliable than that made on admission, since the clinical condition 24 hours after admission should more closely resemble the eventual outcome. However, is such a prediction useful? Prediction of the outcome of head injury should be made as early as possible and should be made based on the relatively few factors which can be evaluated at every hospital. CT findings such as subdural hematoma and intracranial hematoma significantly affect the patient prognosis.^{4,8,9)} The 11 factors selected in this study can be obtained just after patient admission.

Quantification theory type II using these 11 factors enabled us to discriminate the three groups of patient outcomes completely. We consider three groups of outcomes are enough for predictions, though more are better. Only the maximum correlation ratio provided the sample score for each patient plotted on the abscissa in Fig. 1, but the discriminations were not so perfect. Although these factors were qualitative, this multivariate analysis provides quantitative data for the factors as partial correlation coefficients and category scores. The simple summation of these 11 category scores yielded the sample score for a patient and its value implied a patient outcome. Patients with good recovery, severe disability, and death were ranked in order of values of their sample scores. A patient with a sample score based on the maximum correlation ratio of less than 0.01 belonged to the good recovery group, and a patient with a sample score of value more than

0.16 died, whereas nine of 12 patients with sample scores from 0.01 to 0.16 belonged to the intermediate group, i.e. severely disabled. Therefore, 60 of 63 patient outcomes (95%) were predicted correctly using the single sample score based on the maximum correlation ratio.

Individual factors affecting patient outcomes significantly were the level of consciousness, subdural hematoma, and pupil dilation, of which the partial correlation coefficients based on the maximum correlation ratio were more than 0.58 (Table 2). The category score for the presence of subdural hematoma was 0.078, much higher than -0.034 for the absence of subdural hematoma. Higher values indicated worse outcome for the patient, as for the factors of pupil dilation and brain contusion. The category scores for level of consciousness were rather unacceptable. The category score for eyes open without stimuli was 0.024, higher than -0.074 for eyes open with stimuli. The patients in both two categories were all conscious irrespective of the open or closed eyes and there may be no differences between these two groups. The category score for the female group was -0.052 , much lower than that for the male group. Females had better patient outcomes, may be because of their biological advantages or lesser magnitude of injuries. Epidural hematoma had far less effect on patient outcome, because the partial correlation coefficient was less than 0.004. These findings agree with those of previous reports.^{3,4,6,8,9)} The age factor was divided into nine categories and each category included only a small number of patients, so no significant findings were observed. The other four factors were not so important as predictors, since the partial correlation coefficients were less than 0.3 and the differences between the two category scores were small.

The predictive power of our analysis was tested for 59 patients with head trauma admitted to Tottori University Hospital within one hour of injury from January 1993 to December 1994. A pair of sample scores for the maximum and the second correlation ratios was obtained by summation of the two sets of 11 category scores for each patient. The pair of sample scores for each patient were plotted on Fig. 1, and the outcome predicted for the patient according to the area on the plot. The outcomes of 52 of 59 patients (88%) were predicted correctly, when compared to the actual outcome of the patient.

We have also applied quantification theory type II to verify the effect of drug treatment on delayed cerebral vasospasm in patients with subarachnoid hemorrhage. The effect of the drug treatment was confirmed as a high value of the partial correlation

coefficient without requiring comparison with a control group. This is an advantage of the quantification theory type II and will be reported elsewhere. Quantification theory type II is a very useful tool for analyzing qualified factors which affect each other.

In conclusion, analysis of 63 head injury patients using quantification theory type II provided 30 pairs of category scores and a pair of sample scores for each patient. Plotting of the pairs of sample scores allowed complete discrimination of the three groups of patient outcomes. Therefore, quantitative analysis of qualitative data from patients with head injury can provide prediction of outcomes by simple calculations based on the findings of neurological examination, skull radiography, and CT on admission. This prediction of patient outcome will be beneficial for the selection of treatment, as prediction of severe disability or death on admission will allow more aggressive treatments such as mild hypothermia to be considered immediately.

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Commentary

The authors attempted to establish a method of outcome prediction employing multivariate analysis in patients admitted within one hour of severe or mild head injury. The results appear to be promising. This type of outcome prediction, which can be performed in every hospital, may be useful for selecting appropriate care in each patient as well as for increasing the overall efficiency of using social resources. However, firm conclusions regarding the actual value of this method in everyday practice must await prospective studies. It is evident that the determinants of patient outcome include the selection of appropriate treatment, for example, quick evacuation of intracranial hematomas. The decision-making of physicians who see patients on admission is thus based primarily on diagnosis, rather than prognosis such as the outcome prediction reported in the present paper. This is true especially when CT scans have already been taken. Nevertheless, I believe that the authors' approach is extremely important for evaluating the efficacy of new treatments, such as mild hypothermia. The efficacy of new treatments may be effectively analyzed if the differences in treatment are incorporated as one of the variables. Little has yet been achieved regarding this type of approach in the field of neurosurgery. The present paper represents an outstanding example of scientific analysis which should be employed more often for investigating neurosurgical problems in future.

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The authors clearly demonstrated that discriminant analysis using quantification theory type II for sex, age, two clinical factors, and seven neuroradiological characteristics within one hour of head injury correctly predicted the outcomes of patients at the 95% level. In the emergency room, assessment of intracranial pathology and prediction of patient outcomes are essential to employ further multimodal treatments. In this respect, the authors should be congratulated for their excellent study which enabled to predict the patient outcomes with this analysis. However, we also have to note that some patients rapidly deteriorate one to several hours after head injury so that close observation of the patient is required even if this kind of analysis indicates a good outcome.

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This paper introduces us to a new mathematical methodology for relating clinical findings to outcome after craniocerebral trauma. Prior publications have generally relied on linear regression techniques or neural net models; they have shown moderate promise in predicting outcome, but have not been adopted either because of complexity, inaccuracies in predictions or a limited spectrum of outcome categories. The "quantification theory type II" seems to have performed well in the patients examined in this report, largely discriminating all patients into 3 outcome groups without overlap in 60 of 63 patients across 3 outcome groups (using a maximum correlation ratio of <0.04 for good outcome and >0.1 for death, coupled with a second highest correlation ratio of about ≤ 0.1 to identify 6 of 9 patients with severe disability). This seems superior to prior outcome prediction models. The authors test their initial model

data on a second subset of patients with an accurate prediction within 3 outcome categories in 88% of 59 patients.

These observations should be extended to larger data sets. Will the technique be more robust if the initial data set is expanded? Will it be applicable across centers or countries? These questions likely can be answered with examination of this methodology using larger numbers of patients treated at Tottori, or examining other patient databases such as the American or European Brain Injury Consortium.

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It is important to correctly predict the prognosis for the head-injured patient as soon as possible after hospitalization by the fastest and simplest method possible for prompt determination of therapeutic method. In this paper, the authors used quantification theory type II to select 11 factors as predictors, i.e. age, sex, two factors based on neurological examination, and seven factors based on neuroradiological examination. This trial was applied for patients admitted within one hour of severe or mild injury.

They concluded that their quantitative analysis could predict outcome for head-injured patients. If it is right, their method provides us with useful information in the selection of treatment. Their method seems to be practical and worth evaluating, but it will be necessary to conduct this analysis in many more cases before it is established as a completely reliable method.

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