

# Outcome Prediction in Moderate or Severe Head Injury Using an Artificial Neural Network

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**Objective:** Many studies have constructed predictive models for outcome after traumatic brain injury. Most of these attempts focused on dichotomous result, such as alive vs dead or good outcome vs poor outcome. If we want to predict more specific levels of outcome, we need more sophisticated models. We conducted this study to determine if artificial neural network modeling would predict outcome in five levels of Glasgow Outcome Scale (death, persistent vegetative state, severe disability, moderate disability, and good recovery) after moderate to severe head injury. **Methods:** The database was collected from a nation-wide epidemiological study of traumatic brain injury in Taiwan from July 1, 1995 to June 30, 1998. There were total 18583 records in this database and each record had thirty-two parameters. After pruning the records with minor cases ( $GCS \geq 13$ ) and missing data in the 132 variables, the number of cases decreased from 18583 to 4460. A step-wise logistic regression was applied to the remaining data set and 10 variables were selected as being statically significant in predicting outcome. These 10 variables were used as the input neurons for constructing neural network. **Results:** Overall, 75.8% of predictions of this model were correct, 14.6% were pessimistic, and 9.6% optimistic. This neural network model demonstrated a significant difference of performance between different levels of Glasgow Outcome Scale. The prediction performance of dead or good recovery is best and the prediction of vegetative state is worst. **Conclusion:** An artificial neural network may provide a useful "second opinion" to assist neurosurgeon to predict outcome after traumatic brain injury.

Key words: head injury, artificial neural network, outcome prediction

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## Introduction

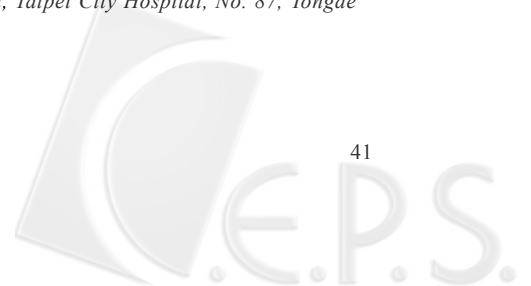
Considerable effort has been devoted to improving our ability to predict outcome after traumatic brain

injury (TBI). More reliable prediction of outcome would be helpful for clinicians as an important aid to decision making about management and for communication with relatives and other healthcare

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professionals.

Mathematical and statistical methods have been used to develop models for outcome prediction. The most commonly used methods include Bayes' theorem<sup>[1]</sup>, logistic regression and neural networks.<sup>[2]</sup>

An artificial neural network is a computerized construct consisting of input neurons (which process input data) connected to hidden neurons (to mathematically manipulate values they receive from all the input neurons) connected to output neurons (to output a prediction). Artificial neural networks have been successfully used for pattern recognition and outcome prediction in several clinical settings. The advantage of a neural network is the ability of the model to capture nonlinearities and complex interactions between factors related to the outcome of interest. Neural networks differ from other decision support systems in that the learning occurs by example through training and not by programming or pre-defined rules.

We conducted this study to determine if artificial neural network modeling would predict outcome using five levels of Glasgow Outcome Scale<sup>[3]</sup> (death, persistent vegetative state, severe disability, moderate disability, and good recovery) after moderate and severe head injury (initial Glasgow Coma Scale-Score

of 3-12 )

## Materials and Methods

This study was conducted using data collected from a nation-wide epidemiological study of traumatic brain injury in Taiwan from July 1, 1995 to June 30, 1998. One hundred and sixteen large to medium-sized teaching hospitals with qualified neurosurgeon participated in this study. There were total 18583 records in this database. The causes of head trauma were traffic crashes (14354 cases, of whom more than 65% were motorcycle crash victims), falls (2534 cases), and others (1695 cases). The mean age of the victims was 36.5 +/- 15.3 (SD), range 1 to 85 years old. In 7.8% of the cases, the victims were older than 60. The male to female ratio was about 3:1.

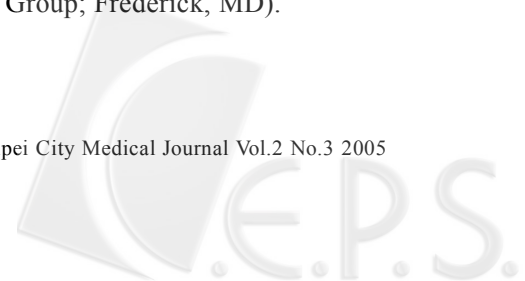
One hundred and thirty-two parameters including age, gender, causes of head trauma, GCS scores at the emergency department, CT findings and craniotomy for intracranial hematoma were recorded for each patient. The outcome was estimated by the Glasgow Outcome Scale (GOS), and was assessed as longer as 12 months after injury if possible.

After pruning the records with mild cases (GCS  $\geq$  13) and missing data in the 132 variables, the number of cases decreased from 18583 to 4460. In the second step, a step-wise logistic regression was applied to the remaining data set and 10 variables (Table 1) were selected as being statically significant ( $p < 0.05$ ) in predicting of the dependent variable (Glasgow Outcome Scale).

From the 4460 cases, 75% were randomly selected as the training group (n=3345) in the development of the neural network models. The validation group (n=1115) was used to test the performance of this model. Generalized regression neural network software was used (NeuralShell Classifier Version 2; Ward Systems Group; Frederick, MD).

**Table 1.** Variables as input neurons in the ANN model.

Age
Number of nonreactive pupils
Score of motor response
Score of verbal response
Score of eye opening
Use of helmet in motorcycle crash
Intracerebral hematoma on CT
Subdural hematoma on CT
Craniotomy for intracranial hematoma
Alcohol-related traffic accident



The accuracy, sensitivity and specificity are used to describe the performance of the predictive model.

### Results

The prediction results from the artificial neural network are shown in Table 2. As can be seen from the diagonal cells in the contingency table, Overall, 5.8% of predictions were correct, 14.6% were pessimistic (outcome better than predicted), and 9.6% optimistic (outcome worse than predicted). For patients with good recovery, 91.6 % of predictions are correct. For patients with moderate disability, 70.5% of predictions were correct. For patients with severe disability, 64.0% of predictions were correct. For death, 77.0% of prediction were correct but for vegetative state only 48.0% of prediction were correct. The sensitivity and specificity for each level are shown in Table 3.

### Discussion

Approaches to developing prognostic models vary from using traditional probabilistic techniques, originating from the field of statistics, to more qualitative and model-based techniques, originating from the field of artificial intelligence (AI).

Until recently, attempts to predict outcome have focused on dichotomous result, such as alive vs dead or good outcome vs poor function.<sup>[4]</sup> The use of single variables, such as GCS<sup>[5]</sup>, image finding<sup>[6]</sup>, intracranial pressure<sup>[7]</sup> or cerebral blood flow<sup>[8]</sup>, has allowed for a reasonable degree of accuracy in predicting those outcomes. With increased interest in predicting more specific levels of function, however, more sophisticated models are required. Such models require inclusion of multiple variables and better algorithm.

The neural network model developed in this study provided acceptable performance of overall outcome prediction. However it demonstrated a significant difference of performance between different levels of prediction. The prediction performance of dead or good recovery is best and the prediction

**Table 2.** Actual and predicted outcome for 1115 patients.

	Actual "1"	Actual "2"	Actual "3"	Actual "4"	Actual "5"	Total
Predicted as "1"	134	10	17	12	23	196
Predicted as "2"	2	12	3	5	1	23
Predicted as "3"	0	0	66	7	9	82
Predicted as "4"	20	2	14	132	19	187
Predicted as "5"	18	1	3	31	574	627
Total	174	25	103	187	626	1115

1=death, 2=vegetative, 3= severe disability, 4= moderate disability, 5=good recovery.

**Table 3.** The sensitivity and specificity of prediction.

	1	2	3	4	5
Sensitivity	77.01%	48.00%	64.08%	70.59%	91.69%
Specificity	93.41%	98.99%	98.42%	94.07%	89.16%

1=death, 2=vegetative, 3= severe disability, 4= moderate disability, 5=good recovery.

of vegetative state is worst. This may be due to the small case number of the vegetative group in this study.

In most outcome prediction studies of TBI patients, death and vegetative state are combined as a single level (poor outcome). However, these two states have significant difference for clinicians and patient's relatives. Some people even think survival in a persistent vegetative state is worse than death. Any model could predict persistent vegetative state in early stage would be very helpful for clinicians in assisting treatment limiting decisions. But the predictive power of our model is still not good enough for that purpose.

We excluded the mild cases in our study, because most these patients will have a good recovery. Including mild cases could let prediction models have better performance without clinical significance.

Many other authors have shown age<sup>[9,10]</sup>, GCS score, pupillary responsiveness<sup>[11,12]</sup> and findings of computed tomography (CT) to be significant predictors of outcome after traumatic brain injury. In our study, use of helmet in motorcycle crash was a significant outcome predictor. Before implementation of the motorcycle helmet use law, motorcycle collisions accounted for 74% of the traffic accidents in Taiwan, and most of the motorcycle riders were not helmet users. The motorcycle-related deaths have reached 48 percent of all motor vehicle-related deaths.<sup>[13]</sup> After implementation the helmet law in Taiwan on June 1, 1997, the mortality and morbidity from motorcycle-related head injuries decreased effectively in Taiwan.<sup>[14]</sup>

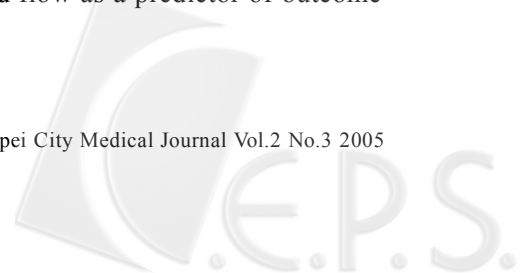
Although the ANN is a valuable method for outcome prediction, some of its nature should be noted before it can be widely applied. One is the 'black box' nature of the ANN, which means that the logical procedure of how networks determine a prediction cannot be observed. Hart and Wyatt believe that this "black box" aspect is a major obstacle to the

acceptance of neural nets as part of medical decision support systems.<sup>[15]</sup>

Accurate prediction of outcome in the individual patient remains difficult to achieve for both clinicians and computer program. Our research indicates that an artificial neural network may provide a useful "second opinion" to assist neurosurgeon to predict outcome after traumatic brain injury.

## References

1. Barlow P, Teasdale GM, Jennett B, et al: Computer assisted prediction of outcome of severely head-injured patients. *J Microcomputer Appl* 1984; 7:271-7.
2. Lang EW, Pitts LH, Damron SL, Rutledge R: Outcome after severe head injury: an analysis of prediction based upon comparison of neural network versus logistic regression analysis. *Neurol Res* 1997; 19(3):274-80.
3. Jennett B, Bond M: Assessment of outcome after severe brain damage. A practical scale. *Lancet* 1975; 1:480.
4. Benzer A, Mitterschiffthaler G, Marosi M, et al: Prediction of non-survival after trauma. *Lancet* 1991; 338:977-8.
5. Jennett B, Teasdale G, Braakman R, Minderhoud J, Knill-Jones R: Predicting outcome in individual patients after severe head injury. *Lancet* 1976; 1(7968):1031-4.
6. van Dongen KJ, Braakman R, Gelpke GJ: The prognostic value of computerized tomography in comatose head-injured patients. *J Neurosurg* 1983; 59:951.
7. Czosnyka M, Guazzo E, Whitehouse M, et al: Significance of intracranial pressure waveform analysis after head injury. *Acta Neurochir* 1996; 138(5):531-41.
8. Kelly DF, Martin NA, Kordestani R, et al: Cerebral blood flow as a predictor of outcome



- following traumatic brain injury. *J Neurosurg* 1997; 86(4):633-41.
9. Luerssen TG, Klauber MR, Marshall LF: Age and outcome from head injury: A longitudinal prospective study of adult and pediatric head injury. *J Neurosurg* 1988; 68:409.
  10. Vollmer DG, Torner JC, Jane JA, et al: Age and outcome following traumatic coma: Why do older patients fare worse? *J Neurosurg* 1991; 75:S37.
  11. Price DJ, Knill-Jones R: The prediction of outcome of patients admitted following head injury in coma with bilateral fixed pupils. *Acta Neurochir* 1979; Suppl 28:179.
  12. Jennett B, Teasdale G, Braakman R, et al: Predicting outcome in individual patients after severe head injury. *Lancet* 1976; 1:1031.
  13. Chiu WT: The motorcycle helmet law in Taiwan. *JAMA* 1995; 274(12):941-2.
  14. Chiu WT, Kuo CY, Hung CC, Chen M: The effect of the Taiwan motorcycle helmet use law on head injuries. *Am J Public Health* 2000; 90(5):793-6.
  15. Hart A, Wyatt J: Evaluating black-boxes as medical decision aids: issues arising from a study of neural networks. *Med Inform* 1990; 15: 229-36.

## 以類神經元網路預測中重度頭部外傷病患之預後

許明暉<sup>1,3</sup>、李友專<sup>4</sup>、邱文達<sup>5</sup>、顏如娟<sup>2</sup>

**目的：**目前已知之頭部外傷預後預測模式大多為兩極性結果之選擇，如存活相對於死亡；良好的預後相對於不良之預後。如欲預測更詳細的預後等級則需建構更複雜的預測模式。**方法：**在本實驗中我們嘗試以類神經元網路預測中重度頭部外傷病患在格拉斯哥預後量表中五個等級(死亡、植物人狀態、嚴重殘障、中度殘障、恢復良好)之落點。分析資料來源為臺灣頭部外傷資料庫1995年6月1日至1998年5月30日收錄之個案。資料庫中共有18583筆資料，每筆資料有132個變數。在剔除輕

度頭部外傷(昏迷指數 $\geq 13$ )與資料不完整之個案後個案數為4460。首先我們使用逐步邏輯回歸篩選出10個具統計意義之變數，再用這個變數來建構類神經網路。**結果：**此一類神經網路預測有75.8%為準確，14.6%預測較實際為悲觀，9.6%預測較實際為樂觀。此一類神經網路對於不同預後的預測能力有顯著差異；預測死亡與恢復良好準確性最高，預測植物人狀態準確性最差。**結論：**我們認為此一類神經網路可作為神經外科醫師為頭部外傷病患進行預後預測之參考。

關鍵詞：頭部外傷，類神經元網路，預後預測。

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