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Application of Multiple Neural Networks to Time Sequence Data - Prediction of Nosocomial Infection in Intensive Care Unit Patients

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Abstract

We have invented the method of modeling time sequence data for prediction using multiple neural networks (NNs). In this study, we examined whether multiple NNs outperforms logistic regression and single NN in the prediction of nosocomial infection in intensive care unit patients (n=16,584). The three predictive models were developed using the 80% training subset and their predictive performances were assessed using the 20% testing subset in terms of classification accuracy and the area under a receiver operating characteristics curve. Overall the highest predictive performance was found in multiple NNs, followed by logistic regression and single NN. The predictive performance of multiple NNs was kept at a constant level, whereas that of logistic regression and single NN decreased with increasing a follow-up period.

Keywords:

Comparative study, predictive model, time sequence data, neural networks, nosocomial infection, intensive care units

Introduction

Multivariate regression models, particularly logistic regression, have commonly been used to estimate probabilities of outcome events. The predictors are usually selected from baseline data. Accordingly, the developed predictive models take no account of subsequent events, which may affect the patient's outcome.

We have invented the method of modeling time sequence data for prediction using multiple neural networks (NNs). The model was designed to use baseline data and subsequent events for estimating the probability of the outcome event - nosocomial infection in intensive care unit patients. We compared the predictive performance of multiple NNs with that of logistic regression and single NN using the cross-validation method.

Methods

A large cohort database was accumulated from the Japanese Nosocomial Infection Surveillance System. In the cohort of 16,584 eligible patients aged 16 years, hospitalized in 28 intensive care units for 2 days, there were 915 patients (5.5%) who had at least one episode of nosocomial infection during the first 10 days. After stratification by the outcome event, the original data set was randomly divided into 80% training and 20% testing subsets. The three predictive models - logistic regression, single NN, and multiple NNs were developed using the training subset and their predictive performances were assessed using the testing subset in terms of total classification accuracy (TCA) and the area under a receiver operating characteristics curve (AUC).

Logistic regression and single NN incorporated the following baseline data: sex, age (16-39, 40-69, 70+), severity of illness (0-10, 11-20, 21+; APACHE II), operation (none, elective, urgent), ventilator (yes, no), urinary catheter (yes, no), central venous catheter (yes, no). Multiple NNs incorporated subsequent events (ventilator, urinary catheter, and central venous catheter used at a specific period after admission) in addition to the baseline data.

As shown in Figure 1, multiple NNs consisted of 4 three-layer networks, which were responsible for predictions at four periods (Day 3-4, 5-6, 7-8, and 9-10 after admission), respectively. Two neighboring networks were connected in series to represent dependencies of subsequent periods. As shown in Figure 2, estimates for period t_a, $P(t_a)$ were passed forward to a subsequent network as inputs and used to enhance estimates for the following period t_b, $P(t_b)$. The first network with 13 input, 10 hidden, and 1 output neurons was used to input baseline data (sex, age, severity of illness, operation, ventilator, urinary catheter, and central venous catheter) to estimate the probability of the outcome event at Day 3-4 after admission. The second network with 4 input, 10 hidden, and 1 output neurons was used to input the output of the first network and subsequent events (ventilator, urinary catheter, and central venous catheter used at Day 3-4 after admission) to estimate the probability of the outcome event at Day 5-6 after admission. The third and

fourth networks followed the second network in a similar fashion (Figure 1). Each network employed back propagation learning with the momentum of 0.8. The learning rate was 0.01.

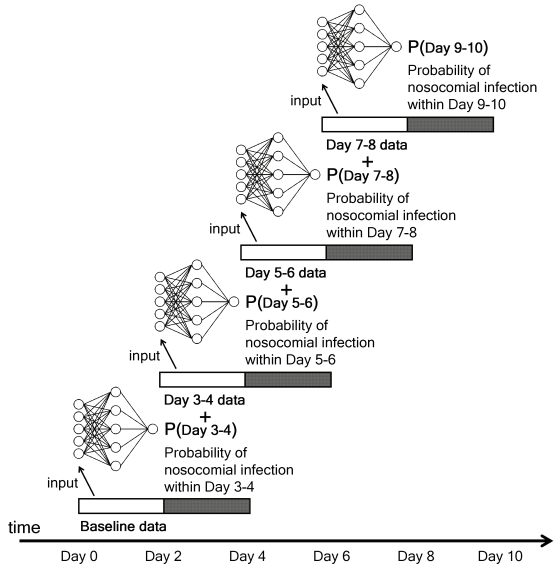

Figure 1 - Multiple NNs

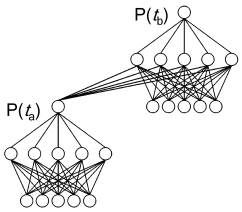

Figure 2 - Connection of two neighboring networks

Results and discussion

Table 1 shows the classification accuracy of the three predictive models. Multiple NNs showed the highest classification accuracy for total (TCA), positive (sensitivity), and negative (specificity) cases among the three predictive models.

Table 1 - Classification accuracy

	Total (TCA)	Positive (sensitivity)	Negative (specificity)
Logistic regression	0.63	0.71	0.62
Single NN	0.37	0.85	0.35
Multiple NNs	0.73	0.92	0.72

The receiver operating characteristics curve nearest to upper left corner was found in multiple NNs, followed by logistic regression and single NN. The AUCs of multiple NNs, logistic regression, and single NN were 0.83, 0.73, and 0.60, respectively. These results suggest that multiple NNs may be superior to logistic regression and single NN in terms of the discriminatory ability at a threshold level (indicated by TCA) and also the overall discriminatory ability independent of the setting of threshold level (indicated by AUC).

Table 2 shows the predictive performances of the three predictive models by period. Multiple NNs showed no significant change in TCA or AUC, whereas logistic regression and single NN showed noticeable declines in TCA and AUC. This result suggests that multiple NNs may be useful for improving predictive performance especially at later periods.

Table 2 - Predictive performance by period

		Day 3-4	Day 5-6	Day 7-8	Day 9-10
Number of patients (positive cases)		1625 (68)	610 (51)	292 (34)	612 (21)
Logistic regression	TCA	0.75	0.61	0.52	0.38
	AUC	0.79	0.73	0.67	0.62
Single NN	TCA	0.43	0.37	0.33	0.25
	AUC	0.63	0.58	0.55	0.55
Multiple NNs	TCA	0.73	0.66	0.79	0.77
	AUC	0.86	0.77	0.84	0.82

Conclusion

Multiple NNs outperformed logistic regression and single NN in the prediction of nosocomial infection in intensive care unit patients. The predictive performance of multiple NNs was kept at a constant level, whereas that of logistic regression and single NN decreased with increasing a follow-up period.

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