Prediction of the hospitalization due to congestive heart failure using an artificial neural network based on doppler echocardiography

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Running title: *The hospitalization due to congestive heart failure using an artificial neu*ral network *method*

ABSTRACT

Congestive heart failure (CHF) is a major cause of hospitalization in population older than 65 years of age. There are high mortality rate if the congestive heart failure is not well controlled. Doppler echocardiography is a traditional method to evaluate the heart function. These evaluation provides us to understand whether heart function is normal or impaired. The aim of this study was to design an artificial neural network (ANN) capable of predicting the exact possibility of hospitalization due to CHF. A total 7475 Patients were included in the study from Jan. 2008 to Dec. 2008 as training cases. Another 591 patients collected from Jan. 2007 as testing cases. Fifteen echocardiographic variables and two clinical variables were collated from 7475 patients received cardiac echo examination including OPD and hospitalization patients. ANN analysis was carried out by training the network with data from 7475 cases and subsequently testing with data from another 591 unseen cases to determine the optimal ANN architecture. The optimal ANN architecture was found to be a standard feed-forward, fully-connected, back-propagation multilayer perceptron. The overall accuracy rate of ANN was 80.7%, which is higher than that of logistic regression (LR) (74.8%). By using the area under the receiver operating characteristics curve as a measure of performance, the ANN outperformed the LR (0.873±0.0109 versus 0.793±0.0129; p < 0.001). The superiority of models for prediction of hospitalization due to congestive heart failure was found in ANN analysis, but not in LR analysis.

Keywords: artificial neural network, echocardiography, congestive heart failure

INTRODUCTION

Nearly 5 million Americans have heart failure today, with an incidence approaching 10 per 1000 population among persons older than 65 years of age. Heart failure is the reason for at least 20 percent of all hospital admissions among persons older than 65. Over the past decade, the rate of hospitalizations for heart failure has increased by 159 percent. [1] In 1997, an estimated $5,501 was spent for every hospital-discharge diagnosis of heart failure, and another $1,742 per month was required to care for each patient after discharge. At present, angiotensin-converting–enzyme (ACE) inhibitors, angiotensin-receptor antagonists, beta-blockers, spironolactone, biventricular pacing, coronary bypass surgery, and the use of multidisciplinary teams to treat heart failure have all been shown to reduce the rate of hospitalizations substantially, as well as to reduce mortality or improve functional status [2-4].

Not all patients with the condition have poorly contracting ventricles and a low ejection fraction. Many have uncorrected valvular disease, such as aortic stenosis or mitral regurgitation, or abnormal filling, resulting in diastolic heart failure. A large majority of patients with heart failure are elderly, and 75 percent of patients have a history of hypertension. Many patients have at least one serious coexisting condition, in addition to advanced age.

The artificial neural network (ANN) is a form of artificial intelligence that employs non-linear mathematical models to mimic the human brain's own problem-solving process. The artificial neural network can take previously solved examples to build a system of "neurons" that makes new decisions. At present, there is no medical literature to predict the hospitalization due to congestive heart failure using an artificial neural network method. If we can use the method to predict the hospitalization for congestive heart failure. We can pre-treat these patients to avoid hospitalization. Then the expenditure of medical insurance will decrease.

The aim of this study was to examine the hypothesis that an artificial neural network (ANN) based on doppler echocardiography is capable of predicting the possibility of hospitalization due to congestive heart failure. ANN are a family of computational algorithms which are modeled on the capabilities of the human nervous system [5-7]. They permit recognition of patterns in data that cannot be detected with linear statistical analysis. The neuron (node) is the basic computational unit of an ANN. It receives a variety of inputs from other neurons through connections that resemble synaptic structure and has a binary (all or nothing) output [5]. This output is determined by the sum of the inputs as well as the weight (synaptic strength) attached to these input variables [7]. The weight attached to each node is altered through a period of familiarization ''training'' until an optimal weight which best describes the influence of the data set, represented by the node, is reached. Each of the input nodes corresponds to a single input variable. Initial values are set for the ''weights'' associated with each link in the network. Input data for which an output is known are presented to the network. If the predicted output from the model does not equal the known output, the weights within the network are changed so as to narrow this difference. This process continues until the prediction errors are minimized. Once the network is trained and validated, it may be used on unseen data for prediction or classification purposes [7].

A wide variety of neural network designs with varying degrees of complexity have been described [7]. The simplest and most commonly used form is the multilayered perceptron (MLP). The structure of this neural network model is illustrated in Figure 1 [7].

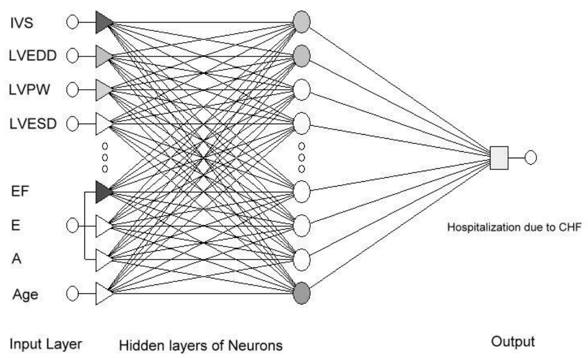

Fig. 1. A simplified diagram depicting MLP structure.

MATERIALS AND METHODS

Study population

Between January 2008 and December 2008, there were total 8966 patients received echocardiography examination in Taipei Medical University – Wanfang Hospital. 1752 patients were performed during hospitalization no matter due to CHF or other disease and 7214 patients were outpatients. We excluded patients with poor cardiac windows and atrial fibrillation (Af) due to absent of peak late left ventricular filling velocity (A) data in atrial fibrillation patients. Another 591 patients collected from January 2007 was used as testing cases. Finally there were total 7475 patients involved in this study.

Data preparation

The Doppler cardiac echo image was performed using HP sono 5500 cardiac vascular ultrasound system with a 21330A S4 (2.0-4.0 MHz) sector probe (Hewlett-Packard Development Company, L.P.) .

All of these patients received Doppler echocardiography with M-mode method for interventricular septal thickness (IVS), left ventricular end diastolic diameter (LVEDD), left ventricular posterior wall thickness (LVPW), left ventricular end systolic diameter (LVESD), Aortic root internal diameter (AO), left atrium diameter (LA) measurement. Parasternal long axis, short axis and apical four chambers views were performed for all patients. Left ventricular ejection fraction was calculated with fractional shortening formula. The valvular regurgitation or stenosis was checked with color Doppler method.

Neural Network Design

MLP ANN models with a back-propagation circuit were constructed using Statisca version 8.0 software (StaSoft. INC. USA). This neural network design was selected because of its good analytical power and relative simplicity of design. The MLP models which were developed had seventeen input nodes, consisting of entries corresponding to Age, Interventricular septal thickness (IVS), left ventricular end diastolic diameter (LVEDD), left ventricular posterior wall thickness (LVPW), left ventricular end systolic diameter (LVESD), Aortic root internal diameter (AO), left atrium diameter (LA), ejection fraction (EF), peak early left ventricular filling velocity (E), peak late left ventricular filling velocity (A), Sex, Mitral regurgitation (MR), Mitral stenosis (MS), Aortic regurgitation (AR), Aortic stenosis (AS), Tricuspid regurgitation (TR), Pulmonary regurgitation (PR). We constructed feed-forward networks consisting of three layers – an input layer, a hidden layer, and an output layer. Several architectures of ANN were examined including multilayer perceptrons, radial-basis-function, and linear function networks. The ANN was designed to give a categorical value of 1 for the output node when the patient was hospitalization due to congestive heart failure (CHF) and 0 when the patient was outpatient or hospitalization not due to CHF. The training technique was set to back-propagation and conjugate gradient descent algorithms, which adjust the internal parameters of the network over the repeated training cycles to reduce the overall error. One iteration consists of a single presentation of each set of inputs for all cases followed by automatic adjustments of the weight connections to minimize the total error for all patients whose data were used in the training. The estimation of error was based on the sum-squared error or entropy function [8].

Several types of ANN analysis were performed. Because no well-established theoretical method exists for designing an ideal ANN [9], and the optimal number of hidden nodes and iterations are unknown, the best designs are typically determined through trial and error [10]. To find an optimal network, different ANN architectures with 9–15 hidden neurons were constructed and trained with the training test [11]. Then all models were tested with the testing set to determine their predictive accuracy of hospitalization due to CHF. The network with the highest classification accuracy was kept [11].

Logistic regression model

Multiple logistic regression was constructed using SPSS version 14 software (SPSS INC. USA). It was trained using the same training dataset of the ANN analysis with maximum likelihood estimation. Although logistic regression does not involve training, we used a “training set” to refer to that portion of the database used to derive the regression equations [12]. The model was then applied to predict the possibility of hospitalization in CHF patients.

RESULTS

There were total 7475 patients involved in this study after we excluded poor cardiac windows and Af patients. 416 patients were admitted due to CHF and 7059 patients were outpatients or hospitalization not due to CHF. The mean age of subjects was 59.46 years (standard deviation = 17.06); 3950 were female and 3525 were male. In hospitalization due to CHF group, the mean age of subjects was 73.34±13.95 years; 198 were female and 218 were male. The mean left ventricular ejection fraction 57.93±15.03 % and the mean LVEDD was 49.54±9.70 mm. In outpatients or hospitalization not due to CHF group, the mean age of subjects was 58.65±16.87 years; 3752 were female and 3307 were male. The mean left ventricular ejection fraction 71.30±9.26 % and the mean LVEDD was 44.18±6.98 mm. The statistical significant difference was found in Age, LVEDD, LVESD, AO, LA, EF, E, A, MR, MS, AS, AR, TR and PR parameter (Table 1).

Table 1. Baseline characteristics between two groups.

Variable	Total (n=7475)	Hospitalization due to CHF (n=416)	Outpatient or hospitalization not due to CHF (n=7059)	P Value
Age	59.46±17.06	73.34±13.95	58.65±16.87	P<0.001
Male (n)	3525	218	3307	P=0.027
IVS	12.46±2.75	12.47±2.79	12.46±2.75	P=0.937
LVEDD	44.48±7.26	49.54±9.70	44.18±6.98	P<0.001
LVPW	12.03±2.87	12.18±2.57	12.02±2.89	P=0.276
LVESD	26.65±6.94	34.37±10.43	26.19±6.39	P<0.001
AO	31.46±4.21	32.24±4.41	31.41±4.19	P<0.001
LA	36.26±6.13	39.14±8.10	36.09±5.95	P<0.001
EF	70.55±10.14	57.93±15.03	71.30±9.26	P<0.001
E	64.95±21.12	67.84±28.68	64.78±20.58	P=0.004
A	76.90±20.57	83.23±26.42	76.53±20.11	P<0.001
MR (n)	3366	273	3093	P<0.001
MS (n)	12	5	7	P<0.001
AS (n)	365	52	313	P<0.001
AR (n)	1949	162	1787	P<0.001
TR (n)	2795	193	2602	P<0.001
PR (n)	992	82	910	P<0.001

Neural Network Analysis

7475 patients data were used to train the neural network model, and another 591 patients were used for model validation and out-of-sample testing. Following completion of training, the ANN model was able to predict hospitalization of CHF; cross-validation confirmed the validity of the ANN model at predicting hospitalization of CHF. It had a sensitivity of 75.2% and specificity of 84.4%. Area under the curve for the ANN model was 0.873 (P=0.0001). Receiver operating characteristics (ROC) curve analysis was performed as figure 2.

Logistic regression analysis

The same 7475 data was used for logistic regression analysis. It had a sensitivity of 69.1% and specificity of 84.0%. Area under the curve for the logistic regression model was 0.793 (P=0.0001). Receiver operating characteristics (ROC) curve analysis compared with ANN was performed as figure 2.

Therefore the superiority of models for prediction of hospitalization due to congestive heart failure was found in ANN analysis, but not in LR analysis.

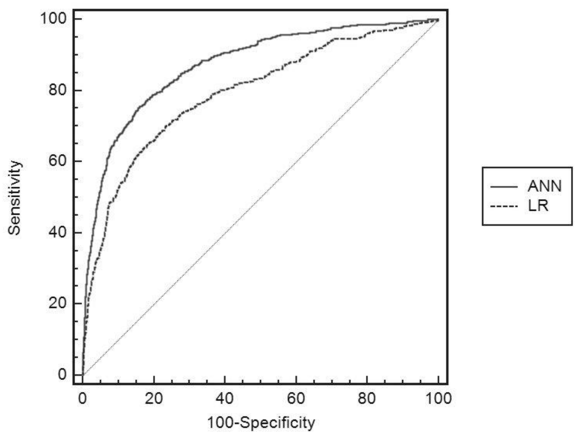

Fig. 2. Comparison of ROC curves between ANN and LR. Solid line indicates artificial neural network analysis with all variables (ANN); Dotted line indicates logistic regression analysis with all variables (LR). The area under the ROC curves for ANN and LR are 0.873 and 0.793, respectively (p < 0.001).

DISCUSSION AND CONCLUSION

The traditional view that heart failure is a constellation of signs and symptoms caused by inadequate performance of the heart focuses on only one aspect of the pathophysiology involved in the syndrome. It is estimated that 20 to 50 percent of patients with heart failure have preserved systolic function or a normal left ventricular ejection fraction. Although such hearts contract normally, relaxation (diastole) is abnormal. Cardiac output, especially during exercise, is limited by the abnormal filling characteristics of the ventricles. We can know the patient with systolic heart failure due to reduced left ventricular ejection fraction. But the diagnosis of diastolic heart failure is usually made by a clinician who recognizes the typical signs and symptoms of heart failure and who is not deterred by the finding of normal systolic function (i.e., a normal ejection fraction) on echocardiography. Echocardiography may be useful in the detection of diastolic filling abnormalities.

It's difficult to predict whether the individual will admit to ward after echocardiography examination. If we can know who is high risk for hospitalization due to CHF. In fact, it may influence the decision to provide the rationale for therapeutic intervention on CHF patients to avoid further exacerbation of CHF. In fact, widespread application of a powerful statistical algorithm such as the ANN, and several low-cost, easily obtainable parameters including the echocardiography data, could lead to considerable cost savings in the management of patients with CHF.

The use of ANNs represents a novel approach in the assessment of the possibility of hospitalization due to CHF. Artificial neural network algorithms have been applied to a variety of clinical conditions where complex relationships within the data set preclude the use of conventional linear statistical analysis. [13]

In conclusions, our results suggest that ANNs have an acceptable degree of accuracy in predicting the hospitalization due to CHF. The models of ANN analysis is superior to LR analysis for prediction of hospitalization due to congestive heart failure. But this study still has some limitation such as the variation of the data from different operator for echocardiography. Another, we excluded the patients with atrial fibrillation. But atrial fibrillation was associated with adverse cardiovascular outcomes irrespective of baseline LVEF [14]. If we can involved these patients, the result may be more powerful for prediction.

REFERENCES

[1] 2001 Heart and stroke statistical update. Dallas: American Heart Association, 2000.

[2] Foody JM, Farrell MH, Krumholz HM. Beta-blocker therapy in heart failure: scientific review. JAMA 2002;287:883-889.

[3] McAlister FA, Lawson FM, Teo KK, Armstrong PW. A systematic review of randomized trials of disease management programs in heart failure. Am J Med 2001;110:378-384.

[4] Shah NB, Der E, Ruggerio C, Heidenreich PA, Massie BM. Prevention of hospitalizations for heart failure with an interactive home monitoring program. Am Heart J 1998;135:373-378.

[5] Cross SS, Harrison R, Kennedy RL. Introduction to neural networks. Lancet 1995;346:1057-1063.

[6] Warner B. Understanding neural networks as statistical tools. Am Stat 1996;50:284-294.

[7] Drew PJ, Monson JRT. Artificial neural networks. Surgery 2000;127:3-11.

[8] G.D. Tourassi, C.E. Floyd, The effect of data sampling on the performance evaluation of artificial neural networks in medical diagnosis, Med. Decis. Making 17 (1997) 186–192.

[9] A.S. Miller, B.H. Blott, T.K. Hames, Review of neural network applications in medical imaging and signal processing, Med. Biol. Eng. Comput. 30 (1992) 449–464.

[10] W. Penny, D. Frost, Neural networks in clinical medicine, Med. Decis. Making 16 (1996) 386–398.

[11] CC Lin, YC Wang, JY Chen, YJ Liou, YM Bai, IC Lai, TT Chen, HW Chiu, YC Li, Artificial neural network prediction of clozapine response with combined pharmacogenetic and clinical data. computer methods and programs in biomedicine 2008:91-99

[12] Tourassi GD, Floyd CE. The effect of data sampling on the performance evaluation of artificial neural networks in medical diagnosis. Med Decis

Making 1997; 17:186–192.

[13] Baxt WG.. Application of artificial neural networks to clinical medicine. Lancet 1995;346:1135-1138.

[14] Olsson LG, Swedberg K, Ducharme A, et al. Atrial fibrillation and risk of clinical events in chronic heart failure with and without left ventricular systolic dysfunction: results from the Candesartan in Heart failure-Assessment of Reduction in Mortality and morbidity (CHARM) program. J Am Coll Cardiol 2006;47:1997–2004.