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Application of artificial neural network in the diagnostic system of osteoporosis

Xinghu Yu [a], Chao Ye [b], Liangbi Xiang [a,*]

[a] Jinzhou Medical University, No. 3-40, Songpo Road, Linghe District, Jinzhou 121001, China
[b] School of Astronautics of Harbin Institute of Technology, No. 92, Xidazhi Street, Harbin 150080, China

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ABSTRACT

In order to achieve a diagnosis system of osteoporosis with the assistance of a network, an artificial neural network model is established and applied. We extract features through the observation of X-ray images and clinical main symptoms from patients with osteoporosis by three experienced orthopedists and three experienced radiologists and score the features related to osteoporosis according to the quantified standard. Then parts of patients are selected randomly as the training set and the rest is regarded as the prediction set. Input score results and biochemical parameters are related to osteoporosis. The prediction results of all samples are compared with the predicted results of logistic regression. Diagnostic results of the artificial neural network model are compared with the results of logistic regression. The sensitivities are 94.5% and 63.6%, respectively. The specificities are 96.9% and 87.5%, respectively. The area under the receiver operating characteristic curve of the artificial neural network (0.950) is larger than that of logistic regression (0.870), P=0.034. The results of this study show that the artificial neural network is effective in the diagnostic system of osteoporosis.

1. Introduction

Osteoporosis is a systemic disease that characterized by decreased bone mass, bone microstructure damage that increases osteopsathyrosis and the fracture probability and regarded as one of senile degenerative diseases [1–4]. More than 200 million individuals suffer from osteoporosis worldwide [5], and there are about 9 million osteoporotic fractures happening each year [6], which represents a burden for society [7,8]. In osteoporosis, there is reduction of the Bone Mineral Density (BMD) and disruption of the bone micro-architecture [9]. However, there are lack of direct methods to determine bone strength. Although bone mineral density is the best quantitative indicator to diagnose osteoporosis, predict risk of osteoporotic fracture, detect natural course and evaluate the effect of the drug intervention, many of which can not be reflected by the measurement of bone mineral density [1]. Therefore, a more reasonable method is that we integrate large image data with biochemical indexes from the patients with osteoporosis as a database to form an automatic identification diagnostic system in order to improve the diagnostic rate and reduce the doctors' workload. In brief, we should make full use of clinical big data in the diagnostic system [10].

It is worth pointing out that lots of diagnostic methods of osteoporosis at present are focused on single auxiliary diagnosis without combining with other factors that can lead to osteoporosis, which may cause higher misdiagnosis rate.

As we all know, osteoporosis can occur at any age and gender and also can be seen more at postmenopausal women and older men [11]. In clinical classification, osteoporosis can be divided into two categories including primary and secondary osteoporosis. Primary osteoporosis can also be divided into three different types, including postmenopausal osteoporosis (Type 1), senile osteoporosis (Type 2), and idiopathic osteoporosis (including teenagers). Quantitative assessment of bone mineral density (BMD) measured by dual energy X-ray absorptiometry (DXA) is used in operational definition of osteoporosis [12]. And then judge the results according to T-score and Z-score. The recommended anatomic region of interest is the femoral and lumbar spine [13]. Usually, T-score (formula (1)) is used to represent the bone mineral density of such people, for example, perimenopausal, postmenopausal women and more than 50-year old male. Z value (formula (2)) is suggested to be used as the bone mineral density of such people, for instance, children, premenopausal women and men less than 50-year old [14]. T-score diagnostic criteria are shown in Table 1. Now we try to use the artificial neural network with assistance of a computer to diagnose and predict that if one person suffers from osteoporosis. This approach combines patients complains and X-ray radiograph with clinical blood biochemical

* Corresponding author.
E-mail address: xlb_2016@163.com (L. Xiang).

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Table 1
T-score diagnostic criteria for osteoporosis [15,18,39].

Condition	Diagnostic criteria
Normal	T≥ − 1.0 SD
Osteopenia	− 2.5 SD<T< − 1.0 SD
Osteoporosis	T≤ − 2.5 SD

SD= Standard Deviation

examination in order to improve the correct diagnostic rate of osteoporosis, so as to reduce the misdiagnosis rate.

$$\mathbf{T}=(\mathbf{EV}-\mathbf{PBM})/\mathbf{NASD} \tag{1}$$

# EV=Estimated Value PBM=Peak Bone Mass.
NASD=Normal Adult Standard Deviation

$$\mathbf{Z}=(\mathbf{EV}-\mathbf{PMBD})/\mathbf{PBMDSD} \tag{2}$$

# EV=Estimated Value PMBD= Peers' Mean Bone Density.
PBMDSD=Peers' Bone Mineral Density Standard Deviation.

At present, in the aspect of clinical diagnosis of osteoporosis, although the dual-energy X-ray absorptiometry (DXA) is recognized by the international academia as bone mineral density examination method and the measured value is regarded as the gold standard for osteoporosis diagnosis [15,16], we can also see many different cases, for example, one person has T-score > − 2.5 SD, but he suffers from osteoporosis; however, another person has T-score ≤ − 2.5 SD, he does not suffer from the fracture, and there also exist some patients with fracture without T-score ≤ − 2.5 SD, but T-score > − 2.5 SD. So it can confuse osteoporosis with non-osteoporosis if we diagnose the patient only with T-score and be unfavorable to reasonably choose people who is at high risk of osteoporosis to proceed corresponding control scheme. Therefore, we use X-ray radiograph, T-score and biochemical examination for integrated treatment and analysis to diagnose and predict patients' condition so as to determine whether the patients suffering from osteoporosis.

The main contribution of this work is to achieve osteoporosis diagnosis using the artificial network method to carry on comprehensive analysis with 17 characteristics extracted from different clinical examinations and set up one diagnostic prediction model for the clinical diagnosis of osteoporosis. It makes one of the first attempts to achieve an artificial neural network model for osteoporosis diagnosis with the least numbers of characteristics with improving the accuracy of the osteoporosis significantly.

The rest of the paper is organized as follows: in Section 2, the artificial neural network model is constructed and described in detail. Section 3 introduces the experiments and interpretation of the results, with detailed discussions in Section 4 and we have the final conclusions in Section 5.

2. Artificial neural network

Artificial neural network (ANN), which is a nonlinear system, is the abstraction and simulation of a number of basic features extracted from neurophysiological models [17–21]. Its organizations can simulate the interaction which is made in response to objects in the real world by biological nervous system [20].

ANN has the advantage on the aspect of the modeling and analysis of systems where response of interest, which is determined by lots of factors and the relationship between independent and dependent variables in a system, is unknown [22]. When conventional methods are ineffective or cannot solve the problem, the approach of ANN can show its superiority. The ANN will be the best advantageous tool especially when we have no idea of the mechanism of the problem or we cannot express it in a mathematical model of the system, for example, fault diagnosis, feature extraction and prediction. In addition, ANN shows great flexibility and adaptability when to deal with a large number of original data which can not be described with rules or formula.

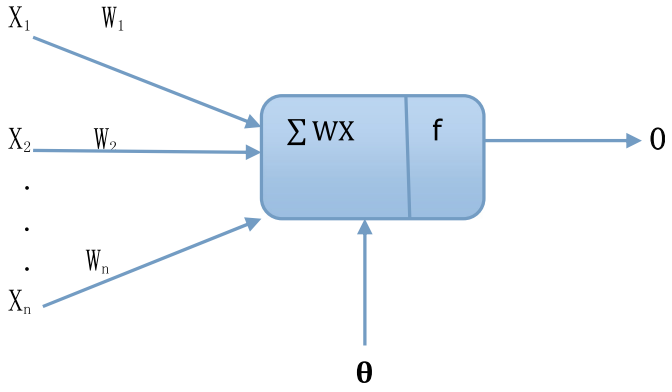

Fig. 1. Artificial neuron model.

2.1. Artificial neuron model

Artificial neuron, which is a basic processing unit of the neural network [23], connects with each other and accepts a weighted input to produce a corresponding output by means of an activation function [24]. At present, ANN mostly adopts M-P model which was put forward by psychologists Mcculloch and mathematical logician Pitts. Fig. 1 shows an artificial neural model.

In the figure, X= (X1, X2, ……,Xn) is considered to be n input value which is derived from outside or output of other neurons. W= (W1, W2, ……,Wn), which is also called weight, stands for the connection strength between this neuron and other n neurons. $\sum$WX is called an activation value and equals to the total input of the artificial neurons. O stands for the output of the neurons. θ represents the threshold of this neuron. When the weighted sum of this input signal is more than θ, the artificial neurons are activated. In this way, the output of the artificial neuron can be described as:

$$\mathbf{O}=\mathbf{f}\left(\sum \mathbf{WX}-\boldsymbol{\theta}\right) \tag{3}$$

f(•), which is also called activation function or output function, represents the input–output function of the neuron. Generally, the threshold θ is not a constant and changes with the stimulation degree of neurons.

2.2. The activation function

In the neural network, the ability and efficiency to solve the problem, to a large extent, depends on the activation function used by the network in addition to the network structure [25]. The choice of the activation function has great influence on the convergence speed of the network. The choice of activation function should be different according to different actual problem.

In this paper, we adopt the logarithmic Sigmoid function (Sigmoid), which is the most widely used activation function in neurons. Its expression is:

$$\mathbf{f}(\boldsymbol{\mu}) = \frac{1}{1+\mathbf{exp}(-a\boldsymbol{\mu})} \tag{4}$$

a stands for slope. The output scope of the logarithmic sigmoid function is between 0 and 1, which is often chose by the signal whose output scope is between 0 and 1.

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