

A Self-adaptive Dynamic Evaluation Model for Diabetes Mellitus, Based on Evolutionary Strategies

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Received: August 03, 2015

Accepted: February 15, 2016

Published: March 31, 2016

Abstract: In order to evaluate diabetes mellitus objectively and accurately, this paper builds a self-adaptive dynamic evaluation model for diabetes mellitus, based on evolutionary strategies. First of all, on the basis of a formalized description of the evolutionary process of diabetes syndromes, using a state transition function, it judges whether a disease is evolutionary, through an excitation parameter. It then, provides evidence for the rebuilding of the evaluation index system. After that, by abstracting and rebuilding the composition of evaluation indexes, it makes use of a heuristic algorithm to determine the composition of the evolved evaluation index set of diabetes mellitus, It then, calculates the weight of each index in the evolved evaluation index set of diabetes mellitus by building a dependency matrix and realizes the self-adaptive dynamic evaluation of diabetes mellitus under an evolutionary environment. Using this evaluation model, it is possible to, quantify all kinds of diagnoses and treatment experiences of diabetes and finally to adopt ideal diagnoses and treatment measures for different patients with diabetics.

Keywords: Diabetes treatment efficacy, Syndrome evolution, Index rebuilding, Evaluation model.

Introduction

With increasing demands for traditional Chinese medicine (TCM), many domestic and foreign government agencies and social organizations are paying more and more attention to studies on TCM efficacy. Since 2004, the U.S. National Institutes of Health (NIH) and other institutions have been engaged in relevant research evaluating the effectiveness of traditional and alternative medical therapy [2, 3, 8]. *The Medium and Long-term Development Outline of TCM Standardization (2011-2020)*, promulgated by the State Administration of Traditional Chinese Medicine, expressly advocated further research on TCM evaluation techniques and on building a standard evaluation index system. Although many domestic and foreign agencies focus on studies of TCM efficacy, there has been no development of a set of clinical efficacy evaluation methods and models, in line with TCM laws [11]. The lack of a TCM efficacy evaluation system has become an obstacle to the development of TCM modernization.

At present, China and other countries mainly study the evaluation of TCM efficacy from

TCM syndromes, quantitative scoring tables and evidence-based medicine, among other methods. These methods boost different aspects of the development of clinical TCM evaluation. Most, however, try to build a uniform and static evaluation method and system, while neglecting the evolutionary characteristics of disease. TCM syndromes, in fact, keep evolving and transforming with the development of the disease. The diagnosis and treatment process is somewhat complex and vague [12]. Therefore, the evaluation of TCM efficacy should be a dynamic process based on disease evolution. With the development and changes of the course of a disease, evaluation indexes are added, deleted and merged constantly. The weights of indexes also change accordingly.

In recent years, in the field of diabetes treatment efficacy evaluation, a lack of proper models has meant that evaluation mechanisms with evolutionary characteristics are not abstracted or formalized [9]. This then makes it impossible to describe various laws, relations and hypotheses between efficacy information using symbols, and even more difficult to integrate and evaluate accurately. This paper, based on dynamic evaluation thoughts, changes the existing static evaluation model. A self-adaptive dynamic evaluation model for diabetes mellitus is put forward, based on evolutionary strategies. The purpose of the model is to quantify all kinds of diagnoses and treatment experiences of diabetes and to adopt ideal diagnoses and treatment measures for different diabetic patients.

A formalized description of diabetes syndrome evolution

A syndrome is the body's overall response to combined internal and external factors. During its development process, the syndrome will change in response to the severity of the disease and the strength of righteousness and will consequently exhibit various characteristics, such as evolution, development, and accompanying symptoms [10]. The evolution of a syndromes can therefore be interpreted as taking place in a continuous time, stimulated by internal and external factors, a patient's treatment demands, interventions and evaluation indexes, as well as change of the disease itself (i.e., the disease changes from one state to another).

Assume that the diabetes state at a certain moment is $S\langle t_i, EISDM(X_e, i; X_w, i) \rangle$, where t_i ($0 \leq i \leq n$) stands for the moment the disease has been measured at. $EISDM(X_e, i; X_w, i)$ is the evaluation index system for diabetes mellitus (EISDM). (X_e, i) is the evaluation index set at moment i . (X_w, i) stands for the index weight set at moment i .

Under the influence of many internal and external factors, assume that diabetes evolve in the time interval $(t_i, t_j]$, to change from state S to state S' . The state transition function is:

$$STF(\tau) = S\langle t_i, EISDM(X_e, i; X_w, i) \rangle \rightarrow S'\langle t_j, EISDM(X_e, j; X_w, i) \rangle,$$

where τ is an excitation parameter, or a measure of the diabetes' evolution.

A self-adaptive dynamic evaluation model for diabetes mellitus

Based on the above discussion, in order to evaluate diabetes treatment efficacy accurately, when causing disease state transition under evolutionary mechanisms, it is necessary to design a certain model and algorithm and to rebuild EISDM. The rebuilding of EISDM is mainly manifested in two ways: one is in the increase or decrease of the evaluation indexes (EI) for diabetes efficacy and the formalized description and rebuilding of the index components. The other is in the addition, deletion, or revision of evaluation index weights, i.e., the abstraction and rebuilding of index weights. Although EISDM rebuilding is divided into two aspects, these often happen simultaneously in rebuilding.

The abstraction and rebuilding of evaluation indexes

When diabetes is evolving and a certain index becomes normal after treatment, this index can be deleted in the next stage of efficacy examination. Similarly, when a disease deteriorates, adding new indexes should be considered. Regardless of additions or deletions, the composition of the evaluation indexes will change dynamically with the evolution of the disease. Assume that the efficacy evaluation index set at moment i is

$$\{X_e, i\} = \{a_1, a_2, a_3, \dots, a_i, \dots, a_n\} \quad (1 \leq i \leq n).$$

As the disease develops, at moment $i + 1$, the components of the efficacy evaluation index set $\{X_e, i\}$ change to $\{X_e, i + 1\} = \{a'_1, a'_2, a'_3, \dots, a'_j, \dots, a'_m\}$ ($1 \leq i \leq m, m \neq n$). Below, a heuristic algorithm will be used to realize this dynamic change process automatically and to rebuild the evolved evaluation index components. The heuristic algorithm can be divided into three circumstances as follows:

When some indexes are preserved before evolution, i.e., $a_i \subseteq a'_j$, those satisfying the evaluation requirements of index a_i are bound to satisfy the evaluation of index a'_j . Therefore, a'_j can be reduced. a_i is added to $\{X_e, i + 1\}$ and the index set is revised.

When indexes remain the same before and after evolution, i.e., $a_i \equiv a'_j$, after the course of evolution, the indexes do not change. In this case, either index a_i or a'_j can be deleted. a_i (or a'_j) can be preserved, without the need for revising the index set.

When evolved indexes are increased or decreased, i.e., $a_i \oplus a'_j$, those satisfying the evaluation requirements of index a_i do not necessarily satisfy the evaluation requirements of index a'_j and vice versa. Evaluation indexes that satisfy $a_i \cap a'_j$, however, also satisfy a_i and a'_j simultaneously. Thus, a_i and a'_j can be simplified as $a_i \cap a'_j$ and the index set is revised.

The abstraction and rebuilding of evaluation index weights

A formalized description of index relation

Changes of the evaluation index components of diabetes treatment efficacy will inevitably lead to weight changes, but there are often complex interactions between evaluation indexes [6]. The weights of the indexes cannot be treated simply, the relation between the indexes must be fully considered. With the aid of a dependence matrix in the field of engineering, this paper describes the relation between different efficacy indexes and calculates the changes of weights, according to their relation degree.

Assume that at moment i the evaluation index set of diabetes mellitus is

$$\{X_e, i\} = \{a_1, a_2, a_3, \dots, a_i, \dots, a_n\}.$$

The relation matrix is R . The relation degree $r_{i,j} \in (-1, 1)$ is the quantified relation degree of index a_i for index a_j , $r_{i,j} \neq r_{j,i}$. To be specific,

$$\{X_w, i\} = \begin{cases} r_{i,j} > 0, & a_i, a_j; \text{positively correlated (complementary)} \\ r_{i,j} = 0, & a_i, a_j; \text{not correlated (completely independent)} \\ r_{i,j} < 0, & a_i, a_j; \text{negatively correlated (repulsive)} \end{cases}$$

The value of relation degree $r_{i,j}$ is mainly determined by experience, historical data, brainstorming or group decision-making theory [1]. The relation matrix R simplifies semantic information between indexes, through a formalized description of direct interaction. It is obviously conducive to the automatic rebuilding of evaluation indexes.

The automatic rebuilding method of index weights

The dynamic changes and rebuilding of index weights includes the deletion, addition and revision of weights. Assume that at moment i the weight set of EISDM is

$$\{X_w, i\} = \{w_1, w_2, w_3, \dots, w_i, \dots, w_n\} \quad (1 \leq i \leq n).$$

After evolution, the weight set at moment $i + 1$ is

$$\{X_w, i + 1\} = \{w'_1, w'_2, w'_3, \dots, w'_j, \dots, w'_m\} \quad (1 \leq j \leq m, m \neq n).$$

The specific rebuilding method is designed as below.

The deletion of weights

When the deleted indexes lie in line i of the relation matrix and are all 0, these indexes are not associated with any other indexes. They are independent. In this case, index a_i can be deleted directly. The deletion will not affect other indexes, but will change the structure of EISDM. It is necessary to resolve the weights of the remaining indexes under the new structure. Define a_s ($t = 1, \dots, n, s \neq i$) as the remaining evaluation indexes. After deleting a_i , the relative weight of a_s can be calculated from Eq. (1):

$$W'_s = ((n - 1)w_s + w_i) / (n - 1), \quad s = 1, \dots, n, s \neq i. \quad (1)$$

When the deleted indexes lie in line i of the relation matrix and at least one of them is not 0, the indexes are not independent. They are associated with each other. In this case, index a_i cannot be deleted directly. Otherwise, not only will the structure of the evaluation index system be changed, other associated attributes will also be affected. Assume that RA_i is a finite set composed of indexes related to a_i . $|RA_i|$ is the modulus of the set, representing the number of elements in the set. Define $a_p \in RA_i$ and $a_q \notin RA_i$. r_{ip} stands for the relation degree of $a_i \rightarrow a_p$. After deleting a_i , the relative weights of a_p and a_q can be calculated from Eq. (2):

$$W' = \begin{cases} w_p = w_p - R_{i,p} w_i, & (R_{i,p} \neq 0, 0 \leq w_p \leq 1) \\ w'_q = w_q - \frac{\sum (w'_p - w_p) - w_i}{n - |RA_i| - 1}, & (R_{i,p} = 0, 0 \leq w'_q \leq 1) \end{cases} \quad (2)$$

The addition of weights

When adding a new evaluation index a_i , it should be determined which indexes are associated with it directly and their relation degree $R_{i,p}$ ($t = 1, \dots, n$) and $R_{p,i}$ ($t = 1, \dots, n$) should be calculated. Next, a new relation matrix should be built. After adding new indexes, the Analytic hierarchy process (AHP) method [7] should be used to redefine the weight of each index.

The revision of weights

Some evaluation indexes do not change during the evolution of diabetes. However, their relative significance changes with the evolution of the disease, meaning the sizes of weights

change and need revision. Assume that RA_i is a finite set composed of indexes related to index a_i . Define $a_p \in RA_i$ and $a_q \notin RA_i$. $R_{i,p}$ stands for the relation degree of $a_i \rightarrow a_p$. w_p and w_q represent the weights of a_p and a_q in state k . Their weights w'_p and w'_q in state $k + 1$ can then be represented as:

$$W' = \begin{cases} w'_p = w_p + R_{i,p}(w'_i - w_i), & (R_{i,p} \neq 0, 0 \leq w'_p \leq 1) \\ w'_q = w_q - \frac{\sum(w'_i - w_i) + (w'_i - w_i)}{n - |RA_i| - 1}, & (R_{i,p} = 0, 0 \leq w'_q \leq 1) \end{cases} \quad (3)$$

The structure of the self-adaptive dynamic evaluation model

According to the above discussion, the overall structure of the self-adaptive dynamic evaluation model for diabetes mellitus based on evolutionary strategies is shown in Fig. 1.

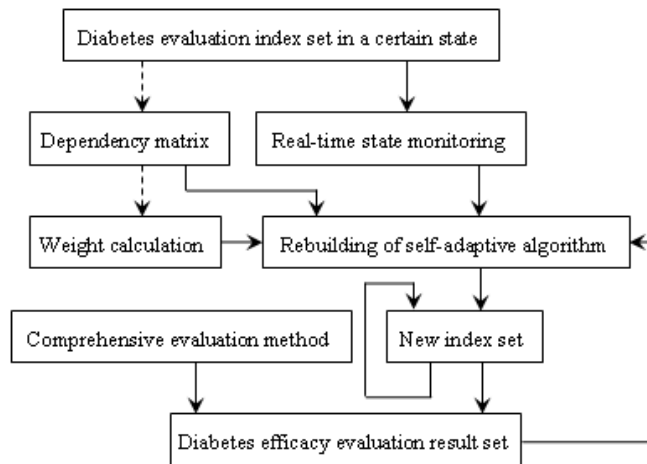


Fig. 1 The structure of the self-adaptive dynamic evaluation model of diabetes

This model realizes the self-adaptive dynamic evaluation of diabetes mellitus, based on state monitoring and excitation. When the system detects that the evaluation index system evolves in a certain state, it starts the excitation mechanism and generates the state transition function $STF(\tau)$. Based on the weight calculation method of the dependency matrix and self-adaptive rebuilding algorithm, the system automatically builds an evolved evaluation index set and realizes the comprehensive evaluation of diabetes mellitus, using techniques such as the weighting method or fuzzy mathematics. If the comprehensive evaluation is not in conformity with actual requirements, indexes and weights may well be rebuilt, through the feedback mechanism, until the requirements are met.

The application of the self-adaptive dynamic evaluation model for diabetes mellitus based on evolutionary strategies

A case analysis of this evaluation model

A patient had Type-2 diabetes and was previously diagnosed with a deficiency of both qi and yin. According to the TCM syndrome diagnostic criteria model for Type-2 diabetes [4], the five indexes of this patient, languidness, heart palpitations, dry stool, thirst and insomnia, should be examined. The index set that they constitute is $\{X_e, 1\} = \{a_1, a_2, a_3, a_4, a_5\}$, where '1' stands for the first stage of disease development. Combined with expert experience, using the AHP method, the weight set of the 5 indexes is:

$$\{X_w, 1\} = \{0.35, 0.25, 0.15, 0.2, 0.05\}.$$

According to *New TCM Clinical Research Guiding Principles* [13], promulgated by the State Food and Drug Administration in 2002, the classified quantization of these indexes is shown in Table 1.

Table 1. The classified quantization of indexes

Symptom index	Mild (5 Points)	Medium (3 Points)	Severe (1 point)
Languidness (a_1)	Cannot endure hard work	Can only carry out light physical labor	Can barely support daily activities
Heart palpitations (a_2)	Occasionally	Often, for a short time	Often, for a long time
Dry stool (a_3)	Hard and strenuous	Hard, once in 2-3 days	Hard, once in more than 3 days
Thirst (a_4)	Water intake is slightly higher	Water intake is more than a half time higher	Water intake is doubled
Insomnia (a_5)	Little sleep, easy to wake up	Hard to sleep, easy to wake up	Sleepless all night long

Referring to the grades and scores in Table 1, efficacy evaluation results can be divided into five grades, ‘excellent’, ‘good’, ‘medium’, ‘poor’ and ‘terrible’. The scores from each of the five grades are divided into 5, 4, 3, 2 and 1, respectively. After the patient has been treated for a period of time, based on the patient’s conditions and using the weights of the indexes, as well as the grades and scores from Table 1, the overall efficacy P of this treatment is as follows:

$$P = 0.35 \times 3 + 0.25 \times 1 + 0.15 \times 3 + 0.2 \times 1 + 0.05 \times 3 = 2.1.$$

Referring to the relevant grades and scores, the efficacy of this treatment is ‘poor’, which is not ideal. The patient’s conditions evolve and change from a deficiency of both qi and yin to deficiency of kidney and yin. By now, the examining indexes of the patient have changed into frequent and copious urine, a sore and weak waist and knees, dry stool, thirst, insomnia and dreaminess [13]. The evolution of the disease therefore leads to changes of the indexes. Compared with pre-evolution, two indexes have been added frequent and copious urine; and a sore and weak waist and knees. At the same time, languidness and heart palpitations have been deleted.

When the system detects that indexes have evolved, it will invoke a heuristic algorithm to rebuild the components of the evaluation indexes and to add, delete, or revise weights, by adjusting index weights automatically. The specific process is as follows:

To add new indexes: The 3rd circumstance of the heuristic algorithm is invoked. On the basis of Index $\{X_e, 1\}$ before evolution, two indexes are added, frequent and copious urine; and a sore and weak waist and knees. The index set changes into:

$$\{X_e, 2\} = \{a_1, a_2, a_3, a_4, a_5, a_6, a_7\},$$

where ‘2’ stands for the second stage of disease development. a_6 and a_7 are indexes added after evolution.

To solve the weights of the index system: Although at this moment, languidness and heart palpitations (a_1 and a_2) have not fallen into the evolved index system, their weights should also be considered, because direct deletion will affect the sizes of the associated and retained index weights. Here, the AHP method is used to calculate the weight set of the index system $\{X_e, 2\}$.

$$\{X_w, 2\} = \{0.16, 0.14, 0.11, 0.09, 0.08, 0.23, 0.19\}.$$

To build a dependency matrix: Combined with clinical experience and knowledge, the dependency matrix of $\{X_w, 2\}$, R is:

$$R = \begin{pmatrix} & a_1 & a_2 & a_3 & a_4 & a_5 & a_6 & a_7 \\ a_1 & \times & 0 & 0 & 0 & 0.2 & 0 & 0 \\ a_2 & 0 & \times & 0 & 0 & 0 & 0 & 0 \\ a_3 & 0 & 0 & \times & 0 & 0 & 0 & 0.1 \\ a_4 & 0 & 0 & 0 & \times & 0 & 0.3 & 0 \\ a_5 & 0.1 & 0 & 0 & 0 & \times & 0 & 0 \\ a_6 & 0 & 0 & 0 & 0.2 & 0 & \times & 0 \\ a_7 & 0 & 0 & 0.2 & 0 & 0 & 0 & \times \end{pmatrix}$$

To rebuild the evolved index system: The dependency matrix is used to calculate the weights of the remaining indexes. Meanwhile, the third circumstance of the heuristic algorithm is invoked, while delete languidness heart palpitation (a_1 and a_2) and other redundant indexes are deleted. a_2 in line 2 of the dependency matrix is heart palpitations and all are 0. According to Eq. (1), after deleting a_2 directly, the weight set of remaining indexes is:

$$\{a_1, a_3, a_4, a_5, a_6, a_7\} = \{0.1833, 0.1333, 0.1133, 0.1033, 0.2533, 0.2133\}.$$

a_1 in line 1 of the dependency matrix is languidness and not all are 0. According to Eq. (2), after deleting a_1 directly, the weight set of the remaining indexes is:

$$\{a_3, a_4, a_5, a_6, a_7\} = \{0.18829, 0.16829, 0.0666, 0.30829, 0.26829\}.$$

Therefore, when this patient with diabetes evolves from a deficiency of qi and yin to a deficiency of kidney and yin, the final index set $\{X_e, 2\}$ and weight set $\{X_w, 2\}$ are $\{X_e, 2\} = \{a'_1, a'_2, a'_3, a'_4, a'_5\}$ and $\{X_w, 2\} = \{w'_1, w'_2, w'_3, w'_4, w'_5\}$ respectively. Here, a'_1 to a'_5 represent the 5 indexes of frequent and copious urine; a sore and weak waist and knees, dry stool, insomnia; and dreaminess w'_1 to w'_5 correspond to the weights of the 5 indexes 0.18829, 0.16829, 0.0666, 0.30829 and 0.26829, respectively.

Comprehensive efficacy evaluation: Using rebuilt indexes and weights, combined with the classified quantization table in *New TCM Clinical Research Guiding Principles*, the overall efficacy P' after evolution is:

$$P' = 0.18829 \times 3 + 0.16829 \times 2 + 0.0666 \times 3 + 0.30829 \times 4 + 0.26829 \times 3 = 3.13928.$$

Referring to relevant grades and scores, the efficacy of this treatment is 'medium'.

A comparative analysis of this model and other models

The Endocrinology Department, at the 1st Affiliated Hospital of Anhui University of Chinese Medicine divided 325 diabetic patients whom it treated with poor efficacy into two similar groups by age, gender, and other factors. The two groups consisted of the treatment group (160 patients) and the control group (165 patients). This model was adopted with the treatment group, while the control group was tracked and measured continuously, according to the comprehensive evaluation system built by Zhao Jinxi and Li Jing’s team at the Beijing University of Chinese Medicine. Fig. 2 shows the overall evaluation results of diabetes treatment efficacy derived from the model built by Zhao Jinxi’s team [5]. Fig. 3 is the overall evaluation results of samples derived from this evaluation model.

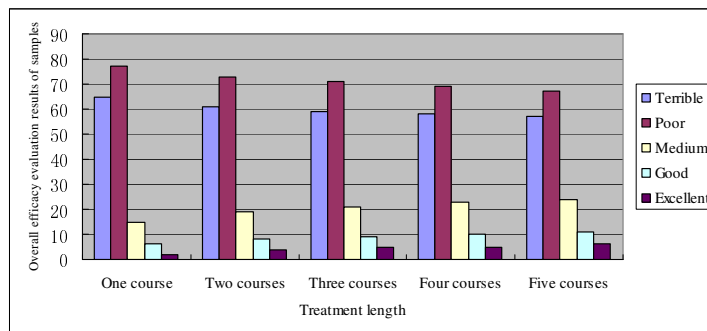


Fig. 2 The overall evaluation results of samples based on reference [5]

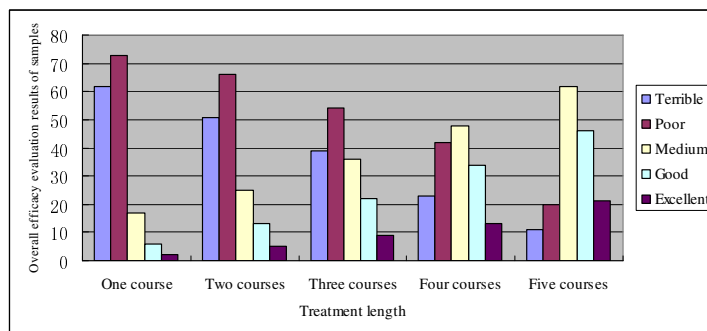


Fig. 3 The overall evaluation results of the self-adaptive dynamic model based on evolutionary strategies

From the above figures, it can be seen that with respect to the overall evaluation results of diabetes efficacy, with the increase of treatment length, this model is superior to the model built in [5]. This is because, with development and changes of the course of diabetes, evaluation indexes and weights are subject to changes, which force doctors to alter their diagnoses and treatment methods accordingly.

Conclusion

Using this evaluation model, the diagnoses and treatment experiences of various diabetes experts can be quantified. Finally, different patients with diabetes can adopt diagnoses and treatment measures in line with their own characteristics. This is of great significance for the improvement of diabetes treatment efficacy evaluation methods and systems, and for the objective and accurate evaluation of diabetes treatment efficacy.

Acknowledgements

This work was supported by the National Science & Technology Support Program (No. 2012BA126B00, No. 2015BAK28B00), the National Natural Fund Project (No. 81072780) and the Center for Research and Development of Guizhou province, China (No. 20144002).

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