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Original Article

Entropy-Based Model for Interpreting Life Systems in Traditional Chinese Medicine

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Traditional Chinese medicine (TCM) treats *qi* as the core of the human life systems. Starting with a hypothetical correlation between TCM *qi* and the entropy theory, we address in this article a holistic model for evaluating and unveiling the rule of TCM life systems. Several new concepts such as acquired life entropy (ALE), acquired life entropy flow (ALEF) and acquired life entropy production (ALEP) are propounded to interpret TCM life systems. Using the entropy theory, mathematical models are established for ALE, ALEF and ALEP, which reflect the evolution of life systems. Some criteria are given on physiological activities and pathological changes of the body in different stages of life. Moreover, a real data-based simulation shows life entropies of the human body with different ages, Cold and Hot constitutions and in different seasons in North China are coincided with the manifestations of *qi* as well as the life evolution in TCM descriptions. Especially, based on the comparative and quantitative analysis, the entropy-based model can nicely describe the evolution of life entropies in Cold and Hot individuals thereby fitting the *Yin–Yang* theory in TCM. Thus, this work establishes a novel approach to interpret the fundamental principles in TCM, and provides an alternative understanding for the complex life systems.

Keywords: Cold and Hot – Entropy – life systems – *qi* – traditional Chinese medicine – *Yin* and *Yang*

Introduction

Traditional Chinese Medicine (TCM) has formed a unique holistic theory for comprehending human life based on its more than 3000 years practice in China. One of the fundamental concepts in TCM theory is *qi*. *Qi* must be balanced and flowing freely to maintain a healthy life system. An imbalance or blocked flow of *qi* in any of the body's energy pathways or organs may result in various illnesses, that is, various ZHENG referring to the key diagnostic and therapeutic concept in TCM (1). Therefore, the TCM approach treats *qi* as the core and the essence of human life systems. TCM treatment always starts with the analysis of the entire *qi* system, and then focuses on the correction of pathological changes through readjusting the *qi* functions. A complex disorder can be differentiated according to its *qi* conditions and treatment by TCM has good success. However, the TCM approach, which is fundamentally different from that of so-called Western medicine (mainstream medicine), makes its scientific evaluation very difficult using existing conventional methods (2). Therefore, developing new methods for exploring the rule of *qi* is one of the key steps to unveil TCM, which will also be of great importance for understanding life process and physiological functions in the human body.

It is both necessary and possible to quantify *qi* since the changes of *qi* are not only closely associated with the development and the outcome of illness, but also corresponding to TCM therapeutic effects. Here, we attempt to

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understand and evaluate *qi* in TCM life system from the view of entropy theory. Albert Einstein said that entropy law is the premier law of all of sciences, which was referred to as the supreme metaphysical law of the entire universe (3). The concept of entropy was first put forward by Rudolf Clausius, a German physical scientist in 1865. A development of entropy theory is given in the Appendix 1. Since then theory of entropy has developed very rapidly and has been applied to many fields (4–7). Ever since the concept of entropy was introduced, people have been attempting to use it to explain the phenomena of life. It was pointed out by Ludwig Boltzmann (8) that the general struggle for existence of animate beings is neither for raw materials nor for energy, but for entropy. This was further explored by Erwin Schrödinger (9), who recognized that an organism stays alive in its highly organized state by importing high quality energy from the outside to support the organizational structure of the system. Thus, to understand the nature of life, it suffices to understand entropy (10,11).

In this article we propose a hypothetical correlation between TCM *qi* and the entropy theory, and introduce some concepts such as acquired life entropy (ALE), acquired life entropy flow (ALEF), acquired life entropy production (ALEP), and give the homologous relation between these concepts and *qi*. The change laws of ALEF, ALEP, etc. are obtained. The life entropies of some markers of life systems, such as various time periods, ages, as well as Cold or Hot constitution, in North China are numerically simulated. Note that Cold constitution and Hot constitution mentioned here refer to an opposite pair of physiological or pathological conditions representing the imbalance of *Yin* and *Yang* in TCM (12). Some criteria on physiological activities and pathological changes of a human body in different stages of life are also given.

Methods

Hypothesis for the Correlation Between Entropy and *Qi*

In some sense, *qi* is the entia of material, energy and information, by which the human body exchanges with the outside world (13–17). Entropy is used to measure the disorder degree of systems. The entropy of an isolated, closed system is either constant or increases with time (18). An aspect of entropy in complementary and alterative medicine has been presented by Olalde (7,16). By TCM, *qi* consists of congenital *qi* and acquired *qi* that complement each other. The human body has begun to struggle for negative entropy since it accepts essence and *qi*, called the congenital essence *qi*, from his parents. Life systems will generally experience five order structures of growth and development under the continual supplement of the acquired essence *qi* (19). These order structures can be looked upon as a result of the stability loss of disorder states. In other words, order emerges from disorder (10). Furthermore, Ohnishi and Ohnishi (16) propose that *qi* has two physical quantities of energy and entropy, which is *qi*-energy and *qi*-entropy. Therefore, entropy can be used to describe the evolution of life systems, which we name as the *total life entropy* (TLE) associated with *qi*. It reflects the degree of order and evolution of the whole life system.

For TLE is associated with *qi*, it also consists of two parts. One, called *congenital life entropy*, S_c, is used to measure the order degree of the body in pre-birth stages. The other, called *acquired life entropy* (ALE) S_a, is used to measure the order degree of the body in after-birth stages. So, the change of TLE can be expressed as $dS = d(S_c + S_a) = dS_a$, where and whereafter, d is a differential operator. In TCM, congenital *qi* and acquired *qi* are closely interdependent. The pre-birth congenital *qi* is the foundation for producing the after-birth acquired *qi*, which in turn, continuously supplements congenital *qi* with nourishments. For simplicity, here we only consider that after birth, the change of *qi* depends on that of acquired *qi*, that is, the change of TLE rests with that of ALE. A body absorbs sources including water, food and natural fresh air from the outside world by *qi* movement and *qi* transformation, then transforms them to nutriments, and at the same time, expels various metabolites and energy out of the body, by which *qi* can be kept frequently enough.

The life entropy supplied to the life system by the exterior in this process is called *external life entropy*, denoted by S_{ea}. Its change dS_{ea} during a time interval dt is called *acquired life entropy flow* (ALEF) [as similarly suggested by Olalde (7)]. Also entropy of open systems changes at all time and incessantly generates (10,20). From the point of view of TCM, the blood can be generated by the functional activity of *qi*. The essential substance may also be transformed into the blood by *qi* transformation. These irreversible motions and their transformations from one to another and all decline due to 'life impacts': aggressors of a mental, physical, chemical or biological nature (21) are accompanied with generation of life entropy and consume *qi* so that they can increase TLE. This life entropy produced in this process is called *internal life entropy*, denoted by S_{ia} [as similarly suggested by Olalde (7)]. Its change dS_{ia} during a time interval dt is called *acquired life entropy productions* (ALEP). So we have $dS = dS_{ea} + dS_{ia}$ where dS_{ia} is always greater than or equal to zero, while dS_{ea} can be negative, positive or zero (7,22,23).

Results and Discussion

Model of Acquired Life Entropy Flow and its Relationship with Age and Season

Generally speaking, *qi* is one of the substantial substances in TCM and, in a certain sense, represents a dynamic

balance of energy along with producing various nutriments and the expelling of various metabolites. That is to say, the human body extracts energy from the outside world and dissipates energy by all kinds of means, which makes *qi* flow freely. So *qi* can be calculated in a suitable way. Here, we apply the dissipated heat of a human body to quantify his energy absorbed. Comparison with heat absorbed and sent out by a human body per day is given in Table 1 (24).

From Table 1 and our previous work (14,25), we introduce the following assumptions: *Assumption 1*: The total energy absorbed by the body is equal to that dissipated and transformed to work by the body. *Assumption 2*: The total energy absorbed by the body comes from water and food (namely nutriments) and natural air. *Assumption 3*: The temperature of kernel body T is constant (i.e. does not change with time) (26). The temperature of air $T_e(t)$ is a periodic function of time t (27), where T and $T_e(t)$ are absolute temperature.

From Assumptions 1 and 2 we know that the total energy absorbed by the body every day can be measured by the total energy that is dissipated and transformed to work, which can also be depicted by heat of conduction and radiation. So, if the heat by conduction and radiation is given, then ALEF per unit time can be obtained. From Stefan' formula of radiate, we have $dQ_r = -(T^4 - T_e^4(t))\sigma(n)dt$, where Q_r is the heat radiated, n is age, $\sigma(n)$ is area of the body surface, T and $T_e(t)$ are the temperature of kernel body and the outside world, respectively. By heat conduction velocity formula, we have $dQ_c = -(K/d)\sigma(n)(T - T_e(t))dt$, where Q_c is the heat conducted, K is the ratio of subcutaneous fatty tissue to skin, d is hair of body.

Let ρ_e be the ratio of the heat radiated and conducted to that dissipated. Then the energy dissipated per unit time dt is

$$dQ_{\text{Total}} = -\frac{1}{\rho_e}\sigma(n)\left[T^4 - T_e^4(t) + \frac{K}{d}(T - T_e(t))\right]dt. \quad (3.1)$$

From Assumptions 1–3, appendix Table and (3.1), we know that ALEF similarly can be expressed as

$$dS(t) = -\frac{\sigma(n)}{\rho_e}\left[\frac{T^4 - T_e^4(t) + (K/d)(T - T_e(t))}{T_e(t)}\right]dt. \quad (3.2)$$

Table 1. Heat absorbed and sent out by a human body per day (24)

Authors	Ex. D.	H. Abs. p.(Cal.)	H. S. O. p.(Cal.)	Deviation
E.O.	25	2268	2259	−0.4
A.W.S	3	2304	2279	−1.1
J.F.S.	9	2118	2136	+0.8
J.C.W	4	2357	2397	+1.7
Average		2246.4	2246.9	

Ex. D., Experiment days; H. Abs. p. (Cal.), Heat absorbed per day (Calorie); H. S. O. p. (Cal.), Heat sent out per day (Calorie).

In the following we will formulate the ALEF of healthy people under normal conditions. *Assumption 4*: The air pressure of the outside world is constant, there is no wind, and the human is in a stable mental or psychological state.

Comparison with the heat dissipated by all means under normal conditions (24), we have $\rho_e = 3/4$. From the formulae of areas of body surfaces of male adults and children (28), the relationship between height and weight of healthy adults and children in North China (29) and (3.2), we obtain the mathematical models of ALEF of male adults and children in North China

$$dS_{\text{eay}} = -\frac{4}{3}\left[\frac{T^4 - T_e^4(t) + K/d(T - T_e(t))}{T_e(t)}\right] \times (0.01877H + 1.6882)dt$$

and

$$dS_{\text{eac}} = -\frac{4}{3}\left[\frac{T^4 - T_e^4(t) + K/d(T - T_e(t))}{T_e(t)}\right] \times (0.0632n + 0.4192)dt,$$

where $2 \le n \le 12$, dS_{eay} and dS_{eac} represent ALEFs of healthy adults and children, respectively; H is height (cm) of the human.

Below are the simulation results of ALEF, in accordance with TCM theory of treatment according to three kinds of conditions (namely, seasonal conditions, local conditions, and the patient's individuality). All data come from the north of China. The change of temperature is referred to Zhang and Lin (30).

As shown in Fig. 1A, ALEF of a human body decreases deeply after midnight, increases in the morning after breakfast, and decreases in the evening and night. The negative life entropy absorbed in the morning is bigger than that in the afternoon. This is in agreement with the statement of the Miraculous Pivot ('Ling Shu' in Mandarin Chinese), one of the oldest extant classics in TCM.

From Fig. 1B, we know that the negative life entropy absorbed by adults is more than that by children and the elderly. The least is that absorbed by children. In four seasons, negative life entropy absorbed in winter is the most, and that in summer is the least. Consequently, all the children, the adult and the old should pay attention to the cold and heat regulation of body. We advocate wearing less clothes in winter. In summer we should pay more attention to replenish vital essence in order to guarantee ALEF free and eliminate the positive life entropy in the body. All these are in agreement with the mechanism of temperature regulation of the body.

As shown in Fig. 2A, the negative life entropy absorbed by children increases asymptotically with age. This is helpful to the accumulation of high quality ALE, which is the base of the highest hierarchical order.

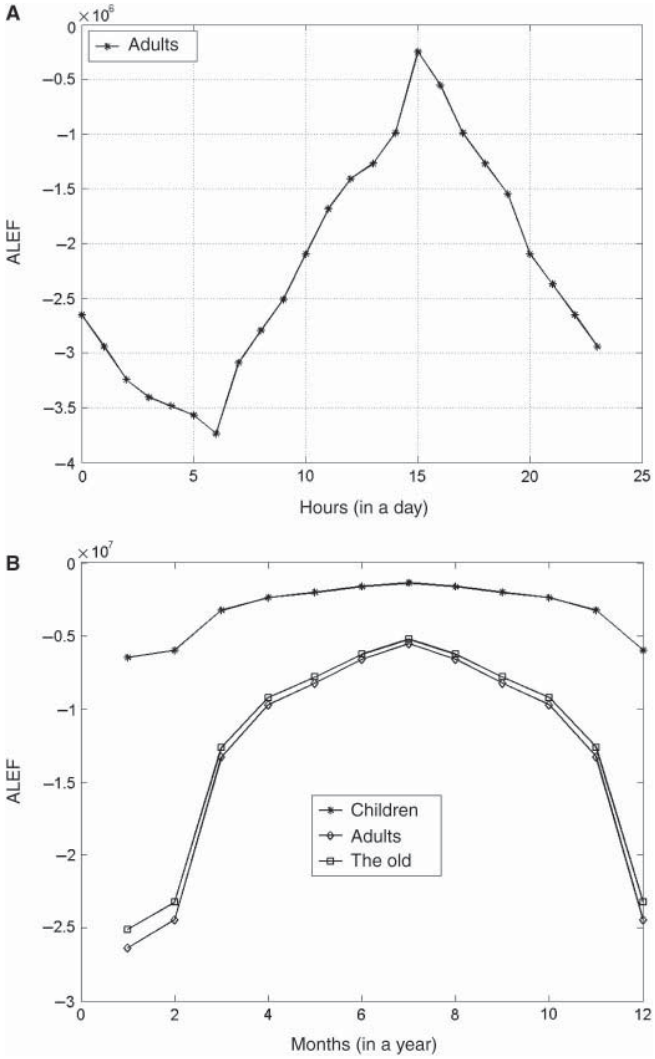

Figure 1. The curve of ALEF of healthy adults per unit time with time in the daytime in summer (**A**) and the curves of ALEF of healthy children, adults and the old per unit time with time in a year (**B**).

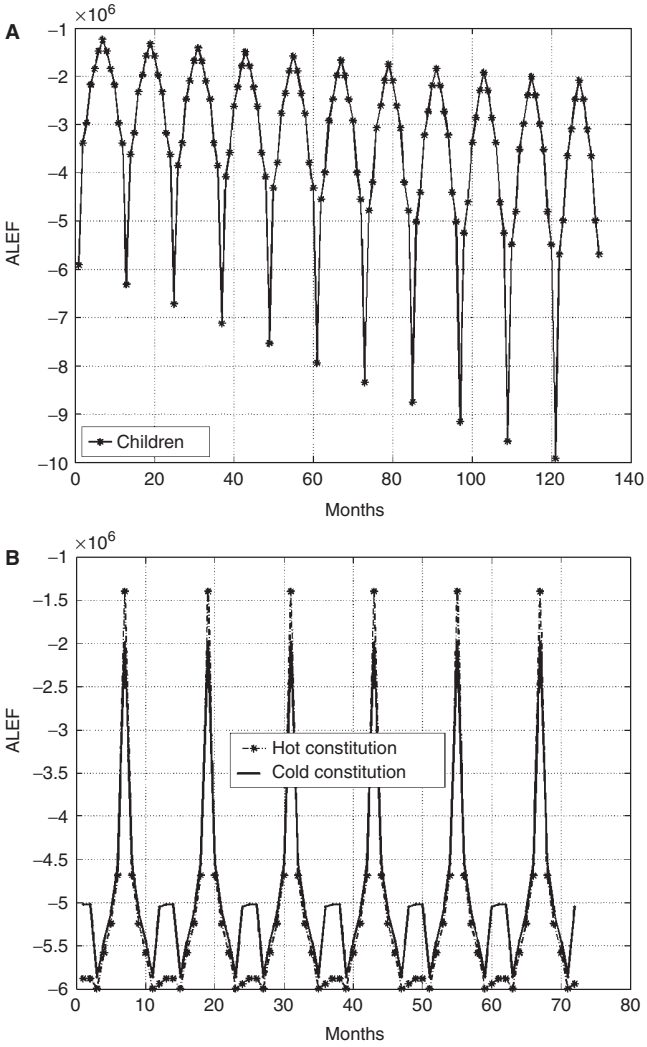

Figure 2. The curve of ALEF of healthy children from age 2 to 12 per unit time with time (**A**) and the comparison with ALEF between Hot and Cold constitutions per unit time in 6 years (**B**).

Acquired Life Entropy Flow and its Relationship with Cold/Hot (*Yin*/*Yang*)

TCM uses eight principles, e.g. *Yin*/*Yang*, Exterior/Interior, Cold/Hot and Deficiency/Excess, for evaluating the state of life systems during the physiological and pathological changes. Among them the paired features of Cold and Hot are comparatively comprehensible (1). According to the *Yin*–*Yang* theory in TCM, Cold can be described as the preponderance of *Yin* or the deficiency of *Yang*, while Hot as the preponderance of *Yang* or the deficiency of *Yin* (12). Figure 2B compares the ALEF of the people of Cold constitution and that of the people of Hot constitution. It is found that the ALEFs of these two groups of people are different, and the difference is small in spring and fall, but much larger in winter and summer. The maximum of the difference is $\sim 1 \times 10^6$ J/K. In summer, the negative life entropy absorbed by the Hot constitution people is smaller than those of the Cold constitution. Thus, people of Cold constitution stand summer-heat well. In winter, it is just the opposite. And people of Hot constitution stand Cold-evil. Such results accord with the descriptions recorded in TCM classic Plain Questions ('Su Wen' in Mandarin Chinese) that believe people having *Yang* preponderant pattern will be improved in winter and worse in summer, whereas people having *Yin* excess pattern will be improved in summer and worse in winter.

So, we can confirm one of TCM basic principles of treatment, 'warming the Cold and cooling the Hot' (12), which holds that desirable treatments and herbal medicines should be prescribed according to the properties of different individuals. For example, people with

Cold constitution should be cautious to use Cold-natured herbal treatments; those with Hot constitution should be cautious to use Hot-natured herbal treatments. This point also accords with our recent investigation about the biological bases of Cold ZHENG and Hot ZHENG oriented herbal treatments in TCM (1). That is to say, based on the comparative and quantitative analysis for the evolution of life entropies, Cold and Hot, two typical features categorized by the *Yin–Yang* theory in TCM, are nicely expressed by our entropy-based model.

Acquired Life Entropy Production and the Balance of Life Systems

TCM holds that in human systems there are two kinds of irreversible processes. One is that *qi* impels the blood flow in the body. The other consists of all sorts of chemical reactions and transformation processes. These irreversible processes generate positive life entropy in the body and dissipate *qi*. The human system is an open system with constantly external disturbances and internal fluctuations, and has a dissipative structure far-from-equilibrium (31). The ALEP per unit time can be described by the following Logistic equation,

$$\Re(t) = \frac{\mathrm{d}S_{\mathrm{ia}}(t)}{\mathrm{d}t} = aS_{\mathrm{ia}}(t)\left(1 - \frac{S_{\mathrm{ia}}(t)}{b}\right), \quad t \in [0,T]. \qquad (3.3)$$

And the difference equation is

$$S_{\mathrm{ia}}(n+1) = (a+1)S_{\mathrm{ia}}(n)\left(1 - \frac{a}{b(a+1)}S_{\mathrm{ia}}(n)\right), \quad n \in [0,m],$$

where $a>0$ and $b>0$ are the intrinsic growth rate and the maximum of internal life entropy, respectively; T and m are, respectively, time of survival and life-span of people; $\mathrm{S_{ia}}(t)$ and $\mathrm{S_{ia}}(n)$ are internal life entropy at time t and age n, respectively.

The equilibrium solutions of differential equation (3.3) are $S_{\mathrm{ia}}(t) \equiv 0$ and $S_{\mathrm{ia}}(t) \equiv b$, for all $t \in [0,\ T]$ For the life system, the equilibrium solutions are impossible. So, here we only consider the general case with initial value $S_{\mathrm{c}} \in (0,\ b)$. In this case, the solution $S_{\mathrm{ia}}(t;\ S_{\mathrm{c}},\ 0)$ of (3.3) starting from the initial time *0* is

$$S_{\mathrm{ia}}(t;\ S_{\mathrm{c}},0) = \frac{bS_{\mathrm{c}}}{S_{\mathrm{c}} + (b - S_{\mathrm{c}})e^{-\mathrm{at}}}, \quad t \in [0,T]. \qquad (3.4)$$

From this, one can see that $S_{\mathrm{ia}}(t;\ S_{\mathrm{c}},\ 0)$ is continuously dependent on the initial condition S_{c}. Hence, the internal life entropy will evolve in the neighborhood of this solution trajectory $S_{\mathrm{ia}}(t;\ S_{\mathrm{c}},\ 0)$ when a small disturbance happens to the initial value.

Figure 3 presents the curve of internal life entropy of a hypothetical 100-year-old healthy people in North China. We can easily see that there are two points, about age 8 and age 60 at the curve, between which the value of internal life entropy of the people in North China increases very fast. It means that from age 8 the five Zang viscera and six Fu viscera begin to be stable. From age 60, life system begins to wane. All these are in agreement with the related statements in the Plain Questions ('Su Wen') and the Miraculous Pivot ('Ling Shu' in Mandarin Chinese), as described in Appendix 2.

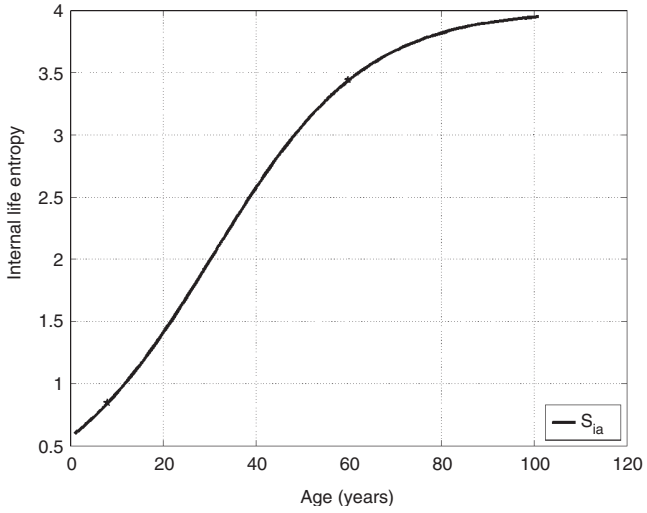

Figure 3. Curve of internal life entropy of a hypothetical 100-year-old healthy people.

Dynamic Model of Total Life Entropy

From the previous two sections we can obtain discrete mathematical model on TLE $S(n) = S_{\mathrm{c}} + S_{\mathrm{ea}}(n) + S_{\mathrm{ia}}(n)$, where S_{c} is the congenital life entropy, $S(n)$ and $S_{\mathrm{ea}}(n)$ are the TLE and external life entropy at the age of n, respectively. Following formulae of exergie (20), which is the energy that can be transformed to work in a given setting, we obtain a mathematical model of *qi*, $E_{\mathrm{q}} = T(S_{\mathrm{equi}} - S(n))$, (J) where E_{q} is energy of *qi*, S_{equi} is an upper limit of TLE.

Figure 4 is a simulation on the evolution of TLE and *qi* of a hypothetical 100-year-old people in North China. TLE of human decreases first and then increases. The change of TLE describes the change trend of the order. At the end, TLE reaches the maximum. Figure 4 also reflects the harmonious balance self-organization between ALEF and ALEP, which makes life systems internally stable. In the course of growth and development, the *qi* is from vigorous to wane, which influences the physiological activities. Thereby we can confirm the reactive ability and the style of body with different constitutions and ages to categorize pathogenetic factors.

Entropy-Based Judgment for the State of Life Systems

As described in the Plain Questions ('Su Wen' in Mandarin Chinese), TCM believes that one can be

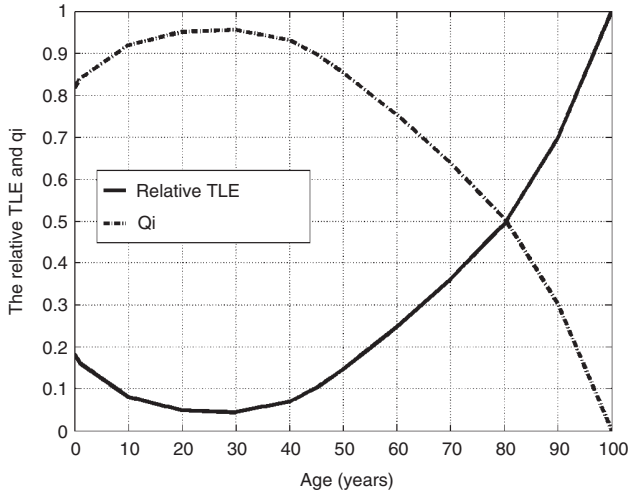

Figure 4. Curves of evolutions of the relative TLE and *qi* of a 100-year-old people healthy man. The congenital life entropy is $S_c = 6 \times 10^5$ J/K.

prevented from the invasion of pathogenic factors if he has abundant vital *qi*. TCM holds that most of basic pathological changes are due to the disorder of *qi*. To a certain extent, the disorder of *qi* can be mimicked by the abnormal change of TLE, or the imbalance between ALEF and ALEP in our model.

At the stage of growth, generally speaking, the change of TLE satisfies $dS/dt < 0$, which ensures that the human body moves for order to greater degree by regulation action of innate vitality *qi* itself or external life entropy. If otherwise, i.e. $dS/dt \geq 0$, which means that TLE increases and *qi* decreases, then the body is unhealthy and disease results. At the stage of prime, the function of the body is in bloom. In this case, if $dS/dt > 0$, or equivalently the TLE increases, then the body is chaotic and sick. At the stage of oldness, generally speaking, the change of TLE satisfies $dS/dt \geq 0$. Life entropy becomes higher and higher. This makes the body run to oldness and death.

From the above, we can judge physiological and pathological states of human in the light of TLE. Likewise, we can predict the trend of ALE by the healthy index and give its prediction curve. In practice, if there is a big deviation between value of ALE and the estimate, then some indexes must go beyond the healthy range. This means that the internal steady states generated by harmonious balance between ALEF and ALEP lose stability. In this case, some remedies that will provide negative entropy to life systems should be taken to help to fortify the body against disease (32–34).

In conclusion, our preliminary results demonstrate that although TCM *qi* may not be mere entropy, the entropy-based model helps to understand life systems in TCM and shows a way to interpret preferably qualitative descriptions of *qi* as well as the paired features of Cold and Hot regarding the *Yin–Yang* theory. Some quantified bases for studying TCM in the light of systematism and self-organization structure theory are offered. Further development work on ascertaining the essential nature of *qi* and applying entropy principles to the Five-Phase theory and so on all need investigating in the future. We hope that this effort could provide further motivation to conduct more researches for evaluating and interpreting TCM. The application of entropy theory is also expected to span the gaps in our knowledge about human complex diseases in both TCM and the coming systemic medicine.

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Appendix 1

Table A1. A brief description on the development of the entropy theory

Source (Reference)	Expression	Notes
Thermodynamics (18)	$dS = \Delta Q/T$	The entropy of reversible processes is only function of states and independent of thermodynamic path.
Statistical Physics (18)	$S = k \ln w$	The entropy S is a measure of order prevailing in the system.
Information Theory (5)	$H = -c\Sigma p_i \ln p_i$	The entropy H measures the degree of the uncertainty of states.
Non-equilibrium Thermodynamics (3)	$dS = d_eS + d_iS$	The change of entropy of open systems has two parts: entropy flow and entropy production. d_eS is the transfer of entropy across the boundaries of the system; d_iS is the entropy produced within the systems.

Appendix 2

The Plain Questions ('Su Wen' in Mandarin Chinese): At a hypothetical age of 7, kidney *qi* of a woman will become stronger, and she will have replacement of her teeth and growth of hair. A man will have growth of hair and replacement of the teeth at the age of 8 due to the gradual replenishment of the kidney *qi*.

The Miraculous Pivot ('Ling Shu' in Mandarin Chinese): At a hypothetical age of 10, a man will have a primarily developed five viscera ('Wu Zang' in Mandarin Chinese), smoothly flowing *qi* and the blood, so he likes running. At a hypothetical age of 50, liver *qi* starts to be weak, the liver lobes will become thinner, the bile stops secreting, and eyes become blurred.

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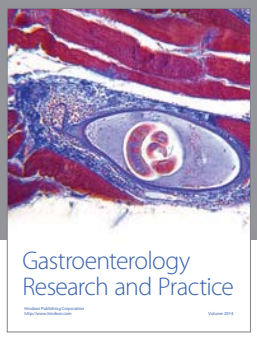

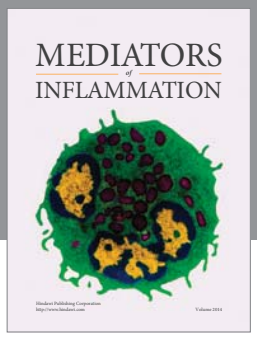

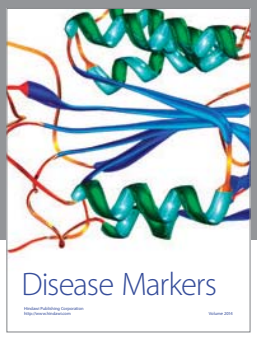

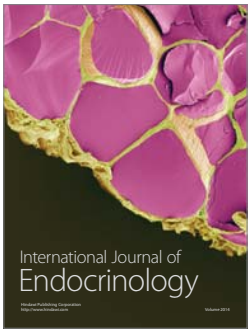

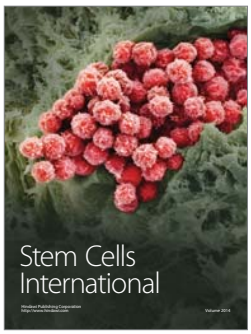

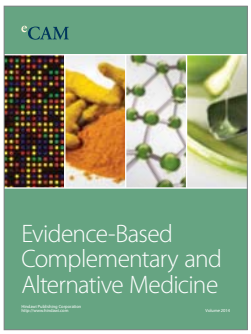

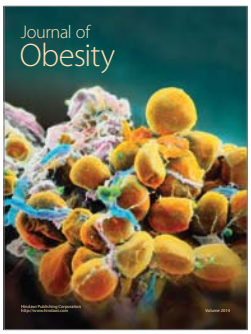

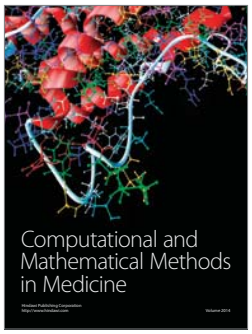

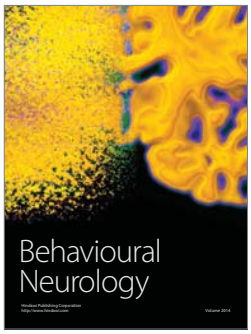

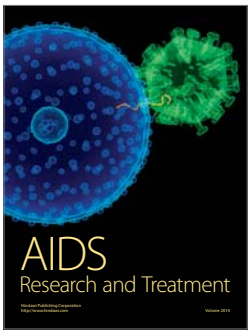

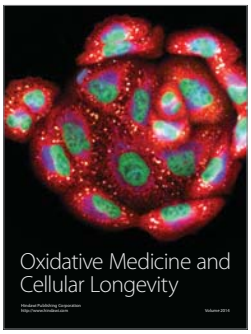

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