JTCM 中医杂志 Journal of Traditional Chinese Medicine

Online Submissions: http://www.journaltcm.com
info@journaltcm.com

J Tradit Chin Med 2013 August 15; 33(4): 538-544
ISSN 0255-2922

THEORETICAL STUDY

Mechanisms of *Qi*-blood circulation and *Qi* deficiency syndrome in view of blood and interstitial fluid circulation

Wei Yao, Hongwei Yang, Guanghong Ding

Wei Yao, Hongwei Yang, Guanghong Ding, Department of Mechanics and Engineering Science, Fudan University, Shanghai Research Center of Acupuncture, Shanghai 200433, China
Supported by National Natural Science Foundation of China (No.11202053); Shanghai Science Foundation (No. 12ZR1401100) and the 973 Project (No. 2012CB518502)
Correspondence to: Prof. Guanghong Ding, Department of Mechanics and Engineering Science, Fudan University, Shanghai Research Center of Acupuncture, Shanghai 200433, China. ghding@fudan.edu.cn
Telephone: +86-21-55665696
Accepted: December 18, 2012

Abstract

OBJECTIVE: Based on comparison between fundamental theories of Traditional Chinese Medicine (TCM) and Western Medicine (WM) and modern scientific research on meridians, we find that "*Qi*" in TCM is closely related to tissue fluid. In this study, the essence of *Qi* is explored in the view of circulation of blood and interstitial fluid.

METHODS: Because the concept of *Qi* is complicated, *Qi* deficiency syndrome (QDS) is chosen to probe the relationship between of *Qi* deficiency and *Qi*-blood circulation (QBC). We analyze *Qi-blood* theory in terms of WM, set up a hemodynamic model to describe QBC, and review clinical research on QDS in the view of blood-interstitial fluid circulation.

RESULTS: QDS is caused by imbalances of substance exchanges between blood and interstitial fluid, leading to an increase in the interstitial liquid volume or a decrease in nutrients and retention of metabolic wastes in interstitial fluid.

CONCLUSION: This study describes the essence of *Qi*, providing support for further research on theories of *Qi* and *Qi*-blood circulation in TCM.

Key words: Medicine, Chinese traditional; Hemodynamics; Meridians; *Qi* blood circulation; *Qi* deficiency

INTRODUCTION

Qi-blood circulation (QBC) theory is one of the basic theories of Traditional Chinese Medicine (TCM). Because of the influence of Chinese philosophy and the limitations of perceiving the objective world, the concept of *Qi* in TCM is intricate. However, *Qi* is used to describe the refined nutritious substances constituting the human body and maintaining life activities, such as *Gu-Qi* and nutrient *Qi*. *Qi* is also used to describe functions of *Zang-Fu* organs, such as heart *Qi* and liver *Qi*. The types and functions of *Qi* are all-inclusive, and too difficult to sum up in a word. Although the concept of blood in TCM is also used to describe body's functions, it is clearer than *Qi*, and in most conditions, it is the same as the blood in Western Medicine (WM). Because of the importance of QBC theory in TCM, much research has been performed. Presently, there are two study methods, i.e. probing into the substance basis of QBC by a combination of clinical experiments and ancient books and records, and achieving physiopathological foundations about QBC diseases by observing objective indexes of the patient. These studies provide a scientific foundation and research methods for syndrome differentiation treatment in TCM. However, a scientific system for QBC has not yet been formed.

Qi-blood theory in TCM is complicated and lacks scientific definitions. Therefore, understanding it with modern science is difficult. *Qi* deficiency syndrome (QDS) is one of the main symptoms of QBC and is fully described in TCM.[1-3] QDS can be expressed by objective physiological phenomena and indexes, such as shortness of breath, spontaneous perspiration, lassitude and weakness,[4] a pale and enlarged tongue with teeth prints, and a weak pulse. These symptoms are caused by dysfunction or incoordination of *Zang-Fu* organs, and are related to the interstitial fluid. For example, a pale and enlarged tongue with teeth imprints may be correlated with an interstitial volume increase. Moreover, a decrease in nutrient concentrations in the interstitial fluid affects the normal physiological function of cells and leads to lassitude and weakness. Finally, excessive plasma in the interstitial space may lead to lower blood volume (weak pulse) and an increase in interstitial pressure easily induces perspiration. Research shows that QDS commonly appears in heart disease,[5,6] metabolic syndrome,[7] and chronic obstructive pulmonary disease.[8,9] Therefore, based on characteristics of interstitial fluid and the laws of *Zang-Fu* organs influencing the interstitial fluid, QDS is selected to study mechanisms of *Qi* and QBC .

MODEL AND METHODS

Qi and blood keep a dynamic balance of functions and activities among all organs and mix the human body and the surrounding environment. In other words, *Qi* and blood make the human body keep a relatively stable internal environment. Living cells in organisms are mainly composed of blood and interstitial fluid. The description of blood in TCM, a red liquid with rich nutrients running in vessels, is equivalent to blood in WM. *Qi* and blood can transform each other, nutrient *Qi* can transform into blood, and blood can transform into *Shen-Qi*. There is a continuous exchange between blood and interstitial fluid. Interstitial fluid is filtered from the blood capillaries and can return, continuously exchanging substances with blood. The function of *Qi* is to maintain normal living activities, and a relative balance of interstitial fluid is part of normal growth and function of organs. Based on these comparisons between TCM and WM, we hypothesized that *Qi* is closely related to interstitial fluid.

Studies have found that there is a low fluid resistance path along meridians,[10] and radioactive isotopes move along meridians.[11] Further study shows that the movement of isotopes along a meridian is correlated to blood circulation, but is not in blood circulation,[12] indicating that directional flow of substances may exist in the interstitial space. Our experiment shows there exists abundant blood vessels in the earth region of acupoints,[13] and they are nearly parallel to the meridian.[14] Computer simulation shows that the interstitial fluid at acupoints with such capillary arrays continually flows along the meridian.[15]

Hemodynamic model describing Qi-blood circulation

We hypothesize that meridian and meridian phenomena are correlated to the directional flow of interstitial fluid.[16] Meridians are the channels transporting *Qi* and blood. *Qi* running though meridians should be interstitial fluid and the contained nutrients (proteins), information (interstitial fluid volume, oxygen concentration etc), and energy (sugar). The meridians connect the *Zang-Fu* prgans with the extremities, make all the body's organs anf tissues an organic whole. Research also shows that QDS is an essential syndrome in TCM.[5] Therefore, we set up a hemodynamic model describing QBC to discuss QDS (Figure 1). Our model consists of five sections:

(a) Heart functions. Based on the research of Sunagawa and others,[17] the expression of cardiac output (CO_v) is attained[18] as follows:

$$CO_v = E_k \frac{V_T}{R_T} \quad (1)$$

where E_k is a combinative parameter of the heart and vessels, V_T is blood volume, and R_T is the circulation resistance of the whole circulation system.

(b) Systemic circulation. Arterial resistance, microvascular resistance, venous resistance, and lymph flow resistance are expressed respectively by R_{AT}, R_{CS}, R_{VS}, and R_{LS}. If the pressure of right atrium (RA) is zero, p_a (the pressure in the systemic artery), p_v (the pressure in the systemic vein), and lymph flow can be obtained.[19]

$$p_a = CO_v \cdot R_T = E_k V_T \quad (2)$$

$$p_{ma} = E_k V_T \cdot (R_{vs} + R_{cs})/R_T \quad (3)$$

$$p_v = p_{mv} = E_k V_T \cdot R_{vs}/R_T \quad (4)$$

$$Q_{LS} = \frac{p_i}{R_{LS}} \quad (5)$$

Here, p_{ma} is the blood pressure in the capillary near the arteriole and p_{mv} is the blood pressure in the capillary near the vein. Substances exchange between the blood and interstitial fluid in the capillary, and under rational supposition,[20] the filtering flow of the whole circulation system is

$$Q_f = K_1(\frac{p_{ma} + p_{mv}}{2} - p_i - \pi_p + \pi_i) \quad (6)$$

where π_p is the colloid osmosis pressure in the blood plasma, π_i is the colloid osmosis pressure in the interstitial fluid, and p_i is the interstitial fluid pressure.

(c) Metabolism of energy substances. To simplify, sugar and fat are regarded as one kind of energy — sugar. Metabolism of water, protein, and sugar are expressed respectively by equations 7-9.

$$V_{Tn} = V_{T0} + (V_{in} - V_{ur} - \Delta V_i)\big|_T \quad (7)$$

$$W_{pn} = W_{p0} + (W_{inp} - W_{trap} - W_{subp})\big|_T - C_{urp} V_{ur}\big|_T \quad (8)$$

$$W_{sn} = W_{s0} + (W_{ins} + W_{trap} - W_{mets} + \Delta W_{deps})\big|_T - C_{urs} V_{ur}\big|_T \quad (9)$$

Here, V_{Tn}, W_{sn}, and W_{pn} are respectively quantities of V_T, W_s (sugar in the whole blood), and W_p (protein in

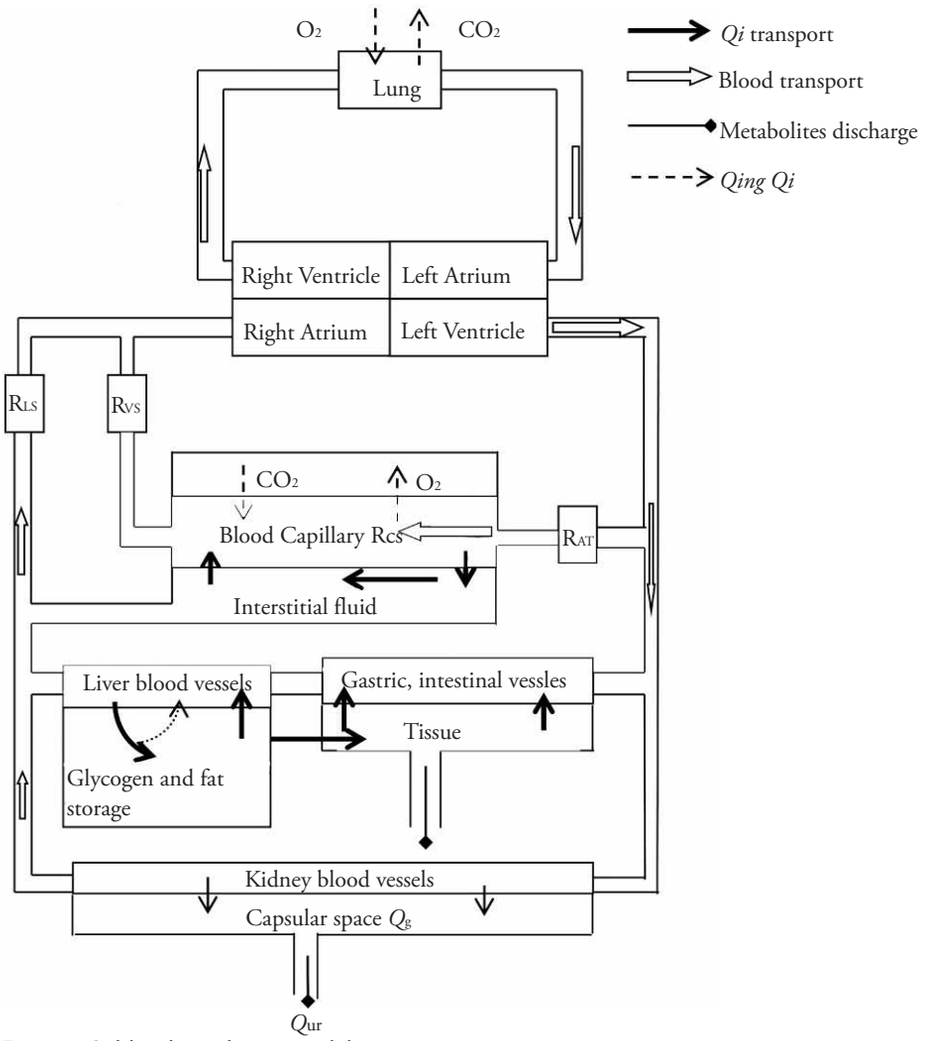

Figure 1 *Qi*-blood circulation model

whole blood) after T seconds from initiation. According to physiological data, $\pi_p \approx 47\frac{W_{pn}}{V_{Tn}}$. V_{T0}, W_{s0}, W_{p0} are the initial values of V_T, W_s, and W_p, respectively. V_{in} is the liquid volume absorbed within T seconds, V_{ur} is the urine generation volume, and ΔV_i is the increase in value of the interstitial fluid volume (V_i). W_{inp} is the absorption amount of protein, W_{trap} is the amount of protein transformation, and W_{subp} is the supply amount of protein. C_{urp} is the protein concentration in urine, W_{ins} is the absorption amount of sugar, W_{mets} is the amount of energy substances consumed, ΔW_{deps} is the decrease in the amount of energy substances, and C_{urs} is the sugar concentration in urine.

(d) Renal function. According to Starling equation,[18] original urine flow is:

$$Q_g = \int_0^L K_2(p_{gx} - \pi_p + \pi_{bi} - p_{bi})dx = K_2(\frac{p_{gi} + p_{go}}{2} - \pi_p + \pi_{bi} - p_{bi}) \quad (10)$$

Here, K_2 is the filtering coefficient of the capillaries in the kidney, π_{bi} is the colloid osmosis pressure in the original urine, and p_{bi} is the capsular pressure, [$p_{gi} = (p_a - p_v) \cdot \frac{R_{go} + R_g}{R_{go} + R_g + R_{gi}} + p_v$] is the blood pressure of the small artery entering the glomerulus, and [$p_{go} = (p_a - p_v) \cdot \frac{R_{go}}{R_{go} + R_g + R_{gi}} + p_v$] is the blood pressure of the small artery leaving the glomerulus. R_{gi}, R_{go}, and R_g are the resistances of the artery entering the glomerulus, the artery leaving the glomerulus, and the capillaries of the kidney, respectively.

According to the model, correlation between Q_g and Q_{ur} is:

$$Q_g = Q_{ur} K_{suck}, \quad (11)$$

where K_{suck} is the reabsorbing coefficient.

(e) The pulmonary circulation. This has been previously studied by us.[9]

Governing equations and methods of calculating physiological parameters

Based on the above primary equations, the physiological parameters can be deduced.

Calculation of interstitial fluid volume (V_i):

Edema is a main symptom of QDS and it is closely correlated with V_i increase. The variation of V_i is:

$$\frac{dV_i}{dt} = Q_f - Q_{LS} = K_1(\frac{p_{ma} + p_v}{2} - \pi_p + \pi_i) - (K_1 + \frac{1}{R_{LS}})p_i \quad (12)$$

From Eq. 3, 4, and 12, and according to the dynamic balance of exchange between blood and interstitial fluid ($\frac{dV_i}{dt} = 0$), p_i can be found:

$$p_i = \frac{R_{LS}K_1}{K_1R_{LS} + 1}(\frac{1}{2} \cdot E_k V_T(\frac{R_{cs}}{R_T} + \frac{2R_{vs}}{R_T}) - \pi_p + \pi_i) \quad (13)$$

From Eq. 2, 4, 10, and 11, Q_{ur} can be attained:

$$Q_{ur} = K_2(E_k V_T(\frac{R_T - R_{ts}}{R_T} \cdot \frac{2R_{go} + R_g}{2(R_{go} + R_g + R_{gi})} + \frac{2R_{ts}}{R_T}) - \pi_p + \pi_{bi} - p_{bi})/K_{suck} \quad (14)$$

Integrating Q_{ur} into $V_{ur} = \int_0^T Q_{ur} dt$, T = 1 day, and inputting V_{ur} into Eq. 7, attains:

$$\Delta V_i = V_{T0} + (V_{in} - V_{ur}) - V_{Tn} . \quad (15)$$

If the compliance of interstitial space id defined as $C_i = \frac{\Delta V_i}{\Delta p_i}$, then $\Delta V_i = C_i \cdot (p_i - p_{i0})$. W_{pn} can be calculated from Eq. 8 to get $\pi_p \approx 47\frac{W_{pn}}{V_{Tn}}$ (Pa • m^3/kg). If Eq. 13 and 15 are input into $\Delta V_i = C_i \cdot (p_i - p_{i0})$, then

$$C_i(\frac{R_{LS}}{K_1 R_{LS} + 1}(\frac{1}{2} \cdot E_k V_{Tn}(\frac{R_{cs}}{R_T} + \frac{2R_{ts}}{R_T}) - 47\frac{W_{pn}}{V_{Tn}} + \pi_i) - p_{i0}) = V_{T0} + (V_{in} - V_{ur}) - V_{Tn} \quad (16)$$

V_{Tn} can be found from Eq. 16 and input it into Eq. 15, attaining ΔV_i.

Calculation of concentration of NPN in blood:

In the renal circulation section, metabolites are considered. For example, non-protein nitrogen (NPN) in the human body comes from proteins. The proteins absorbed by the human body contain 16% nitrogen (Some proteins replenish decomposed tissue protein, which is expressed as W_{subp}, and some are transformed into sugar or adipose, which is expressed as W_{trap}). Therefore, the output of NPN is 16% (W_{subp} + W_{trap}). W_{subp} is constant.

If the renal tubule and collecting tube do not absorb any NPN in original urine, then the NPN excretion amount (Q_{urN}) will be:

$$Q_{urN} = C_{urN} \cdot Q_{ur} = C_{bN} \cdot Q_g ,$$

where C_{urN} is the NPN concentration in urine, and C_{bN} is the NPN concentration in blood. If NPN can be excreted through the urine completely, then,

$$C_{bN} = \frac{16\%(W_{trap} + W_{subp})}{V_{ur} K_{suck}} \quad (17)$$

Calculation of lactic acid concentration in blood and the storage of energy substances:

When 1 g glucose is oxidized in mitochondria, 1.07 g oxygen will be consumed and 15.7 KJ energy will be generated. However, it will generate only 1.3 KJ energy and 1 g lactic acid under anaerobic conditions. 1 g protein will generate 15.7 KJ energy when consuming 1.12 g oxygen. According to Eq.17,

$W_{subp} + W_{trap} = 6.25 V_{ur} C_{urN}$, so E_n (produced energy) is

$$E_n = 1.57 \times 10^7 (6.25 V_{ur} C_{urN} + W_{mets} - W_{lact}) + 1.3 \times 10^6 W_{lact} \quad (18)$$

where, W_{lact} is the produced amount of lactic acid.

The oxygen consumption volume (V_{O_2}) is

$$V_{O_2} = 1.07(W_{mets} - W_{lact}) + 1.12 \times 6.25 V_{ur} C_{urN} . \quad (19)$$

If Eq. 19 is put into Eq. 18, then

$$W_{lact} = \frac{E_n - 1.46 \times 10^7 V_{O_2} + 4.6 \times 10^6 V_{ur} C_{urN}}{1.3 \times 10^6} . \quad (20)$$

The decrease in W_{deps} is:

$$\Delta W_{deps} = W_{sn} - W_{s0} - (W_{ins} + W_{trap} - W_{mets})\big|_T + C_{urs} V_{ur}\big|_T .$$

Therefore, according to Eq. 19:

$$W_{mets} = \frac{V_{O_2} - 7 V_{ur} C_{urN}}{1.07} + W_{lact} .$$

RESULTS

Table 1 is the normal values of parameters deduced from physiological data.[9,18,21]

V_i and C_p

If the parameters in Table 1 are changed then the correlativity between ΔV_i and C_p can be calculated. Table 2 shows calculated results. The second column indicates the relative rate of change of V_i one day after the parameter is changed, which is defined as $\frac{\Delta V_i}{V_{i0}}\big|_{1day}$. The third and fourth columns indicate the time required, T_d, and C_{pd}/C_{p0} when $\frac{\Delta V_i}{V_{i0}} \geqslant 10\%$, respectively.

Concentration of NPN in blood

Table 3 shows the theoretical results of C_{bN} calculated by Eq. 17 one day after the changes of correlative parameters.

Generation of lactic acid and decrease of W_{deps}

Table 4 shows the calculations of W_{lact} and ΔW_{deps} one day after correlative parameter changes.

DISCUSSION

In Table 2, the second to fifth lines indicate that abnormality of renal function could lead to *Qi* deficiency (QD). When $\frac{\Delta V_i}{V_{i0}} \geqslant 10\%$, the protein concentration only slightly decreases and T_d is shorter (about 1 day). The calculations also show that V_T and V_i increase corresponding to these abnormal renal parameters. Therefore, the main reason for QD is liquid retention in the body due to the obstruction of liquid drainage. The mechanism of the sixth line's result (V_{in} increase may lead to edema) is the same. Both the seventh and eighth lines show that the abnormality of splenic function will also lead to edema. When $\frac{\Delta V_i}{V_{i0}} \geqslant 10\%$, the protein concentration decreases significantly, to less than 70% of the normal value, while the value of V_T + V_i changes slightly, indicating the main reason of QD is a decrease in the protein concentration. Table 2 also shows that T_d is longer than the time needed for the edema induced by abnormality of renal function parameters, and ΔV_i is relatively less. The tenth and eleventh lines show that abnormal cardiovascular function can also lead to edema. The protein concentration and the value of V_T + V_i will have some changes when $\frac{\Delta V_i}{V_{i0}} \geqslant 10\%$, indicating the main reason for QD is high blood pressure induced by abnormal cardiovascular parameters.

Table 1 Normal values of parameters

Parameter	Normal value	Parameter	Normal value
R_{vs}	1.3×10^{7} Pa·s/m^3	V_T	4.5×10^{-3} m^3
R_{cs}	6.7×10^{7} Pa·s/m^3	V_{in}	2.0×10^{-3} m^3/d
R_{AT}	5.3×10^{8} Pa·s/m^3	V_i	8.2×10^{-3} m^3
R_{LS}	2.6×10^{8} Pa·s/m^3	V_{O2}	0.3L/min (0.62 kg/d)
R_{liv}	1.2×10^{8} Pa·s/m^3	W_{subp}	0.04 kg/d
R_{gi}	8.0×10^{7} Pa·s/m^3	W_{trap}	0.06 kg/d
R_g	1.2×10^{8} Pa·s/m^3	W_{inp}	0.1 kg/d
R_{go}	2.0×10^{8} Pa·s/m^3	W_{ins}	0.4 kg/d
R_T	1.3×10^{8} Pa·s/m^3	C_i	2.0×10^{-5} m^3/Pa
p_i	400 Pa	C_p	70 kg/m^3
E_k	3.0×10^{6} Pa/m^3	C_{bN}	0.08 kg/m^3
π_i	400 Pa	C_{urs}	0
π_b	3.3×10^{3} Pa	C_{urp}	0
C_s	1.0 kg/m^3	K_2	1.5×10^{-9} m^3/(Pa·s)
π_{bi}	0 Pa	p_{bi}	1.9×10^{3} Pa
W_{mets}	0.47 kg/d	E_n	9×10^{6} J
K_{suck}	100	K_1	7.5×10^{-10} m^3/Pa/s

Notes: R_{vs}: venous resistance; R_{cs}: microvascular resistance; R_{AT}: arterial resistance; R_{LS}: lymph flow resistance; R_{liv}: resistance of liver circulation; R_{gi}: resistance of the artery entering glomerulus; R_g: pressure of capillary in kidney; R_{go}: resistance of the artery leaving glomerulus; R_T: resistance of the whole circulation system; p_i: interstitial fluid pressure; E_k: combinative parameter of heart and vessels; π_i: colloid osmosis pressure in interstitial fluid; π_b: colloid osmosis pressure in blood plasma; C_s: concentration of blood sugar; π_{bi}: colloid osmosis pressure in original urine; W_{mets}: amount of metabolized sugar; K_{suck}: reabsorbing coefficient; V_T: blood volume; V_{in}: liquid volume absorbed within T seconds; V_i:interstitial fluid volume; V_{O2}: oxygen consumption volume; W_{subp}: supply amount of protein; W_{trap}: amount of protein transformed; W_{inp}: amount of protein absorbed; W_{ins}: absorption amount of sugar; C_i: compliance of interstitial space; C_p: concentration of blood protein; C_{bN}: NPN concentration in blood; C_{urs}: sugar concentration in urine; C_{urp}: protein concentration in urine; K_2: filtering coefficient of capillary in kidney; p_{bi}: capsular pressure; E_n: produced energy; K_1: filter coefficient of whole body capillary; E_k: composed parameter of vessels.

Table 2 Effects of parameter changes on V_i and C_p

Parameter change	$\frac{\Delta V_i}{V_{i0}}\Big\vert_{1\,day}$ (%)	T_d (day)	$\frac{C_{pd}}{C_{p0}}$ (%)
$R_{gi}\times1.5$	12.5	1	95.7
$K_2\times0.5$	10.2	1	96.7
$p_{bi}\times1.5$	12.4	1	95.7
$K_{suck}\times1.5$	6.6	2	96.4
$V_{in}\times1.5$	5.6	1.5	88.3
$W_{trap}\times1.5$	2.4	4	64.8
$W_{inp}\times0.5$	6.3	2	65.1
V_{urp}=0.03 kg/d	2.4	4	64.9
$R_{cs}\times1.5$	6.7	2	102.9
$E_k\times0.9$	5.6	2	84.3

Notes: V_i: interstitial fluid volume; C_p: concentration of blood protein; R_{gi}: resistance of the artery entering glomerulus; K_2: filtering coefficient of capillary in kidney; p_{bi}: capsular pressure; K_{suck}: reabsorbing coefficient; V_{in}: liquid volume absorbed within T seconds; W_{trap}: amount of protein transformed; W_{inp}: amount of protein absorbed; V_{urp}: volume of urine; R_{cs}: microvascular resistance; E_k: combinative parameter of heart and vessels.

Table 3 Theoretical results of C_{bN} one day after parameter changes

Parameter change	C_{bN} (kg/m^3)	C_{bN}/C_{bN0} (%)
$R_{gi}\times1.5$	0.20	250
$K_2\times0.5$	0.16	200
$p_{bi}\times1.5$	0.20	250
$K_{suck}\times1.5$	0.08	100
$W_{trap}\times1.5$	0.10	125
$E_k\times0.9$	0.14	175

Notes: C_{bN}: NPN concentration in blood; R_{gi}: resistance of the artery entering glomerulus; K_2: filtering coefficient of capillary in kidney; p_{bi}: capsular pressure; K_{suck}: reabsorbing coefficient; W_{trap}: amount of protein transformed; E_k: combinative parameter of heart and vessels.

In Table 3, the second through fifth lines indicate the effects of abnormal renal function on C_{bN}. The data show that C_{bN} is closely related to crude urine production, while reabsorption by the renal tubule and collecting tube has no effect. Therefore, the parameters for crude urine production greatly affect C_{bN}. The sixth and seventh lines show the effects of other parameters.

Table 4 Effects of parameters on W_{lact} and ΔW_{deps}

Parameter change	W_{lact} (kg)	ΔW_{deps} (kg)
V_{O2}×0.5	3.06	0.1
E_n×1.5	3.04	0.35
W_{ins}×0.5	0.01	0.25
$W_{urs}=1.0\times10^{-3}$ kg	0.01	0.1

Notes: W_{lact}: the amount of lactic acid that the body produced; ΔW_{deps}: the decrease in the amount of energy substances; V_{O2}: oxygen consumption volume; E_n: produced energy; W_{ins}: absorption amount of sugar; W_{urs}: the amount of surge in urine.

In the sixth line, the decrease of oxygen pressure in the interstitial fluid induced by abnormal pulmonary function or abnormal enzyme production can lead to an abnormal increase in protein oxidation ($W_{trap}\times1.5$). Table 3 also indicates that abnormal cardiac function not only causes V_i to increase but also causes NPN retention.

Table 4 shows that W_{lact} increases and W_{deps} decreases when V_{O2} decreases. The theoretical result, W_{lact}=3.0 kg, is much higher than the threshold value. The decrease in oxygen inhalation may be caused by a decrease in V_{O2} or a decrease in oxygen utility due to mitochondrial abnormality. Table 4 also shows that W_{lact} increases and W_{deps} decreases when energy requirement (E_n) increases. Motion certainly induces an increase of E_n, leading to more serious symptoms of QD. Therefore, the increase in energy requirement influences the organism, so QD patients are less active. Moreover, Table 4 shows that W_{deps} decreases when sugar absorption decreases ($W_{ins}\times0.5$) or sugar appears in urine ($W_{urs}>0$). These results only show organism parameter changes within one day, induced by the abnormal model parameters. If the abnormal parameter is not corrected in time, after a certain time the energy bank will further decrease, causing QDS.

Clinical research on QDS shows that edema exists in many kinds of QDS,[22] with a decrease in oxygen pressure in the interstitial fluid for lung-QD,[9] the retention of metabolites for kidney-QD,[18] and a decrease in lactic acid accumulation and energy bank for spleen-QD.[21] The model also shows that abnormalities of different organs can induce similar symptoms, reflecting the theory of correlation of each *Zang*-organ and its corresponding *Fu*-organ in TCM. For example, lung-QD can not only induce lung-QD symptoms, but also cause the spleen-QD symptoms. Kidney-QD can also be induced by dysfunctions of kidney and heart.

Studies on various models show that QD is induced fundamentally by the abnormality of parameters in interstitial fluid. An increase of V_i or retention of metabolites and lactic acid influences the stability of interstitial fluid components and causes a harmful environment for cellar normal physiological activity. Therefore, the *Qi* in QDS involves stability of interstitial fluid components, and QDS is caused by insufficiency of nutritional components or excessive toxins in the interstitial fluid. These theoretical results indicate that the key to treating QD is finding a way to supplement the insufficient nutrition in the tissue or accelerate excretion of surplus toxins and water in interstitial space, and provide a clean and stable environment for cell living.

REFERENCES

1 **Zhao H**, Xiong WH, Zhao X, et al. Development and evaluation of a Traditional Chinese Medicine syndrome questionnaire for measuring sub-optimal health status in China. J Tradit Chin Med 2012; 32(2): 129-136.

2 **Wang LM**, Zhao X, Wu XL, et al. Diagnosis analysis of 4 TCM patterns in suboptimal health status: A structural equation modelling approach. Evid Based Complement Altern Med 2012: 1-6.

3 **Hijikata Y**, Makiura N, Kano T, et al. Kampo Medicine, based on traditional medicine theory, in treating uncured glossodynia: efficacy in five clinical cases. Am J Chin Med 2008; 36(5): 835-847.

4 **Xue XL**, Wu XY, Xing JM, et al. Xiaopiyishen herbal extract granule improves the quality of life among people with fatigue-predominant subhealth and liver-*Qi* stagnation and spleen-*Qi* deficiency syndrome. Evid Based Complement Altern Med 2012; 1-9.

5 **Ma XL**, Zhai X, Li YB, et al. Exploration of the biological basis of coronary heart disease angina pectoris with *Qi* deficiency and *Qi* stagnation based on GenCLiP gene mining software. Afr J Pharm Pharmacology 2012; 6(22): 1625-1630.

6 **Gao ZY**, Xu H, Shi DZ, et al. Analysis on outcome of 5284 patients with coronary artery disease: The role of integrative medicine. J Ethnopharmacology 2012; 141(2): 578-583.

7 **Feng YL**, Zheng GY, Ling CQ. The Investigation of the correlation between metabolic syndrome and Chinese medicine constitution types in senior retired military personnel of the People's Liberation Army. Zhong Guo Zhong Xi Yi Jie He Za Zhi 2012; 18(7): 485-489.

8 **Li JS**, Hu JL, Wang ZW, et al. Study of TCM diagnosis of syndromes of acute exacerbation of chronic obstructive pulmonary disease based on dynamic fuzzy kohonen network. ICIC 2010: Proceedings of the 6th International Conference on Intelligent Computing; 2010 Aug 18-21; Changsha. China: Springer, 2010: (CCIS 93) 258-265.

9 **Yao W**, Ding GH. Simulation of oxygen supply in the tissue and its relationship with Lung *Qi* -Deficiency. IEEE 2010: Proceeding of the 8th IEEE International Conference on Control and Automation, 2010 Jun 9-11; Xiamen, China. ICCA 2010: 981-984.

10 **Zhang WB**, Zhuang FY, Li H. An improved Guyton's method to measure hydraulic conductance and its use in measuring conductance in meridian tissue of animals. Beijing Sheng Wu Yi Xue Gong Cheng Xue Bao 1997; 16(4): 199-204.

11 **Li HY**, Yang JF, Chen M, et al. Visualized regional hypodermic migration channels of interstitial fluid in human beings: Are these ancient meridians? J Altern Complement Med 2008; 14(6): 621-628.

12 **Li RW**, Wen C, Meng JB, et al. Analysis of the linear migration of the radionuclide along meridians in perfused ex-

tremities of monkey. Zhen Ci Yan Jiu 1992; 17(1): 67-70.

13 **Fei L**, Cheg HS, Cai DH. Experimental exploration and research prospect of physical bases and functional characteristics of meridians. Chin Sci Bull 1998; 43(15): 1233-1252.

14 **Zhang D**, Yao W, Ding GH, et al. A fluid mechanics model of tissue fluid flow in limb connective tissue-a mechanism of acupuncture signal transmission. J Hydrodynamics 2009; 21(5): 675-684.

15 **Yao W**, Ding GH. Interstitial fluid flow: Simulation of mechanical environment of cells in the interosseous membrane. Acta Mechanica Sinica 2011; 27(4): 602-610.

16 **Xia Y**, Ding GH, Wu GC. Current research in acupuncture. New York: Springer, 2013: 53-88.

17 **Sunagawa K**, Sagawa K, Maughan WL, et al. Ventricular interaction with the vascular system in terms of pressure-volume relationships, In: Yin F.C.P. ed. Ventricular/vascular coupling. New York: Spring-Verlag Press, 1987: 210.

18 **Yao W**, Ding GH, Shen XY, et al. A hemodynamic model describing the regulation of tissue fluid and its application in kidney QDS. Zi Ran Ke Xue Jin Zhan 2002; 12(2): 151-155.

19 **Yao W**, Wang SZ, Ding GH, et al. A dynamic model describing lymph circulation, J Hydrodynamics 2009; 21(1): 118-123.

20 **Keener J**, Sneyd J. Mathematical physiology. 2th edition. New York: Springer, 2009: 480.

21 **Yao W**, Ding GH, Shen XY, et al. A hemodynamic model describing metabolism of substance and its relation with and SQD. Zi Ran Ke Xue Jin Zhan 2002; 12(6): 607-611.

22 **Yao W**, Ding GH, Shen XY, et al. A hemodynamics model describing deficiency of heart-*Qi* (Vital Energy). Sheng Wu Yi Xue Gong Cheng Xue Bao 2002; 19(1): 53-56.