

## On a dynamical view on the meridian transmission

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### Abstract

**Objective:** To describe meridian physiology and qi-blood circulation from the dynamical viewpoint.

**Methods:** By applying numerical method to solve the transport equations for the normal Newtonian fluid at electro-osmotic motion.

**Results:** The flow rate of fluid along meridian is very compatible to the migration velocity along the meridian of small particles in the previous literatures. When the **permeability** of capillary wall and the blood pressure of capillary change, the flow rate of qi will be correspondingly changed, which is confirmed with the physiologic reaction at acupuncture treatment. The changes in static pressure of the meridian routes and the inflow condition explain the theory of qi stagnation and blood stasis, and flow of qi can induce blood circulation.

**Conclusion:** By applying the equations for electro osmotic flow, it can explain meridian theory of traditional Chinese medicine (TCM), which is valuable to understand the conduction phenomena of electric wave and the electric current of meridians.

**Keywords:** Qi-blood circulation; electro-osmotic; meridian

Famous Dr. Shi-Zhen Li (1518-1593AD) of Ming Dynasty has described that, “Internal meridian visualization can only be viewed and felt by high-level meditation practitioners with extra-ordinary sensation.” It was also reported that when meditation practitioner already enters a complete meditation condition, who can view and feel qi migrating on the meridian routes. Numerous meditation practitioners without any doubt have confirmed this objective phenomenon at all. Why are we still unable to detect meridian track by modern electronic microscope? This mystery has been unresolved for by thousands of years. Modern researchers have applied many different scientific research methods to prove the subjective evidences of the existence of meridians. Professor Jing-Bi Meng et al. had used the radioisotope scitigraph technology to inject  $TcO_4$  subcutaneous at the acupoints of wrists and ankles of four extremities. The images of the propagating lines in their experiments are highly compatible to the twelve meridian routes in the classic meridian map. Their research results confirmed that there are many small particles conducting function along the meridians. Professor Wei-Bo Zhang analyzing the description of “chi-mai” and “mai-dong” of *Mai-shu* from Ma-wong-dui assumed that there are at least two different structures including “diastima between meats” and arteries in the meridian transmission routes. The “diastima between meats” in TCM is the interstitial tissue in physiology. At the same time, professor Wei-Bo Zhang

proposed that meridians are located between interstitial tissues with a lower flow resistance to carry the tissue fluid, chemical substance, and physical matters with multiple-pores medium passage. Professor Guang-Hong Ding regarded meridian system as a fluid mechanic model. In addition, by applying electric research we know that meridians are good electric conductors. Comparing with the direction of meridians and its surrounding areas, meridians have the characteristics of electric conductivity (low electric resistance) and wave conductivity (through polarization of meridian, velocity of electromagnetic wave transmission is faster).

The electric conductivity and wave conductivity of the meridians show advantageous direction. This direction of higher electric conduction directs from the distal parts of four extremities toward the trunk. This indicates that qi of twelve meridians in TCM should include the effect of electric current. The advantage direction of wave conductivity of meridians (faster direction of wave) demonstrates the regulation of ying ascending and yang descending. Thus, we propose that “Jin Juan Yin qi” (the nutrition of foodstuffs) in TCM can be sent to the meridian and travel in it. According to above scientific methods, we can assume that meridians have the ability to transmit electric charges and energy. Accordingly, meridians are possible physiological network inside the living beings. Meridian system acts as the most important role to communicate and carry matter, energy, and signal inside the living beings. In other words, meridians (as main tracks) and collaterals (as networks) can connect and integrate five zang, six fu, face, head, trunk, and four extremities as one. It communicates and carries matter, energy, and signal to activate physiological metabolism of all cells inside the living beings.

In the theory of TCM, it defines three different depths of acupoints from the superficial part to the profound part as heaven, human, and earth (from the skin to the profound connective tissue). In our research, we explore the depth of the earth of acupoints of Stomach and Gallbladder meridians of the lower extremities. According to *Huang Di Nei Jing*, we know that there is a strong relation between the meridian *mai* and the blood *mai*. The traveling route of large vessels and meridian *mai* is different. Thus, we assume that the structure of meridian *mai* is only related to the capillary of the blood vessels. Professor Lun Fei thought that meridian route should have different cross-section tunnel structures. It is composed of liquid crystal materials (including  $Ca^{2+}$ ,  $K^+$ ,  $Fe^{2+}$ ,  $Zn^{2+}$ ,  $Mn^{2+}$  and so on) to flow in the tunnel structure of the meridians, which is a good conductor of heat, electricity, and light, and can produce many different colors. Through the secretion of the stem cells and oriented stem cells, it can produce matter to convect and to conduct heat, light, electricity and macro-particles and micro-particles, and signals. Because capillary exists in the meridian system, by applying relaxation of smooth muscle of capillary it can increase the local blood flow. Thus it can strengthen the function (tonification in TCM). On the contrary, when smooth muscle becomes contracting, the local blood flow will decrease, which will reduce function (purgation in TCM).

Transmission model of meridians and collaterals conducts intermittently. They stop at the sites of the acupoints. Physiological location of acupoints is located at the sites of denser capillary of the muscles. In order to understand the characters of the meridian transmission, in this article, electro-osmotic meridian (EOM) dynamic model is applied

in the tubule interstitial tissue of muscles. The capillary is to distribute segmental distribution according to the location of acupoints. From the basic physiology, we know that one end of the capillary vessels (diameter around 5~15 $\mu\text{m}$ , and length around 1mm) is to connect to arterioles, which have one circular smooth muscle, called pre-sphincter muscle of capillary. The other end is to connect the small venule. The capillary is submerged in the tissue fluid. When blood flows through capillary, substances inside the blood (glucose, amino acid, uric acid, sodium, chloride, electrolytes, and lipids and so on) pass through the small pores (diameter around 0.04~0.08 $\mu\text{m}$ ) of the wall of capillary to exchange the substance with the tissue fluid. Thus, tissue fluid and blood can be continuously mixed.

### 1. Dynamical model of meridian (Stomach and Gallbladder meridians of the lower legs)

According to the physiological characteristics of Gallbladder and Stomach meridians of the lower legs, we have the following conclusions from the meridian dynamic model: (a) Along meridian routes, there is a strong relation between the deeper location of acupoints and the connective tissue; (b) Higher density of capillary at the acupoints than that at the non-acupoints. In other words, segmental distribution of capillary is along the meridian; (c) Parallel row of capillary and meridian at the deep layer of connective tissue of acupoints; and (d) Meridian routes continuously demonstrate different cross-section tubule structures and flows with liquid crystal charged tissue fluid.

Under the above conclusions, we define the physiological structure of the muscular fiber, capillary, lymphatic ducts, and sympathetic nerves as the meridian small body. Blood in the theory of TCM circulates inside the blood of capillary. Qi in the theory of TCM transmits in the diastema of the circular column muscular cells with charged tissue fluid. There are some small meridian bodies to compose of one acupoint. The interaction of qi and blood occurs at the acupoint site.

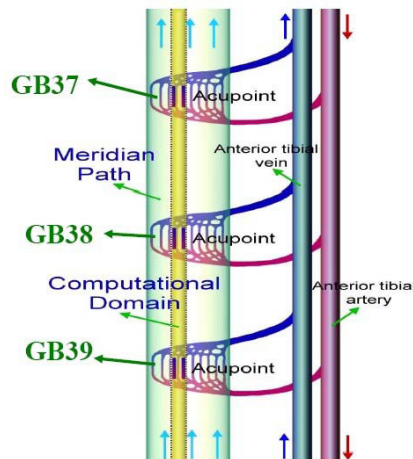


Figure 1 Schematic of the meridian model.

In order to explore this multi-scale problem, we define coordinate  $x$  as the direction of meridians (including three acupoints, each acupoint having one meridian small body; Gallbladder meridian at the lower legs, including Xuangzhong (GB 39), Yangfu (GB 38), and Guangming (GB 37), which has the length around 53mm). The coordinate  $y$  defines

the distance of two parallel capillaries (around  $60\mu\text{m}$ ). In comparison with the distance of capillary, we calculate the width of the region ( $y$  axial) around ten folds of diameter of capillary ( $10\mu\text{m}$ ). The length (in  $x$ -direction) is fifty-three folds of the length (around  $1\text{mm}$ ) of capillary. The whole region under calculation is  $100\mu\text{m} \times 53,000\mu\text{m}$ . There are many round pores in the capillary wall having the ability of osmosis, and which is simulated as porous media in this study. In figure 2, numerical model in a single one acupoint is illustrated. At the arteriole end, because static fluid pressure in the capillary is larger than the static pressure of meridian route, by using this pressure difference  $\Delta p_1$  it can squeeze fluid out from the arteriole end. In addition, because osmotic pressure inside the capillary of the arteriole end is larger than the osmotic pressure of tissue fluid, the pressure difference  $\Delta p_2$  can transmit tissue fluid from meridian route to capillary. Thus, the total pressure difference  $\Delta p_{art}(=\Delta p_1-\Delta p_2)$  is the source of plasma to push out from the arteriole end to the meridian route. This numerical result reveals that from the arteriole end of capillary to the venule end its trend is gradually decreasing. Under normal circumstance, the amount of fluid flow from the arteriole end to meridian route is relatively larger than that from the meridian route to the venule end (total amount  $3\text{L/day}$  in whole human body). At this time, human body uses the lymphatic ducts in the tissues to lead to the venous system. If protein of plasma staying inside the interstitial tissue is too high, it causes edema phenomenon to occur.

According to the Starling Law, capillary carrying osmotic amount of fluid is controlled by  $p_c^*$  (static pressure inside capillary),  $p_0$  (static pressure of tissue fluid),  $\pi_i$  (osmotic pressure of plasma), and  $\pi_0$  (osmotic pressure of tissue fluid). In this study,  $p_c^* - \pi_i + \pi_0$  is shown as  $p_c$ , so we have  $p_c = p_c^* - \pi_i + \pi_0$ . At the same time, in EOM model, blood and tissue fluid can interact with each other. The wall of blood vessels requires the osmotic characteristics. The blood vessels have certain porosity and permeability. In this article, we consider that non-linear Newtonian electric-osmotic flow, fluid density, viscosity, permittivity, Debye-Huckel thickness, porosity, permeability are constant. Without considering the gravity effect, the equations for momentum, mass, electric potential are solved to predict the result.

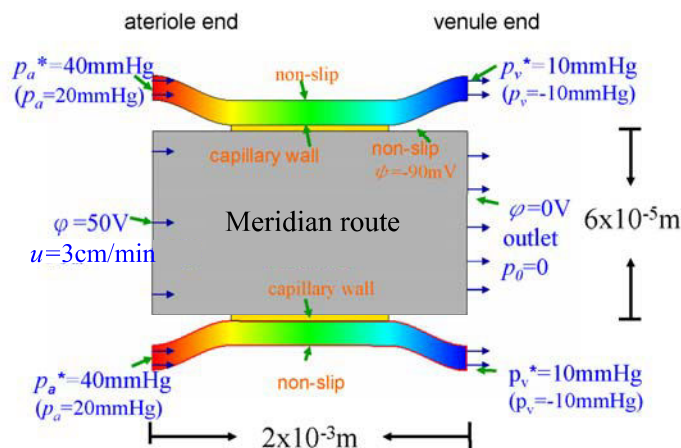


Figure 2 Schematic of the transport in the meridian model, where  $u$ ,  $v$  denote the velocities along  $x$  and  $y$  directions, respectively.

## 2. Numerical model

We apply the finite volume method (CFDRC) which employs the upwinding numerical scheme to decrease the instability due to non-linear term in momentum equation. In addition, we apply algebraic multigrid method (AMG) to accelerate the convergence. Because length and width of the region have different orders, in this article we use a relative bigger mesh of 16,899 grids and 16,416 finite volumes. Furthermore, we add more grids at the no-slip border and capillary sites. In order to retain the stability of numerical results, both Peclet and Courant numbers need to be controlled below 1 ( $Pe < 1$ ;  $Cr < 1$ ).

## 3. Numerical result

According to basic physiology, in this article we assume the arteriole pressure of the capillary ( $p_a^*$ ) is 40mmHg (1mmHg=0.133kPa); venule pressure ( $p_v^*$ ) is 10mmHg; static pressure of tissue fluid ( $p_0$ ) is 0 mmHg; osmotic pressure of tissue fluid ( $\pi_0$ ) is 5mmHg; osmotic pressure of plasma ( $\pi_i$ ) is 25mmHg; viscosity ( $\mu$ ) of blood is  $2.1 \times 10^{-3}$  Pas; and permeability of wall of capillary ( $k$ ) is  $6.9 \times 10^{-9}$  m<sup>2</sup>/s/kg. From the experimental result of professor Jing-Bi Meng et al., we know that the migration velocity of the small-particle circulation is around few cm to ten cm per minute. We assume the inflow velocity of meridian route is  $u=3$  cm/min, outflow pressure is  $p_0=0$  and calculate the results under the no-slip condition of capillary wall ( $u=0, v=0$ ).

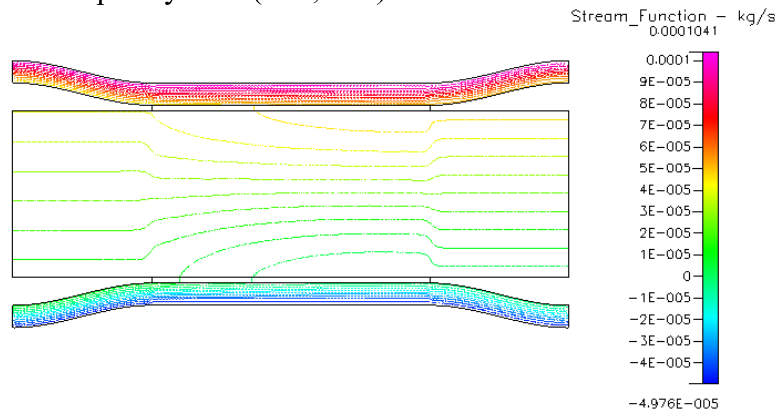


Figure 3 The predicted velocity streamlines. (This figure has been enlarged by ten times in y direction)

The predicted streamline (figure 3) and pressure distribution (figure 4) reveal tissue fluid flowing along x-direction from left to right side of the computing domain and interacting with blood at the segment of the capillary. Others, in meridian route, the density of streamline is denser when tissue fluid flowing through capillary segment. From flow dynamic theory, we know that fluid has a significantly higher speed around the acupoints (capillary segment). In other words, tissue fluid will be accelerated to pass through the acupoint region.

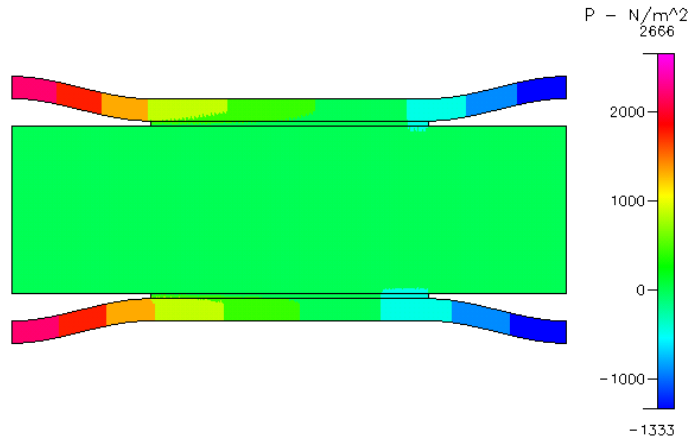


Figure 4 The predicted pressure contours. (This figure has been enlarged by ten times in y direction)

Assuming all physiological parameters of capillaries are the same, the average velocity of tissue fluid traveling along the meridian is  $u$ . Through this simulation, we know that  $u$  is 4.12cm/min, which is very compatible to the value of the experimental result of small particles migration by professor Jing-Bi Meng.

Table 1 Comparison of blood pressure value ( $p_a^*$ ) for different arterioles and averaging velocity of tissue fluid ( $u$ )

| Blood pressure of arteriole (mmHg) | Average velocity of tissue fluid (cm/min) | Comparison with the theory of TCM                                     |
|------------------------------------|---|---|
| 30                                 | 2.83                                      | Blood is the mother of qi<br>Blood deficiency to induce qi deficiency |
| 40                                 | 4.12                                      | Normal health condition   |
| 50                                 | 5.42                                      | Blood excess to induce qi excess                                      |

### 3.1. Blood is the mother of qi

The theory of TCM assumes that “blood is the mother of qi.” “While qi-moving is accompanied with blood, blood and qi are moving correspondingly.” “If there is qi without blood, the qi has nothing to count on its existence.” In this article, we reduce blood pressure of arteriole ( $p_a^*$ ) from 40mmHg to 30mmHg and the remaining conditions are remained the same. It is very similar to “blood deficiency” phenomenon. We predict the value of  $u$  is 2.83cm/min. From this result, we know that decreasing blood pressure of arteriole can decrease the tissue fluid flow at the same time. It is so-called “blood deficiency to induce qi deficiency”. On the contrary, while blood pressure of arteriole increases to 50mmHg, tissue fluid flow increases to 5.42cm/min. This is so-called “blood excess to induce qi excess”.

### 3.2. Theory of qi stagnation to induce blood stasis

*Huang Di Nei Jing* said that, “When qi and blood are not in harmony, all types of diseases will appear”. Qi and blood is the fundamental source to maintain life. The flow of blood requires qi to move forward. It has been said in *Huang Di Nei Jing* that, “While qi is moving, blood is also moving. While qi is in stagnation, blood is also in stagnation.” According to the theories of TCM, qi stagnation is due to slow-down qi (stasis) during qi circulation, which makes blood circulation also to slow down (stasis). In this experiment, we increase the static pressure ( $p_0$ ) of tissue fluid to explore this phenomenon. If static pressure ( $p_0$ ) of tissue fluid is increased from 0 mmHg to 4 mmHg,  $u$  value will be changed to 3.09cm/min. This explains that increasing static pressure of the tissue fluid can induce velocity of the tissue fluid to slow down. From this experiment, when meridian is compressed to increase the static pressure of tissue fluid, migration speed of small particles slows down too. When static pressure ( $p_0$ ) of tissue fluid increases, blood flow speed ( $u_{artery}$ ) of capillary decreases too. This can explain why qi stagnation can induce blood stagnation in the theory of TCM. In addition, if we change the pressure ( $p_0$ ) of tissue fluid from 0mmHg to -4mmHg, the  $u$ -value of tissue fluid will be changed to 5.16cm/min. This can explain when qi is flowing very smooth (tissue fluid pressure decreasing), it can help the tissue fluid to flow and the blood circulation to increase rapidly too ( $u_{artery}$ , increasing).

Table 2 Comparison of static pressure value ( $p_0$ ) for different tissues and averaging velocity of tissue fluid ( $u$ )

| Static pressure<br>Of tissue<br>(mmHg) | Average velocity<br>of tissue fluid<br>(cm/min) | Velocity of<br>Capillary<br>(cm/min) | Comparison with<br>theory of Chinese<br>Medicine |
|--|---|--------------------------------------|--|
| 4                                      | 3.09  | 96.72                                | Qi in stagnation, then blood in stagnation       |
| 0                                      | 4.12  | 97.36                                | Normal health condition                          |
| -4                                     | 5.16  | 98.00                                | Qi is flowing, then blood flows                  |

### 3.3. Theory of qi circulation to aid blood circulation

*Huang Di Nei Jing* said that, “Qi is the primary source of blood. Qi circulates, then blood also circulates.” This explains qi can push the blood to circulate. When qi is excessive, blood is in excess. When qi is deficient, blood is also deficient. In this study, we increase and decrease the inflow velocity of tissue fluid to model qi excess and qi deficiency. According to the predicted result, we know that when the velocity of tissue fluid increases from 3cm/min to 30cm/min, blood flow of arteriole end of capillary will be changed from 97.36cm/min to 96.39cm/min and venule end from 95.97cm/min to 96.92cm/min. This explains while qi is excessive, fluid from meridian system will supply to blood system. It is the so-called “qi circulating then blood circulates; as well as qi is excessive and blood is excessive.” On the contrary, if we reduce  $u$  value from 3cm/min to 0.3cm/min, fluid flow at the arteriole end of capillary will be increased to 97.46 and at the venule end will be decreased to 95.87cm/min. For further analysis, while qi is deficient, blood flow will increase at the arteriole end of blood system and will supply to

the meridian system. It is the so-called “blood is the mother of qi”. Blood flow decreases at the venule end is “qi in deficiency then bloods is also in deficiency” phenomenon.

Table 3 Comparison of different tissue fluid inflow condition and average velocity of arteriole ( $u_{artery}$ ) end and value ( $u_{vein}$ ) end of capillary (cm/min)

| Inflow velocity of tissue fluid | Velocity of arteriole end | Velocity of venule end | Comparison with the theory of TCM                              |
|---------------------------------|---------------------------|------------------------|--|
| 0.3                             | 97.46<br>Increase         | 95.87<br>Decrease      | Qi in deficiency, then blood system supplies meridian system   |
| 3.0                             | 97.36                     | 95.97                  | Normal health condition  |
| 30.0                            | 96.39<br>Decrease         | 96.92<br>Increase      | Qi is excessive, then meridian system supplies to blood system |

### 3.4 Physiological phenomena of acupuncture treatment

When acupuncture needles are inserted into acupoints, it can cause many physiological reactions. What is the physiological mechanism is the main question in the acupuncture physiology. Injured tissue can cause physiological reaction to increase the static pressure of capillary, dilation of capillary, and increase permeability of blood vessels. Therefore, we can change the permeability of blood vessels, increase static pressure of arteriole and venule of capillary. When the values of  $k$ ,  $p_a^*$ , and  $p_v^*$  of the capillary increase from the normal value  $6.9 \times 10^{-9} \text{m}^2/\text{s}/\text{kg}$ , 40mmHg, and 10mmHg to  $1.38 \times 10^{-8} \text{m}^2/\text{s}/\text{kg}$ , 50 mmHg, and 20mmHg,  $u$  value increases significantly to 12.17cm/min. From this result, the physiological reaction makes the plasma to osmose from the blood vessels to the meridian route after acupuncture treatment.

Table 4 Comparison of average velocity ( $u$ ) of tissue fluid of acupuncture effect

| Permeability ( $\text{m}^2/\text{s}/\text{kg}$ ) | Arteriole end (mmHg) | Venule end (mmHg) | Velocity of tissue fluid (cm/min) | Comparison with the theory of TCM   |
|--|----------------------|-------------------|-----------------------------------|---|
| $6.9 \times 10^{-9}$                             | 40                   | 10                | 4.12                              | Normal health condition   |
| $1.38 \times 10^{-8}$                            | 50                   | 20                | 12.17                             | During needles entering, acupoints to cause damage, increase permeability, increase venule pressure of capillary, increase blood to enter tissue fluid, increase qi circulation |

### 3.5. Electric osmotic flow model

Body reaction toward needles inserted to acupoints is directly and rapidly. Except soreness and numbness, some people may demonstrate qi can propagate along the



meridian with qi sensation (nervous tissue stimulated by the accelerating tissue fluid). Some even feel electric shock reaction at the non-acupuncture treatment site. In comparison to other tissues, meridian route is a good conductor of electricity. During acupuncture treatment, electric potential difference (from several to hundred volts) of acupuncture practitioner (donor) and patients (receptor) can produce electric current. Thus, it can cause an electric shock. During electro-acupuncture treatment, negative and positive poles are connected with the electro-acupuncture needles at different acupoints of a meridian. By applying different wave-shape of electric current stimulation, it can have better treatment result than that using only the acupuncture needle. In this research, when we specify voltage difference ( $\Delta\Phi=50$  V) at the inlet and outlet sides of meridian route (attaching electrode paste on different acupoints); zeta potential of meridian route is  $\psi=-0.1V$ ; and Debye-Huckel thickness is prescribed to be the default value  $\lambda_D=10^{-8}m$ . From the predicted result, we find that the average velocity of tissue fluid is changed from 4.12cm/min to 4.22cm/min. For electro-acupuncture reaction, we need to increase permeability of blood vessels and static pressure of capillary. Thus, the velocity of tissue fluid can increase to 12.18cm/min.

Table 5 Comparison of the average velocity ( $u$ ) of tissue fluid of normal health condition, electrode paste and electro-acupuncture treatment

| Location condition                               | Velocity of tissue fluid (cm/min) | Comparison with the theory of TCM  |
|--|-----------------------------------|--|
| Normal health                                    | 4.12                              | ---  |
| Attaching Potential difference (electrode paste) | 4.22                              | Electrode paste attaching at different acupoints to join electric potential to transmit electric ions of meridian to become electric current; this can help qi meridian to circulate; at the same time, electric stimulation can assist metabolic effect |
| Electro-acupuncture Treatment                    | 12.18                             | After needle being punctured at acupoints, different acupoints with the applied electric potential difference can induce needle puncturing and electric osmosis by an additional increase or double fold increase  |

#### 4. Conclusion

From this study, we conclude with the following statements: (a) In the meridian route, the predicted velocity of tissue fluid is compatible to the velocity of small particles of literature. The speed of tissue fluid differs from the velocity of blood flow, transmission speed of nerve, and velocity speed of lymphatic ducts of physiology transmission. (b) When we change the blood pressure of arteriole, it can change the velocity of tissue fluid along the meridian route. This is the significant appearance of “qi movement depends on blood”; and “blood and qi move correspondingly” of theories in TCM. (c) When static pressure ( $p_0$ ) of tissue fluid increases, plasma amount osmosed to meridian route from capillary decreases. In addition, velocity of tissue fluid transmitting

along the meridian decreases, too. When applying certain pressure on skin, velocity of small particles traveling along meridian will be reduced, and it's as compatible to the result reported in the literature. At the same time, increasing  $p_0$  will reduce the velocity of blood flow at the arteriole end of capillary. This concept is compatible to "qi stagnation can cause blood stasis". (d) Puncturing needles at acupoints can cause tissue damage. It increases permeability of capillary. It also increases static pressure of capillary. It can significantly increase the velocity of tissue fluid (qi circulation). This is very compatible to the theory of acupuncture treatment. (e) By applying electric osmosis equations, one can explain the phenomenon of interaction reaction of qi and blood. It also can explain electric wave and electric current conduction phenomenon along the meridian route. From our predicted result, we know that electro-acupuncture has the similar treatment result of double fold of electrode-paste treatment and acupuncture treatment result.

### Reference

1. Meng JB, Tian JH, Exploration of fourteen meridians images, China Scientific Technology Press, Beijing, 1998, PP.75.
2. Meng JB, Liu RY, Xu HR et al, Using radiation  $\gamma$  scitigraphy to detect twelve meridians in normal healthy subjects, Acupuncture Research, 1989, Supplement 14(4), PP.1.
3. Zhang WB, Scientific exploration to the meridian in TCM, Chi-Yeh Book Press, Taipei, 1999, PP27-52, PP.105-184.
4. Ding GH, Chen EY et al, Tissue fluid orientation flow and meridian in the human body, Progress in Natural Science, 2001, 11(8), PP.811-818.
5. Chen GZ, Message viewpoint of acupuncture effect, Journal of Chinese Acupuncture Society, 2000, 11, PP.35-40.
5. Unknown author, Huang Di Nei Jing (The Yellow Emperor's Cannon of Internal Classic) annotated by Bing Wang (Tang Dynasty), Taiwan Business Press, Taipei, 1948.
7. Fei L, Cheng HS, et al, Experimental exploration and research prospect of physical bases and functional characteristics of meridians, Chinese Science Bulletin, 1998, 43(15), PP.658-672.
8. Zhang JX, Meridians and Stem Cell Lines - Discussions about species original and stem cell line evolution, Chinese J Basic Med TCM, 2001, 7(4), PP.17-21.
9. Guyton AC. Textbook of Medical Physiology. 10th Edition, WB Saunders, Philadelphia, 2000.
10. Valtin H, Schafer JA. Renal Function. 3rd Edition, Little-Brown, Boston, 1995.