Visualization of the Meridian of Traditional Chinese Medicine with Electrical Impedance Tomography: An Initial Experience

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Abstract. The meridian is a concept central to traditional Chinese medical techniques such as acupuncture. There is no physically verifiable anatomical or histological basis for the existence of meridians. In Chinese medicine, the meridians are channels along which the energy of the psychological system is considered to flow. It has been proven that the resistance along the meridian channels is lower compared to other paths. Based on this knowledge, we proposed using electrical impedance tomography (EIT) to visualize the meridians of human being. A simplified three dimensional (3D) mathematical model of the forearm developed. Current was injected in the direction perpendicular to the cross-section where eight electrodes were equally placed around the surface of the forearm for the voltage measurements. The model was solved using Finite Element Method (FEM) and dynamic image was reconstructed using truncated singular value decomposition (TSVD) regularization method. The conductivity distributions were compared with different current injections, along the meridian channel and channels around respectively. We also conducted experiments on models and the meridians were shown in final reconstructed images.

1. Introduction
There are many points with different physical properties in human body, which is called Meridian [1] in traditional Chinese medicine. A new approach for research on the Meridian characteristics is proposed on the basis of the low flow resistance characteristics: Tracer currents are injected into points and measuring electrodes are used to get voltages. Meridian image is obtained using dynamic imaging which is an image reconstruction of the change of electrical conductivity. It provides a scientific basis for the research on meridian imaging.

2. A simplified physical model
Some prior knowledge is considered to study properties of meridian including structures and electrical conductivity of interior tissue in medical application. In order to study the meridian more easily, combined with shape and position of meridian, both of the simplified forearm and large intestine meridian are modeled as cylindrical uniform dielectric, as shown in Figure 1, according to the low flow resistance characteristics of the meridian.
3. Method

3.1. Forward problem
In this model forward problem is that the currents are injected into points vertically and then voltages are measured based on EIT. As illustrated in Figure 2, the red on the cylinder is the exciting electrode where current is injected into. Currents are injected into meridian channel and channels around [2] respectively and difference between them are obtained to study characteristic parameters with the method of dynamic imaging.

As the derivation of inverse problem will use the method of sensitivity analysis, it is necessary to establish sensitivity matrix $J$ which is exactly what forward problem should deal with. Sensitivity matrix is based on the theory that a small change of electrical conductivity could induce a change of the boundary voltage to solve a nonlinear problem in a linear way, and the linear physical model is as follows: $J \delta \sigma = \delta U$

Where $J$ is linear system matrix (sensitivity matrix), $\delta \sigma$ is the difference of electronic conductive when current is injected into meridian channel and around, and $\delta U$ is the difference of boundary voltage corresponding to $\delta \sigma$.

Electromagnetic finite element method is applied to analyze the distribution of voltage through COMSOL software. In order to reduce ill-conditioned problems for this established model, rectangular mesh generation is used to solve sensitivity matrix. In this way, imaging field is divided into many small ones, and electrical conductivity in every small area is a constant. After some mathematical derivation [3], $J$ is obtained as follows: $J = \frac{\partial V_{dm}}{\partial \sigma_k} = -\frac{1}{I} \int_{\Omega} E(\tilde{I}^d), E(\tilde{I}^m) dV$

Where $V_{dm}$ is potential difference between $d$ and $m$ types of current, $\sigma_k$ is the conductivity in field k, $E(\tilde{I}^d)$ and $E(\tilde{I}^m)$ are distribution of field strength when the currents are type $d$ and type $m$ respectively.

3.2. Converse problem
Solving converse problem is to obtain distribution of the characteristic parameters in the filed. And for this physical model of meridian, it is an ill-posed problem [4] and $J$ is ill-conditioned. So the study theoretically analyzes TSVD [5] (truncated singular value decomposition) regularization method starting with least square method and image reconstruction of EIT on meridian is performed.

Traditional least squares method to solve cannot make a good image. So we try three methods to improve image. (1) normalized singular value method; (2) norm method; (3) L-curve method. The reconstructed images are shown in Figure 3. We can see the image of normalized singular value method cannot reflect the distribution of conductivity; but both norm method and L-curve method give better images, especially when 1% and 5% random noise are added. Hence both TSVD methods which
can reduce condition numbers of sensitivity matrix and to a great extent restrain noise manage imaging effect well. They commendable reflect distribution of electrical conductivity in the field even the disturbance exists.

Figure 3. (a) is the distribution of original conductivity. (b) comes from Traditional least squares method. (c) comes from normalized singular value method. (d) comes from norm method; (e) and (f) are reconstructed with norm method while 1% and 5% random noise are added respectively. (g) comes from L-curve method; (h) and (i) are reconstructed with L-curve method while 1% and 5% random noise are added respectively.

4. Experiments

4.1. Experiments design
Considering complexity and instability of human meridian, we didn’t experiment on human, but on two simple and steady models: normal saline-resistance wire cylinder model and gel-normal saline model. First, normal saline-resistance wire cylinder model simulate meridian from the perspective of electrical conductivity of tissue. Then gel-normal saline model makes use of model method in physics. This model can simulate not only the low impedance of meridian but also the low flow resistance. What’s more, gel is more stable.

Figure 4. Normal saline-resistance wire cylindrical model. Figure 5. Gel-normal saline model. (a) is a side view picture and (b) is a top view picture.

4.1.1. 0.9% normal saline is prepared with distilled water and NaCl to simulate human fluid. An organic glass rod with the radius of 3 mm is wound by copper wire with the impedance of $20 \, \Omega$ and
this unit simulates meridian. And there are eight electrodes on the side surface of the cylinder and a circle grounding electrode at the bottom, as shown in Figure 4.

4.1.2. Ager powder and 0.9% normal saline are mixed with a ratio of 3 g: 100ml and heated to be dissolved. Then mixture is put into the prepared cylinder container, at the same time, an organic glass rod with the radius of 3 mm is buried in the mixture. After solidification, the rod is removed. At this time, a narrow channel comes where the rod has been. 4.5% saline is pour into this channel to simulate meridian, as seen in Figure 5.

Signal generator and high precision multimeter Agilent 34401A are applied to generate stable currents and to measure voltages. Eight groups current of 100Hz frequency are generated in the range from 8.5mA to 12mA. Every exciting current is injected into meridian and around of models above respectively and we got arrayed voltages at the same cross section by multimeter.

4.2. Results
We realized dynamic imaging based on the established sensitivity matrix $J$ which is solved by TSVD method with norm method and the results are shown in Figure 6. Through the experiences, we can see that the research method that is injecting current vertically and measuring boundary voltages at a cross section can reflect the meridian characteristic of higher electrical conductivity, so it is feasible for EIT. Especially for gel-normal saline model, imaging consequent is fairly good; Normal saline-resistance wire cylinder model due to ions in solution is not good enough, however it can also reflect the characteristic of meridian to a certain extant.

![Figure 6](a) is original conductivity distribution of meridian model; (b) is reconstructed image in normal saline-resistance wire cylinder model; (c) is the image in gel-normal saline model.

5. Conclusion
This paper proposes EIT of meridian on a basis of low flow resistance and other biophysical properties and it proves feasible through experiences. Because of complexity of human meridian, we did not experimented on human. Still it needs further study, for example, to improve physical model of meridian and reconstruction algorithm.

References