The Substrate and Properties of Meridians: a Review of Modern Research

Haifeng Wei, Lawrence Chung-Long Huang, Jian Kong

Summary
Meridians are regarded as the base upon which traditional acupuncture theory is built but, although much research time has been spent on their investigation, no coherent scientific theory has emerged to explain their structure or mode of action. There have been several hypotheses that offer sufficient evidence for a partial explanation for certain meridians. This paper suggests that there is indeed no single answer, but that the various hypotheses should be combined, accepting that different explanations are likely for different meridians or parts of the body.

The most useful tool for investigation seems to be the phenomenon of propagated sensation along meridians. Experiments indicate that physical transmission occurs most generally through the interstitial space, specifically along the neuro-vascular bundles, rather than through vascular channels. The mechanism of meridian activity is likely to be via neuro-transmitters, found particularly along meridian lines, and by ionic movement.

This review of research literature, much of which has emanated from China, concludes that there is a real structural basis for the meridians, but that this structure is the orderly arrangement of normal tissues along the line of meridians rather than any special histological feature.

Key words
Acupuncture, Meridians, Propagated sensation along meridians.

Introduction
Although the beneficial effects of acupuncture have become well known today, how it works remains a mystery. The meridian system is the base upon which traditional acupuncture theory is built (Figure 1), and modern researchers have studied this in different ways over the last fifty years. Some evidence on the substrate and properties of meridians has been assembled, however there has been a tendency to believe that only one hypothesis will provide the final answer. So each group of researchers has looked on its own findings as the
essence of the meridian system. In this way, different hypotheses on the substrate of meridians have been established and the arguments have continued. Because of the lack of progress in identifying the structure of meridians, some authors have even challenged the whole concept (1). To resolve the problem, a comprehensive review of modern research papers on meridians is needed.

The traditional interpretation of a meridian as given in the classical book of traditional Chinese medicine, the Neijing, was a “pathway for the circulation of Qi and blood”. Is the pathway representing an actual pipeline? Earlier anatomical research has denied the existence of any hollow pipeline along meridians. So from the layers of somatic tissue along the meridians and the central nervous system (CNS) modern researchers have explored the substrate of meridians according to the broader possibilities of pathway.

**Structural relationships with meridians**

**Skin**

Some skin disorders tend to occur along the line of a meridian, showing a relationship between skin and meridians (2). By means of measurement using electron and light microscopy it was found that the total numerical density, the mean tangent diameter and the mean square of cuticular cell gap junctions on the cuticle structure of the rat's thoracic-abdominal segment of the stomach meridian were markedly higher than the surrounding areas (3). Along the meridians, stroma and hair follicles full of periodic acid-schiff (PAS) positive proteoglycan mass were found to be thicker and longer than the normal follicle. Also autoradiography showed that a great number of receptors were distributed around the sheaths and nipples of follicles along the meridians (4).

**Peripheral nerves**

Although the meridians do not always run along the lines of peripheral nerves, the acupoints do have a close neurological relationship. In a morphological study, 323 out of 324 acupoints were found to be involved with branches of either spinal or cranial nerves. The nerves innervating acupoints over chest and abdomen arise from the same nerve roots as those supplying the traditionally corresponding viscera; in the limbs, the routes of meridians are directly related to major nerves (5). After a transverse-section study of 295 acupoints in 8 bodies, the autonomic nerves around the peripheral vessels were found to have a close relationship to the main acupoints (6). In rat experiments, Zhang (7) demonstrated a neural connection between the anatomical bladder and the meridian named after it. This was shown by cutting the ventral nerve roots below the level of L2 and applying an electric stimulus to the distal part of the left nervi vesicles: a discharge on the level of non-modulated fibre could be recorded in ipsilateral sural nerve fibres along the Bladder meridian. Further experiments showed this transmission to be a long-axon reflex from the dorsal root ganglion through peripheral axon branches to finally reach the sural nerve.

**Blood vessels**

Blood vessels often accompany the nerve trunks and thus also have a similar relationship with the meridians in limbs. Propagated sensation along a meridian (PSM) is a phenomenon reported by sensitive subjects in which a brief, electric or tingling sensation is felt travelling from a stimulated needle along the line of a meridian. In 30 subjects this phenomenon was induced a total of 360 times, following which the clarity, the number and colour of skin capillary loops, and the skin temperature along the propagating meridians were all shown to have improved significantly (8). The amplitude of microvascular vasomotion on the thumb at Shaoshang (LU.11) observed by laser Doppler flowmetry increased more than 60% after needling at the elbow to Chizhe (LU.5) (9).

**Lymphatic vessels**

Lymphangiography showed that the distribution of superficial lymphatic vessels in the human lower leg was consistent with routes taken by PSM. The red, inflamed line seen on the skin in acute lymphangitis occurs particularly along certain meridians. Moreover, comparison between the surface anatomy of lymphatic vessels and meridians demonstrated a marked similarity (10).

**Skeletal muscle**

The twelve Jingjin form a part of the meridian system that controls movement and is consistent with the position of edges or tendons of skeletal muscle lying superficially (11). Activity in skeletal muscle is often detected by means of myoelectric recording. When PSM was evoked in 19 subjects who had been pressed or needled at specific acupoints, myoelectricity along the corresponding meridians was recorded in 12 of them, while no myoelectric discharge was recorded in the other 7 subjects. When it occurred, the process of myoelectric discharge accorded with that of the PSM (12). Also, whether PSM was evoked or not, four kinds of myoelectricity were recorded at other sites on the same meridians after acupoint needling.
These could also be recorded in the subjects while they were performing Qigong (13). In studying the sites, the discharge characteristics of myoelectricity at acupoints, and their susceptibility to temperature, Yan (14) concluded that this form of myoelectric discharge was caused by contraction of intrafusal fibres.

**Interstitial space**

In the limbs, anatomical studies have found that the traditional meridians run along the spaces in-between individual skeletal muscles and the covering skin (15). Also, in human and Chinese mini-pig experiments, the fluid pressure in the tissue spaces under the skin along the line of meridians was significantly lower than in the surrounding areas. This lower pressure was thought to result from low-resistance fluid-flow channels in the interstitial space along meridians (16). The migration of radioactive tracer Technetium 99m (99mTc), injected as sodium pertechnetate in acupoints, was shown to follow a course corresponding to that of traditional meridians. The migration patterns do not fit that of vascular or lymphatic vessels, but rather seem to correspond with a preferential transmission within connective tissue in association with vascular-nervous bundles (17).

**Central nervous system**

Electrophysiological experiments in the cat showed that the a motor neurons supplying muscles containing acupoints of the Stomach meridian could be activated by afferent excitement from muscles on the same meridian and even by peripheral afferent stimuli from cutaneous nerves of the skin over muscles of the same meridian. However, little excitation could be evoked by stimuli from muscular or cutaneous nerve branches supplying tissues related to other meridians. Also, the dendrites of motor neurons innervating the same muscle or muscles along the same meridian showed the same characteristic of anatomical projection to each other, and their neuron groups in the ventral horn of the spinal cord were arranged together in a columnar structure (18). Moreover, in the rat, lumbar segmental motor neurons innervating gluteal and other superficial muscles along the Bladder meridian were seen to form a wider dendrite field than neurons supplying non meridian-related muscles (19). With the non-invasive, blood oxygenation level dependent (BOLD) technique of fMRI, effects were observed in many parts of the brain during acupuncture in Hegu (LI.4) and Zusanli (ST.36). In the primary somatosensory cortex, it was found that acupuncture at Hegu had activated regions representing both the hand and the face in all three subjects studied; in one of them, activation in the facial region was even greater than that of the hand (20).

**The mechanism of meridian activity**

**Propagated sensation**

The main focus of scientific research into meridian activity has been the phenomenon of PSM (21,22). When normal human subjects were stimulated on the terminal points of the twelve main meridians (the jing points) with a low frequency electric pulse, PSM was reported in 12 to 24%, but this could be improved to 50% by the use of acupuncture and moxibustion at these points (23). In 23 subjects with congenital absence of one or more limbs, plus one amputee, acupuncture stimulation induced a phantom conduction sensation along the meridian through the absent limbs (24). The incidence of PSM was shown to be susceptible to the surrounding temperature, the physical and psychological condition of the subject and genetic factors (23).

PSM transmission can be blocked by pressing the skin along or close to the meridian; the rate of block in 120 sensitive subjects was reported to be 77.5% for pressure on the line of the meridian, and 3.3% if merely close by. Also, PSM can be blocked completely by placing ice bags or injecting physiological saline along the meridian, and it can be partially blocked by scrubbing the skin under which the PSM is passing (25).

**Neuro-transmitters and nerve endings**

A variety of neuro-transmitters has been detected along meridians and significant quantities of cholinesterase are to be found at the acupoints where adrenergic and cholinergic nerve endings are located (26). When injected into tissues along meridians, acetylcholine appeared to be more effective than adrenaline or adenosine triphosphate (ATP) in evoking PSM (27). Micro-injection of atropine, phentolamine or isoproterenol along a meridian could inhibit the acupuncture effect of raising the pain threshold to heat radiation in the rabbit (28), but injecting physiological saline did not inhibit it. Using high pressure liquid chromatography it was found that needling of acupoints led to the release of catecholamines such as noradrenaline and adrenaline from skin tissues along the meridian, and autoradiography demonstrated that catecholamines were grouped in linear columns along the meridian (29). Substance P-releasing fibres and many pleomorphic mast cells have been found in the skin of mice along the routes of six meridians tested (30). Peptidergic nerves and
the nerve endings of substance P-releasing fibres, neuropeptides and vasoactive peptides were also detected along the Stomach meridian in amputated human legs, and in the legs of mice (31). These results suggest that distal neural transmission along a meridian might be related to the activity of that meridian.

**Inorganic ions**

Ionic calcium (Ca$^{2+}$) activity at acupoints in rabbits was found to be higher than in either non-acupoint parts of a meridian or at points outside meridians; also the concentration of Ca$^{2+}$ along the meridians was found to change following acupuncture. When there is pathology of a visceral organ, the Ca$^{2+}$ concentration at acupoints in the corresponding meridian is increased in relation to the severity of the disorder (32). Triphthasine, a Ca$^{2+}$ antagonist, blocked or abolished the increased gastric motility in mice normally noted with acupuncture following an injection of anisodamine (33). Using a pH sensor for needling, the recorded pH at acupoints was found to be markedly lower than prior to the needling (34). When the isotopes $^{24}$Na, $^{47}$Ca and $^{201}$Tl were injected into acupoints of the Stomach meridian, only $^{24}$Na was found to move freely along the meridian (35).

**Properties of meridians**

**Sound conductivity**

The conductivity of sound through limbs was examined before and after surgery in patients requiring amputation. When a tap was given at one point on the Large intestine meridian, a specific note could be heard with a stethoscope at sites along the same meridian, and this note was different from that heard at non-meridian sites. The note was still reproducible after amputation unless the deep fascia was removed (36). Using a sound reflection technique, 10,614 human recordings and 354 in rabbits demonstrated that sound conduction along meridians had better fidelity of transmission compared with the surrounding tissues. The frequency range of best transmission was from 20 to 40Hz and its conduction velocity (4 to 10m/s) along meridians was slower than that of sound conduction in surrounding tissue (37). With quantum biology, a model of soliton excitation in collagen molecules could reasonably explain many features of PSM (38).

**Gaseous exchange**

The oxygen (O$_2$) pressure of deep tissue at acupoints was found to be higher than in non-acupoint sections of the meridians and at non-meridian points (39). The tissue carbon dioxide (CO$_2$) output at acupoints was shown to be significantly higher than at non-acupoint parts of the meridians, and it was significantly higher along the meridians than in non-meridian tissues. After acupuncture into an acupoint, the enhancement of CO$_2$ output in proximal parts of the same meridian was markedly greater than outside the meridian (40). Oxygen utilisation and CO$_2$ production are a measure of local metabolism, so these findings suggest higher metabolic activity at acupoints.

**Bio-electricity**

In 35 out of 50 subjects, the electric potential measured at the surface of acupoints was significantly different from nearby areas (41) and in all the upper limb meridians except the Pericardium, surface electric potentials were larger than at nearby non-meridian points (42). Using an electric micro-transducer system in 112 healthy subjects, the static charge along the Stomach meridian and in the Hé (sea) points of all the meridians was negative. In 454 patients with gastric disorders, this negative electric charge was lower than in healthy people (43).

**Discussion**

PSM appears to be a genuine meridian-based phenomenon, depending for its perception on the cerebral cortex. The occurrence of phantom PSM and PSM without myoelectric discharge (12,24) show that it does not necessary rely on the activity of peripheral structures. It may, however, be caused by activity of neural connections, either central or peripheral. On the other hand, many acupuncture treatments are not accompanied by PSM, which suggests that some acupuncture effects, though achieved via meridian activation, do not depend on central neural activity concerning PSM. Thus, the location of meridians can be regarded as being within the CNS and peripheral structures, and they can act independently in these structures on certain occasions.

The distributions of superficial skeletal muscle and of myoelectric discharge during PSM are consistent with the traditional meridians (11). Moreover, good mechanical conductivity of sound within the tissues along meridians (37) indicates that PSM might result from the high vibration of movement. Spaces among the deep tissues along meridians give enough room for the orderly development of nerves and blood and lymphatic vessels, so tissues along the line of meridians get good nourishment and support due to the concentration of nerves, vessels and active substances along the meridians (5,8,26), and the metabolic activity of tissues and gaseous exchange
at the skin along meridians is also enhanced compared to non-meridian areas (39,40). Skin cells along meridians form more gap junctions (3), adjusting to the requirement of high-tension movement. The myoelectric discharge induced by the contractions of skeletal muscle may contribute to the electrical character of the body surface along meridians (41,42). In this way, the peripheral properties of meridians may be produced by motor activity.

Neural projections of the CNS are responsible for the functioning of the corresponding peripheral tissues and the somatosensory representation on the cerebral cortex can even be rearranged by events after maturity (44,45). Therefore, after a long period, the motor action might have induced changes not only in peripheral structures, but also in somatosensory or motor regions at different levels of the CNS.

There has been plenty of research on the structural substrate of meridians, but less on how exactly meridian conduction occurs in the CNS and peripheral structures and how meridian activity is related to acupuncture effectiveness. Future research would be wanted to focus on these problems.

Conclusion
From this review, we conclude that there really are structural features along the route of the traditional meridian. But by this we mean an orderly arrangement of normal tissues along the meridians rather than any special histological structure. In the tissue space of peripheral regions the nerves, blood and lymphatic vessels and neural transmitters are concentrated along the meridians; structures in the CNS were also found to be related to meridians. Thus it seems that the meridians are not limited to one kind of tissue or structure but are distributed around the body in different forms according to the locality.

References
9. Haifeng Wei MD MS
Second Department of Internal Medicine
Guang An Men Hospital
China Academy of Traditional Chinese Medicine
Beijing, 100053, PR China

Lawrence Chung-Long Huang
Jian Kong
National Meridian Research Center
Institute of Acupuncture and Moxibustion
China Academy of Traditional Chinese Medicine
Beijing, 100700, PR China

Address for correspondence
Haifeng Wei MD MS
Second Department of Internal Medicine
Guang An Men Hospital
China Academy of Traditional Chinese Medicine
No 5. Beixiangle Street, Xuanwu District
Beijing, 100053, PR China
Email: hfwei@public3.bta.net.cn

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