

Relationship of Acupuncture Points and Meridians to Connective Tissue Planes

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Acupuncture meridians traditionally are believed to constitute channels connecting the surface of the body to internal organs. We hypothesize that the network of acupuncture points and meridians can be viewed as a representation of the network formed by interstitial connective tissue. This hypothesis is supported by ultrasound images showing connective tissue cleavage planes at acupuncture points in normal human subjects. To test this hypothesis, we mapped acupuncture points in serial gross anatomical sections through the human arm. We found an 80% correspondence between the sites of acupuncture points and the location of intermuscular or intramuscular connective tissue planes in postmortem tissue sections. We propose that the anatomical relationship of acupuncture points and meridians to connective tissue planes is relevant to acupuncture's mechanism of action and suggests a potentially important integrative role for interstitial connective tissue. *Anat Rec (New Anat)* 269:257–265, 2002.

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KEY WORDS: acupuncture; meridians; connective tissue; anatomy; fascia; signal transduction

INTRODUCTION

During acupuncture treatments, fine needles traditionally are inserted at specific locations of the body known as acupuncture points. According to classic Chinese theory, acupuncture points are linked together in a network of “meridians” running longitudinally along the surface of the body (Figure 1). Despite considerable efforts to understand the anatomy and physiology of acupuncture points and meridians, the definition and characterization of these structures remains elusive (NIH Consensus Statement, 1997). The goal of this article is to

present evidence supporting a conceptual model linking traditional Chinese acupuncture theory with conventional anatomy. We hypothesize that the network of acupuncture points and meridians can be viewed as a representation of the network formed by

through which flows “meridian qi” (Kaptchuk, 2000). Although the concept of meridian qi has no known physiological equivalent, terms used in acupuncture texts to describe the more general term “qi” evoke dynamic processes such as communication, movement, or energy exchange (O'Connor and Bensky, 1981). Disruption of the meridian channel network is believed to be associated with disease, and needling of acupuncture points is thought to be a way to access and influence this system (Cheng, 1987).

Charts representing acupuncture points and meridians date as far back as 300 B.C. (Veith, 1949). Modern acupuncture charts indicate 12 principal meridians “connecting” the limbs to the trunk and head. In addition, many other “accessory” meridians are also described, as well as deep “internal branches” starting at specific points on the principal meridians and reaching internal organs. The names of the principal meridians (e.g., lung, heart) represent physiological functions thought to be specifically related to each meridian, rather than the actual lung or heart organ itself. One meridian named Triple Heater is thought to be related to temperature

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interstitial connective tissue and that this relationship is relevant to acupuncture's therapeutic mechanism.

TRADITIONAL CONCEPTS

Acupuncture meridians are traditionally thought to represent “channels”

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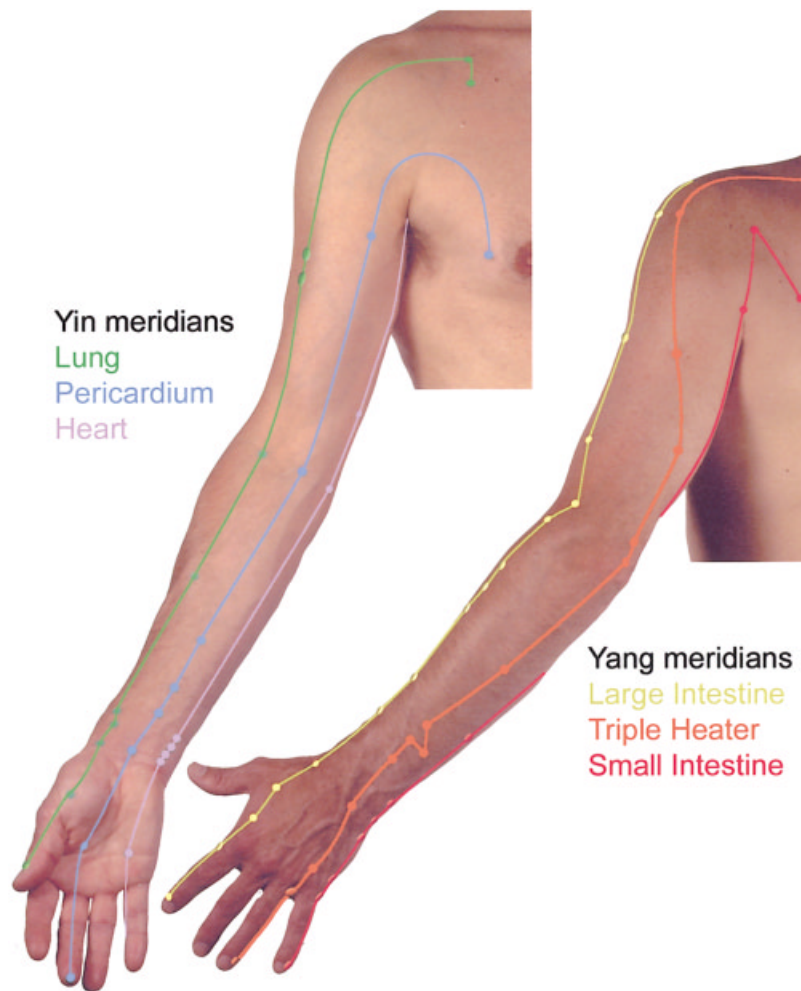


Figure 1. Acupuncture meridians of the arm. Acupuncture points were located by palpation in a living subject, according to anatomical guidelines provided in a major reference acupuncture textbook (Cheng, 1987). Connective tissue planes associated with Yin meridians are more inward and deep, compared with the generally outward and superficial planes associated with Yang meridians.

balance between different parts of the body. Acupuncture points are mostly located along the meridians, although “extra” points outside the meridian system are also believed to exist. Although acupuncture texts and atlases generally agree on the location of the principal meridians, considerable variability exists as to the number and location of internal branches and extra points.

The Chinese character signifying acupuncture point also means “hole” (O’Connor and Bensky, 1981), conveying the impression that acupuncture points are locations where the needle can gain access to some deeper tissue components. Modern acupuncture textbooks contain visual charts as well as written guidelines for locating each acupuncture point. These guidelines refer to anatomical landmarks (such

as bony prominences, muscles, or tendons) as well as proportional measurements (e.g., fraction of distance between elbow and wrist) (Cheng, 1987). During acupuncture treatments, acupuncturists use these landmarks and measurements to determine the location of each point within approximately 5 mm. Precise point location within this range is achieved by palpation, during which the acupuncturist searches for a slight depression or yielding of the tissues to light pressure.

ARE ACUPUNCTURE POINTS DIFFERENT FROM SURROUNDING TISSUE?

Over the past 30 years, studies aimed at understanding the acupuncture point/meridian system from a “Western” per-

spective mainly have searched for distinct histological features that might differentiate acupuncture points from surrounding tissue. Several structures, such as neurovascular bundles (Rabichong et al., 1975; Senelar, 1979; Bossy, 1984), neuromuscular attachments (Liu et al., 1975; Gunn et al., 1976; Dung, 1984), and various types of sensory nerve endings (Shanghai Medical University, 1973; Ciczek et al., 1985), have been described at acupuncture points. However, none of these studies included statistical analyses comparing acupuncture points with appropriate “nonacupuncture” control points.

Other studies have turned their attention to possible physiological differences between acupuncture points and surrounding tissues. Skin conductance has been reported by several investigators to be greater at acupuncture points compared with control points (Reishmanis et al., 1975; Comunetti et al., 1995). Several factors, on the other hand, are known to affect skin conductance (e.g., pressure, moisture, skin abrasion; Noordegraaf and Silage, 1973; McCarroll and Rowley, 1979), and to date, no study has both controlled for these factors and included sufficient numbers of observations to confirm these findings. Attempts to identify anatomical and/or physiological characteristics of acupuncture points, therefore, have remained mostly inconclusive.

Ancient acupuncture texts contain several references to “fat, greasy membranes, fasciae and systems of connecting membranes” through which qi is believed to flow (Matsumoto and Birch, 1988), and several authors have suggested that a correspondence may exist between acupuncture meridians and connective tissue (Matsumoto and Birch, 1988; Oschman, 1993; Ho and Knight, 1998). Recent work done in our laboratory has begun to provide experimental evidence in support of this hypothesis. We have characterized a connective tissue response to acupuncture needling that is quantitatively different at acupuncture points compared with control points (Langevin et al., 2001b) and that may constitute an important clue to the nature of acupuncture points and meridians.

BIOMECHANICAL RESPONSE TO NEEDLING: "NEEDLE GRASP"

An important aspect of traditional acupuncture treatments is that acupuncture needles are manually manipulated after their insertion into the body. Needle manipulation typically consists of rapid rotation (back-and-forth or one direction) and/or pistoning (up-and-down motion) of the needle (O'Connor and Bensky, 1981). During needle insertion and manipulation, acupuncturists aim to elicit a characteristic reaction to acupuncture needling known as "de qi" or "obtaining qi." During de qi, the patient feels an aching sensation in the area surrounding the needle. Simultaneously with this sensation, the acupuncturist feels a "tug" on the needle, described in ancient Chinese texts as "like a fish biting on a fishing line" (Yang, 1601). We refer to this biomechanical phenomenon as "needle grasp."

According to traditional teaching, de qi is essential to acupuncture's therapeutic effect (O'Connor and Bensky, 1981). One of the most fundamental principles underlying acupuncture is that acupuncture needling is thought to be a way to access and influence the meridian network. The characteristic de qi reaction, perceived by the patient as a needling sensation and by the acupuncturist as needle grasp, is thought to be an indication that this goal has been achieved (Cheng, 1987). The biomechanical phenomenon of needle grasp, therefore, is at the very core of acupuncture's theoretical construct.

Needle grasp is enhanced clinically by manipulation (rotation, pistoning) of the acupuncture needle. In previous human and animal studies using a computerized acupuncture-needling instrument (Langevin et al., 2001b, 2002), we have quantified needle grasp by measuring the force necessary to pull the acupuncture needle out of the skin (pullout force). We have shown that pullout force is indeed markedly enhanced by rotation of the needle. Needle grasp, therefore, is a measurable tissue phenomenon associated with acupuncture needle manipulation. In a quantitative study of needle grasp in 60 healthy human subjects (Langevin et al., 2001b), we measured pullout force at eight differ-

ent acupuncture point locations, compared with corresponding control points located on the opposite side of the body, 2 cm away from each acupuncture point. We found that pullout force was on average 18% greater at acupuncture points than at corresponding control points. We also found that needle manipulation increased pullout force at control points as well as at acupuncture points. Needle grasp, therefore, is not unique to acupuncture points, but rather is enhanced at those points.

ROLE OF CONNECTIVE TISSUE IN NEEDLE GRASP

Although previously attributed to a contraction of skeletal muscle, we have shown that needle grasp is not due to a muscle contraction but rather involves connective tissue (Langevin et al., 2001a, 2002). In both in vivo and

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in vitro experiments, we have found that, during acupuncture needle rotation, connective tissue winds around the acupuncture needle, creating a tight mechanical coupling between needle and tissue. This needle-tissue coupling allows further movements of the needle (either rotation or pistoning) to pull and deform the connective tissue surrounding the needle, delivering a mechanical signal into the tissue.

Observation under a microscope of an acupuncture needle inserted into dissected rat subcutaneous tissue reveals that a visible "whorl" of tissue can be produced with as little as one turn of the needle (Figure 2A). When the needle is placed flat onto the subcutaneous tissue surface and then rotated, the tissue tends to adhere to and follow the rotating needle for 180 degrees, at which point the tissue adheres to itself and further rotation results in formation of a whorl. This

phenomenon can be observed to varying degrees with acupuncture needles of different materials (stainless steel, gold) as well as with other objects not customarily used as acupuncture tools such as regular hypodermic needles, glass micropipettes, siliconized glass, and Teflon-coated needles. An important factor appears to be the diameter of the rotating needle. Acupuncture needles are very fine (250–500 μm diameter). With needles greater than 1 mm in diameter, the tissue invariably follows the rotating needle for less than 90 degrees and then falls back, failing to stick to itself and initiate winding. Initial attractive forces between the rotating needle and tissue, thus, may be important to initiate the winding phenomenon. These may include surface tension and electrical forces and may be influenced by the material properties of the needle.

When we compared two equal diameter acupuncture needles, one reusable needle made of gold (ITO, Japan) and one disposable made of stainless steel (Seirin, Japan), the gold needle appeared to initiate winding more readily than the stainless steel one. Scanning electron microscopy images of the two needles (Figure 2B–D) showed that the gold needle had a rougher surface, which may have more successfully "engaged" the tissue during the initiation of winding. These observations also suggest that mechanical coupling between needle and tissue can occur even when the amplitude of needle rotation is very small (less than 360 degrees) as commonly used in clinical practice. We have also shown that, with back-and-forth needle rotation, which is generally preferred clinically over rotation in one direction, winding alternates with unwinding, but unwinding is incomplete, resulting in a gradual buildup of torque at the needle-tissue interface (Langevin et al., 2001b).

The importance of establishing a mechanical coupling between needle and tissue is that mechanical signals (1) are increasingly recognized as important mediators of information at the cellular level (Giancotti and Ruoslahti, 1999), (2) can be transduced into bioelectrical and/or biochemical signals (Banes et al., 1995; Lai et al., 2000), and (3) can lead to downstream

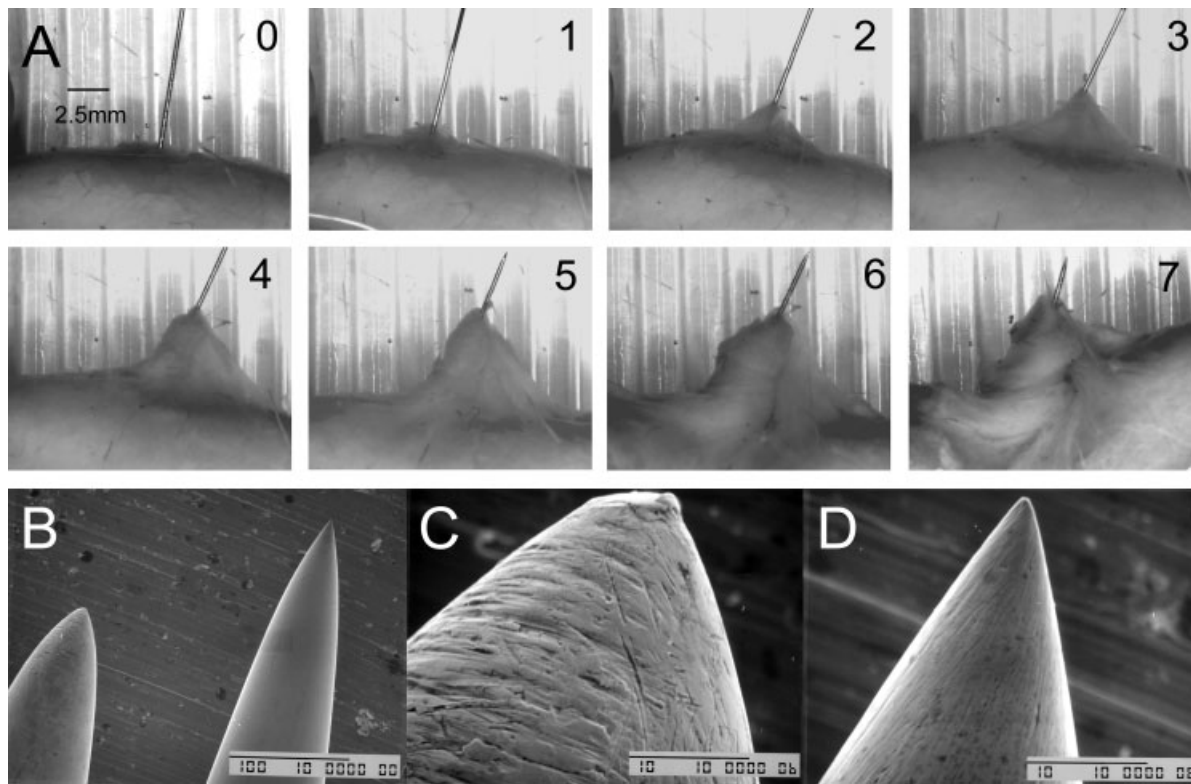


Figure 2. **A:** Formation of a connective tissue “whorl” with needle rotation. Rat subcutaneous connective tissue was dissected and placed in physiological buffer under a dissecting microscope. An acupuncture needle was inserted through the tissue and progressively rotated. Numbers 0 through 7 indicate numbers of needle revolutions. A visible whorl of connective tissue can be seen with as little as one revolution of the needle. **B:** Scanning electron microscopy imaging of reusable gold (left) and disposable stainless steel (right) acupuncture needles. Original magnification, 350 \times . **C,D:** Scanning electron microscopy of gold (C) and stainless steel (D) needles. Original magnification, 3,500 \times . The surface of the gold needle is visibly rougher than that made of stainless steel. Scale bars = 2.5 mm in A, 100 μ m in B, 10 μ m in C,D.

effects, including cellular actin polymerization, signaling pathway activation, changes in gene expression, protein synthesis, and extracellular matrix modification (Chicurel et al., 1998; Chiquet, 1999). Changes in extracellular matrix composition, in turn, can modulate the transduction of future mechanical signals to and within cells (Brand, 1997). Recent evidence suggests that both tissue stiffness and stress-induced electrical potentials are affected by connective tissue matrix composition (Bonassar et al., 1996) and that changes in matrix composition in response to mechanical stress may be an important form of communication between different cell types (Swartz et al., 2001). Acupuncture needle manipulation, thus, may cause lasting modification of the extracellular matrix surrounding the needle, which may in turn influence the various cell populations sharing this connective tissue matrix (e.g., fibroblasts, sensory afferents, immune and vascular cells).

In addition, we have hypothesized previously that, in the vicinity of the needle, acupuncture-induced actin polymerization in connective tissue fibroblasts may cause these fibroblasts to contract, causing further pulling of collagen fibers and a “wave” of connective tissue contraction and cell activation spreading through connective tissue (Langevin et al., 2001a). This mechanism may explain the phenomenon of “propagated sensation,” i.e., the slow spreading of de qi sensation sometimes reported by patients along the course of an acupuncture meridian (Huan and Rose, 2001).

CORRESPONDENCE OF ACUPUNCTURE POINTS AND MERIDIANS TO CONNECTIVE TISSUE PLANES

Acupuncture meridians tend to be located along fascial planes between muscles, or between a muscle and bone or tendon (Cheng, 1987). A needle inserted at the site of a connective

tissue cleavage plane will penetrate first through dermis and subcutaneous tissue, then through deeper interstitial connective tissue. In contrast, a needle inserted away from a connective tissue plane will penetrate dermis and subcutaneous tissue, then reach a structure such as muscle or bone. Because needle grasp involves interaction of the needle with connective tissue (Langevin et al., 2002), the enhanced needle grasp response at acupuncture points may be due to the needle coming into contact with more connective tissue (subcutaneous plus deeper fascia) at those points. The presence of needle grasp at control points as well as at acupuncture points is consistent with some amount of connective tissue (subcutaneous) being present at all points. This concept is illustrated in Figure 3, which shows ultrasound images of the same acupuncture point and corresponding control point in two normal human subjects. The acupuncture point is located on the skin overlying

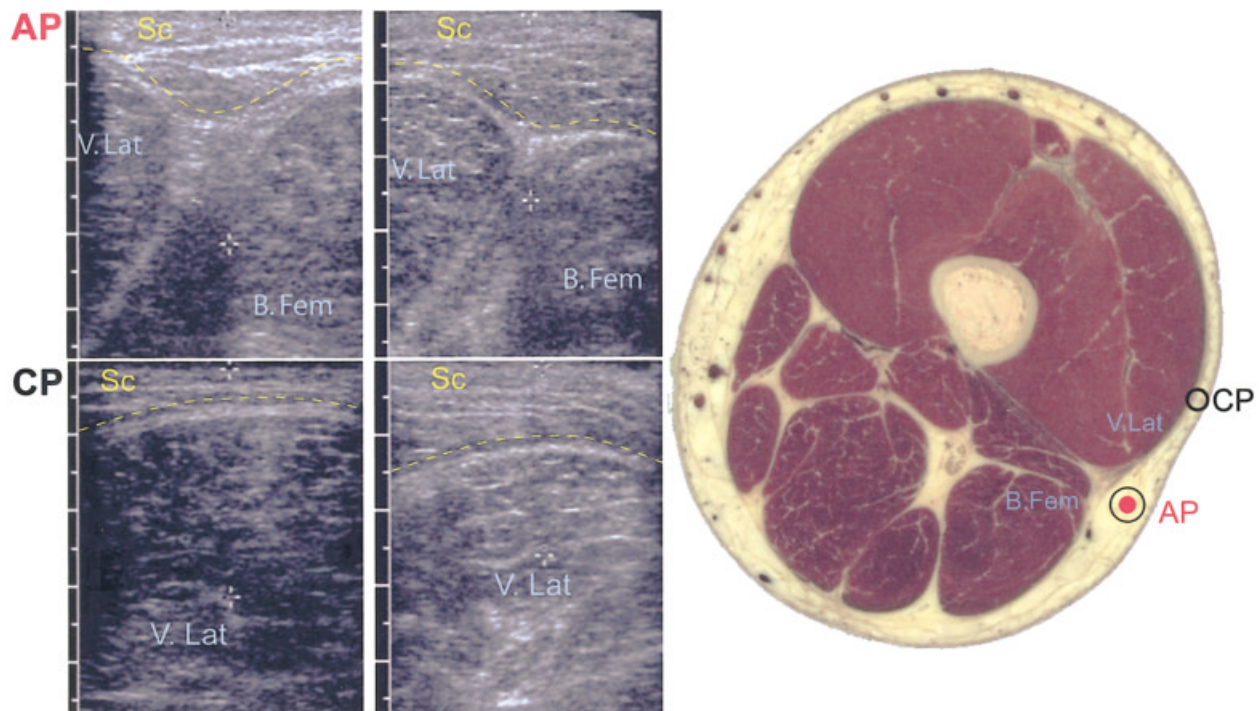


Figure 3. Ultrasound imaging of acupuncture (AP) and control (CP) points. Acupuncture point GB32 was located by palpation in two normal human volunteers, as well as a control point located 3 cm away from the acupuncture point. After marking both points with a skin marker, ultrasound imaging was performed with an Acuson ultrasound machine equipped with a 7 MHz linear probe. A visible connective tissue intramuscular cleavage plane can be seen at acupuncture points but not at control points. V. Lat, vastus lateralis; B. Fem, biceps femoris; Sc, subcutaneous tissue.

the fascial plane separating the vastus lateralis and biceps femoris muscles. The control point, located 3 cm away from the acupuncture point, is located over the belly of the vastus lateralis muscle.

To investigate the hypothesis that acupuncture points are preferentially located over fascial planes, we marked the location of all acupuncture points and meridians in a series of gross anatomical sections through the human arm (Research Systems Visible Human CD, Boulder, CO) (Figure 4). The interval between sections corresponded to one “cun” or anatomical inch (a proportional unit measurement used in acupuncture textbooks to locate acupuncture points) representing 1/9 of the distance between the elbow crease and the axially fold (in this case 2.5 cm). This section interval allowed us to include all acupuncture points located on the six principal meridians of the arm between the olecranon (Figure 4, section 0) and the superior edge of the humeral head (Figure 4, section 12). In each section, we marked all acupuncture points and the intersection of all

meridians with the plane of section (meridian intersection).

Acupuncture points and meridian intersections were located according to written guidelines (based on anatomical landmarks and proportional measurements) and acupuncture charts provided in a major textbook of traditional Chinese acupuncture (Cheng, 1987). Because connective tissue planes were visible on the anatomical sections, every attempt was made to minimize bias by adhering to these guidelines as objectively as possible. In a live subject, palpation is used to locate acupuncture points precisely once the approximate location has been determined by using anatomical landmarks and proportional measurements. For some points, body parts are manipulated and positioned in a specific way to perform this palpation. In the case of our postmortem sections, the points needed to be located in the anatomical position without the benefit of palpation. When written descriptions referred to anatomical landmarks palpable in the anatomical position (such as the olecranon or biceps tendon), we used the position of the bones, tendons, and muscles in the

cross-sections to determine where these landmarks would have been palpable on the surface of the body. For those points where palpation is traditionally performed in a position other than the anatomical position, we guided ourselves on (1) charts from acupuncture textbooks drawn in the anatomical position, and (2) a live human model on which we located acupuncture points by palpating them in the position specified in the textbook, and then placed the model's arm in the anatomical position (Figure 1). Textbook guidelines referring to proportional measurements (such as a fraction of the distance between the elbow crease and axially fold) are traditionally defined in the anatomical position. We, therefore, were able to apply these measurements directly to the postmortem tissue sections by determining appropriate section numbers based on the section interval, and making measurements on individual cross-sections.

By using these guidelines, we marked three acupuncture points on the heart meridian (H3, H2, H1), two points on the pericardium meridian (P3, P2), five points on the lung me-

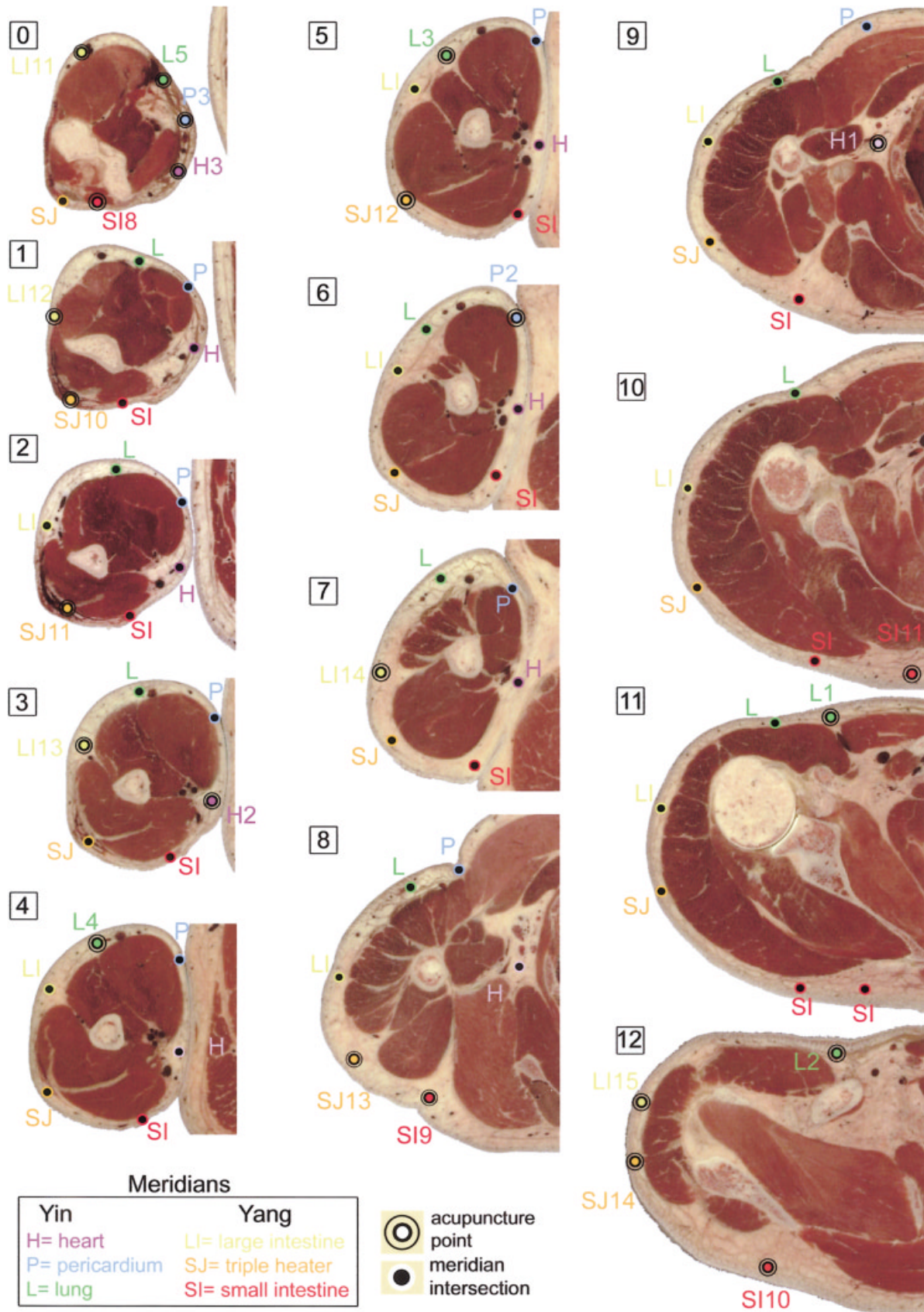


Figure 4. Location of acupuncture points and meridians in serial gross anatomical sections through a human arm. The interval between sections corresponds to one "cun" or anatomical inch representing 1/9 of the distance between the elbow crease and the axillary fold (in this case, 2.5 cm). Sections begin at the olecranon (0) and end at the superior edge of the humeral head (12). Acupuncture points, meridian intersections, and specific meridians are labeled according to the legend.

ridian (L5, L4, L3, L2, L1), five points on the large intestine meridian (LI11, LI12, LI13, LI14), five points on the triple heater meridian (SJ10, SJ11, SJ12, SJ13, SJ14), and four points on the small intestine meridian (SI8, SI9, SI10, SI11) for a total of 24 acupuncture points. Meridians intersected with the plane of section at 51 other sites that were not acupuncture points.

As shown in Figure 4, three of six meridians included portions that followed fascial planes between muscles (biceps/triceps [heart meridian, Figure 4, sections 2–7], biceps/brachialis [lung meridian, Figure 4, sections 4–5], and brachialis/triceps [large intestine meridian, Figure 4, sections 3–5]). Some points on those meridians (H2, LI14, H1) also appeared to be located at the intersection of two or more fascial planes. Two other meridians included portions that followed intramuscular cleavage planes [between heads of biceps (pericardium meridian, Figure 4, sections 5–7) and triceps (triple heater meridian, Figure 4, sections 2–6)]. One meridian (small intestine meridian) did not itself follow any recognizable inter- or intramuscular plane. However, three out of the four acupuncture points on this portion of the meridian (SI9, 10, and 11) clearly coincided with the intersection of multiple fascial planes. Overall, more than 80% of acupuncture points and 50% of meridian intersections of the arm appeared to coincide with intermuscular or intramuscular connective tissue planes.

To estimate the probability that such an event would be due to chance, we tested a model representing the middle portion of the arm (sections 2–7) approximated to a cylinder 12.5 cm long and 30 cm in circumference, and including eight acupuncture points and 28 meridian intersections. Assuming that the average width of the five major fascial planes of the arm (triceps/triceps, biceps/brachialis, brachialis/triceps, between heads of triceps, and between heads of biceps) is 1/60 of the circumference of the cylinder (or approximately 5 mm), 1/12 of the surface of the cylinder will intersect with a fascial plane. If we also assume that the “width” of an acupuncture point is 5 mm, the probability that a random point in any

given section of the cylinder will fall on a fascial plane is 1/12 or 0.083. Using the hypergeometric distribution (sampling without replacement), the probability that either six or seven of eight points (75 or 87%) randomly distributed in six sections through the cylinder would fall on fascial planes is $P < 0.001$. Likewise, taking 5 mm as the “width” of a meridian, the probability of 14 of 28 meridian intersections (50%) falling on fascial planes is also $P < 0.001$.

These findings suggest that the location of acupuncture points, determined empirically by the ancient Chinese, was based on palpation of discrete locations or “holes” where the needle can access greater amounts of

Because the structure and composition of interstitial connective tissue is responsive to mechanical stimuli, we propose that it plays a key role in the integration of several physiological functions with ambient levels of mechanical stress.

connective tissue. Some portions of meridians clearly follow one or more successive connective tissue planes, whereas others appear to simply “connect the dots” between points of interest. On the basis of these findings and our previous experimental results (Langevin et al., 2001b, 2002), we propose that acupuncture charts may serve as a guide to insert the needle into interstitial connective tissue planes where manipulation of the needle can result in a greater mechanical stimulus. A greater therapeutic effect at acupuncture points may be at least partly explained by more powerful mechanical signaling and downstream effects at those points.

We chose the arm for this study because it offers relatively simple anatomy and widely spaced fascial planes (compared with, for example, the

forearm) and also because the arm illustrates how both meridians and connective tissue planes “connect” the arm with the shoulder girdle and chest (see below). We, however, expect that similar results would be obtained in other body regions. In the forearm, leg, and thigh, meridians also appear to generally follow connective tissue planes separating muscles or within muscles. On the trunk, meridians close to the midline (kidney, stomach, spleen, and bladder) run longitudinally in the front and back, whereas more laterally placed meridians (liver, gall bladder) run obliquely, paralleling the orientation of main muscle groups and the connective tissue planes separating them. On the face, meridians criss-cross each other in an intricate pattern compatible with the complexity of facial muscular and connective tissue structures.

MERIDIAN/CONNECTIVE TISSUE NETWORK

Acupuncture meridians are believed to form a network throughout the body, connecting peripheral tissues to each other and to central viscera (Kaptchuk, 2000). Interstitial connective tissue also fits this description. Interstitial “loose” connective tissue (including subcutaneous tissue) constitutes a continuous network enveloping all limb muscles, bones, and tendons, extending into connective tissue planes of pelvic and shoulder girdles, abdominal and chest walls, neck, and head. This tissue network is also continuous with more specialized connective tissues such as periosteum, perimysium, perineurium, pleura, peritoneum, and meninges. A form of signaling (mechanical, bioelectrical, and/or biochemical) transmitted through interstitial connective tissue, therefore, may have potentially powerful integrative functions. Such integrative functions may be both spatial (“connecting” different parts of the body) as well as across physiological systems (connective tissue permeates all organs and surrounds all nerves, blood vessels, and lymphatics). In addition, because the structure and biochemical composition of interstitial connective tissue is responsive to mechanical

TABLE 1. Summary of proposed model of physiological effects seen in acupuncture

Traditional Chinese medicine concepts	Proposed anatomical/physiological equivalents
Acupuncture meridians	Connective tissue planes
Acupuncture points	Convergence of connective tissue planes
Qi	Sum of all body energetic phenomena (e.g. metabolism, movement, signaling, information exchange)
Meridian qi	Connective tissue biochemical/bioelectrical signaling
Blockage of qi	Altered connective tissue matrix composition leading to altered signal transduction
Needle grasp	Tissue winding and/or contraction of fibroblasts surrounding the needle
De qi sensation	Stimulation of connective tissue sensory mechanoreceptors
Propagated de qi sensation	Wave of connective tissue contraction and sensory mechanoreceptor stimulation along connective tissue planes
Restoration of flow of qi	Cellular activation/gene expression leading to restored connective tissue matrix composition and signal transduction

stimuli, we propose that connective tissue plays a key role in the integration of several physiological functions (e.g., sensorineural, circulatory, immune) with ambient levels of mechanical stress.

One of the salient features of acupuncture theory is that the needling of appropriately selected acupuncture points has effects remote from the site of needle insertion, and that these effects are mediated by means of the acupuncture meridian system (O'Connor and Bensky, 1981). To date, physiological models attempting to explain these remote effects have invoked systemic mechanisms involving the nervous system (Ulett et al., 1998; Pomeranz, 2001). A mechanism initially involving signal transduction through connective tissue, with secondary involvement of other systems including the nervous system, is potentially closer to traditional Chinese acupuncture theory, yet also compatible with previously proposed neurophysiological mechanisms.

CONCEPTUAL MODEL FOR ACUPUNCTURE POINTS AND MERIDIANS

Rather than viewing acupuncture points as discrete entities, we propose that acupuncture points may correspond to sites of convergence in a network of connective tissue permeating

the entire body, analogous to highway intersections in a network of primary and secondary roads. One of the most controversial issues in acupuncture research is whether the needling of acupuncture points has "specific" physiological and therapeutic effects compared with nonacupuncture points (NIH Consensus Statement, 1997). By using the road analogy, interaction of an acupuncture needle with connective tissue will occur even at the smallest connective tissue "secondary road." Needling a major "highway intersection," however, may have more powerful effects, perhaps due to collagen fiber alignment leading to more effective force transduction and signal propagation at those points.

In summary, the anatomical correspondence of acupuncture points and meridians to connective tissue planes in the arm suggests plausible physiological explanations for several important traditional Chinese medicine concepts summarized in Table 1. We propose that acupuncture needle manipulation produces cellular changes that propagate along connective tissue planes. These changes may occur no matter where the needle is placed but may be enhanced when the needle is placed at acupuncture points. This conceptual model would be further strengthened by an expanded investigation of the whole body, including lower extremity, trunk, and head. The

anatomy of acupuncture points and meridians, thus, may be an important factor that will begin to unravel the veil of mystery surrounding acupuncture.

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LITERATURE CITED

- Banes AJ, Tsuzaki M, Yamamoto J, et al. 1995. Mechanoreception at the cellular level: The detection, interpretation and diversity of responses to mechanical signals. *Biochem Cell Biol* 73:349–365.
- Bonassar LJ, Stinn JL, Paguio CG, et al. 1996. Activation and inhibition of endogenous matrix metalloproteinases in articular cartilage: Effects on composition and biophysical properties. *Arch Biochem Biophys* 333:359–367.
- Brand RA. 1997. What do tissues and cells know of mechanics? *Ann Med* 29:267–269.
- Bossy J. 1984. Morphological data concerning the acupuncture points and channel network. *Acupunct Electrother Res* 9:79–106.
- Cheng X. 1987. Chinese acupuncture and moxibustion. Beijing: Foreign Language Press.
- Chicurel ME, Chen CS, Ingber DE. 1998. Cellular control lies in the balance of forces. *Curr Opin Cell Biol* 10:232–239.
- Chiquet M. 1999. Regulation of extracellular matrix gene expression by mechanical stress. *Matrix Biol* 18:417–426.
- Ciczek LSW, Szopinski J, Skrzypulec V. 1985. Investigations of morphological structures of acupuncture points and meridians. *J Trad Chin Med* 5:289–292.
- Comunetti A, Laage S, Schiessl N, Kistler A. 1995. Characterization of human skin conductance at acupuncture points. *Experientia* 51:328–331.
- Dung HC. 1984. Anatomical features contributing to the formation of acupuncture points. *Am J Acupunct* 12:139–143.
- Giancotti FG, Ruoslahti E. 1999. Integrin signaling. *Science* 285:1028–1032.

- Gunn CC, Ditchburn FG, King MH, Renwick GJ. 1976. Acupuncture loci: A proposal for their classification according to their relationship to known neural structures. *Am J Chin Med* 4:183–195.
- Ho MW, Knight DP. 1998. The acupuncture system and the liquid crystalline collagen fibers of the connective tissues. *Am J Chin Med* 26:251–263.
- Huan ZY, Rose K. 2001. A brief history of Qi. Brookline, MA: Paradigm Publications.
- Kaptchuk TJ. 2000. The web that has no weaver. Understanding Chinese medicine. Chicago: Contemporary Publishing Group, Inc.
- Lai WM, Mow VC, Sun DD, Atesian GA. 2000. On the electric potentials inside a charged soft hydrated biological tissue: Streaming potential versus diffusion potential. *J Biomech Eng* 122:336–346.
- Langevin HM, Churchill DL, Cipolla MJ. 2001a. Mechanical signaling through connective tissue: A mechanism for the therapeutic effect of acupuncture. *FASEB J* 15:2275–2282.
- Langevin HM, Churchill DL, Fox JR, Badger GJ, Garra BS, Krag MH. 2001b. Biomechanical response to acupuncture needling in humans. *J Appl Physiol* 91:2471–2478.
- Langevin HM, Churchill DL, Wu J, Badger GJ, Yandow JA, Fox JR, Krag MH. 2002. Evidence of connective tissue involvement in acupuncture. *FASEB J* 16:872–874.
- Liu KY, Varela M, Oswald R. 1975. The correspondence between some motor points and acupuncture loci. *Am J Chin Med* 3:347–358.
- Matsumoto K, Birch S. 1988. Hara diagnosis: Reflections of the sea. Brookline: Paradigm Publications.
- McCarroll GD, Rowley BA. 1979. An investigation of the existence of electrically located acupuncture points. *IEEE Trans Biomed Eng* 26:177–182.
- Noordegraaf A, Silage D. 1973. Electroacupuncture. *IEEE Trans Biomed Eng* 20:364–366.
- NIH Consensus Statement. 1997. Acupuncture. Bethesda, MD: NIH. 15:1–34.
- O'Connor J, Bensky D. 1981. Acupuncture, a comprehensive text (Shanghai College of Traditional Medicine) Seattle: Eastland Press.
- Oschman JL. 1993. A biophysical basis for acupuncture. Proceedings of the First Symposium of the Committee for Acupuncture Research.
- Pomeranz B. 2001. Acupuncture analgesia-basis research. In: Stux G, Hamerschlag R, editors. Clinical acupuncture-scientific basis. Berlin: Springer-Verlag.
- Rabischong P, Niboyet JEH, Terral C, Senelar R, Casez R. 1975. Bases experimentales de l'analgésie acupunctureale. *Nouv Presse Med* 4:2021–2026.
- Reishmanis M, Marino AA, Becker RO. 1975. Electrical correlates of acupuncture points. *IEEE Trans Biomed Eng* 22:533–535.
- Senelar R. 1979. Les caractéristiques morphologiques des points chinois. In: Niboyet JEH, editor. Nouveau traité d'acupuncture. Paris: Maisonneuve.
- Shanghai Medical University, Human Anatomy Department. 1973. A relationship between points of meridians and peripheral nerves: Acupuncture anaesthetic theory study. Shanghai: People's Republic Publishing House.
- Swartz MA, Tschumperlin DJ, Kamm RD, Drazen JM. 2001. Mechanical stress is communicated between different cell types to elicit matrix remodeling. *Proc Natl Acad Sci USA* 98:6180–6185.
- Ulett GA, Han S, Han JS. 1998. Electroacupuncture: mechanisms and clinical applications. *Biol Psych* 44:129–138.
- Veith I. 1949. The yellow emperor's classic of internal medicine. Berkeley: University of California Press.
- Yang J. 1601. The golden needle and other odes of traditional acupuncture, 1601. Translated by R Bertschinger. Edinburgh: Churchill Livingstone.