The Effects of Acupuncture Needle Manipulation on Fascia

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Western medical experts have been inherently skeptical of acupuncture's therapeutic value for the treatment of pain and other medical conditions. One reason is that it seems very unlikely that the simple act of inserting fine needles into tissue could elicit any effect at all, let alone wide-ranging and long-lasting therapeutic effects. What these skeptics may not be aware of is that after needle insertion, acupuncture typically involves manual needle manipulation such as rapidly rotating (back-and-forth or one direction) and/or pistoning (up-and-down motion) of the needle. The manipulation can be brief (a few seconds), prolonged (several minutes), or intermittent depending on the clinical situation. Manipulation also occurs when electrical stimulation is applied to the inserted needles (a relatively recent development in the history of acupuncture).

A new model involving connective tissue has been proposed to explain acupuncture's effect. This model is supported by human and animal experiments that show acupuncture needle manipulation causes mechanical stimulation of connective tissue and the network formed by interstitial or "loose" connective tissue corresponds to the acupuncture meridian network as it is defined by traditional Chinese medicine theory. This has led to a new way to think about acupuncture. The biochemical effects brought about by mechanical stimulation of connective tissue and the potential spreading of these effects along connective tissue planes may explain acupuncture's therapeutic effect as well as traditional acupuncture theory.

Fascia, what is it?

“Fascia – what a fascinating tissue! Also known as dense irregular connective tissue, this tissue surrounds and connects every muscle, even the tiniest myofibril, and every single organ of the body. It forms a true continuity throughout our whole body. Fascia has been shown to be an important element in our posture and movement organization. It is often referred to as our organ of form.” (Schleip, R. Fascial plasticity – a new neurobiological explanation, part 1. , January 2003)

> The fasciæ are fibroareolar or aponeurotic laminæ, of variable thickness and strength, found in all regions of the body, investing the softer and more delicate organs. They have been subdivided, from the situations in which they occur, into superficial and deep. The superficial fascia is found immediately beneath the integument over almost the entire surface of the body. It connects the skin with the deep fascia, and consists of fibroareolar tissue, containing in its meshes pellicles of fat in varying quantity. Fibro-areolar tissue is composed of white fibers and yellow elastic fibers intercrossing in all directions, and united together by a homogeneous cement or ground substance, the matrix. The superficial fascia connects the skin to the subjacent parts, facilitates the movement of the skin, serves as a soft nidus for the passage of vessels and nerves to the integument, and retains the warmth of the body, since the fat contained in its areolæ is a bad conductor of heat. The deep fascia is a dense, inelastic, fibrous membrane, forming

> sheaths for the muscles, and in some cases affording them broad surfaces for attachment. It consists of shining tendinous fibers, placed parallel with one another, and connected together by other fibers disposed in a rectilinear manner. It forms a strong investment which not only binds down collectively the muscles in each region, but gives a separate sheath to each, as well as to the vessels and nerves. The fasciæ are thick in unprotected situations, as on the lateral side of a limb, and thinner on the medial side. The deep fasciæ assist the muscles in their actions, by the degree of tension and pressure they make upon their surfaces; the degree of tension and pressure is regulated by the associated muscles, as, for instance, by the Tensor fasciæ latæ and Glutæus maximus in the thigh, by the Biceps in the upper and lower extremities, and Palmaris longus in the hand. In the limbs, the fasciæ not only invest the entire limb, but give off septa which separate the various muscles, and are attached to the periosteum: these prolongations of fasciæ are usually spoken of as intermuscular septa. (The Bartleby.com edition of , 1918.)

Fascia is essentially all of the connective tissue in the body. It is a tough, gristly covering, much like a sausage casing, that surrounds every muscle. It forms a vast network throughout the body and is continuous from head to toe. Fascia envelopes the muscles, bones and joints and holds us together supporting the body structure and giving us our shape. Fascia provides protection and autonomy for the individual muscles and viscera.

It joins and bonds these separate entities and establishes spatial relationships. Chemically it is the collagen in the fascia that enables it to change. Collagen, a colloid is capable of changing from fluid to solid, and solid to fluid in response to the forces acting upon it. Fascia is composed mainly of collagen fibers, together with water and other proteins which provide a glue-like quality. Due to the regular alignment of the fibers, fascia often has a crystal-like appearance. The connective tissue fibers extend deep in between individual muscle cells and between practically all cells of the body.

Fascia is strong connective tissue which performs a number of functions, including enveloping and isolating the muscles of the body, providing structural support and protection. Fascia has three layers; superficial fascia is found in the subcutaneous layer in most regions of the body; deep fascia is the dense fibrous connective tissue that interpenetrates and surrounds the muscles, bones, nerves and blood vessels of the body; and visceral, or subserous, fascia, suspends the organs within their cavities and wraps them in layers of connective tissue membranes.

The top layer of fascia is superficial fascia, which may be mixed with varying amounts of fat, depending on where it is on the body. The skull and hands have a particularly noticeable layer of superficial fascia which connects the skin to the tissues and bone underneath it. By wriggling your scalp, you can see that superficial fascia is strong but flexible, keeping the skin firmly anchored while allowing it to move freely.

Deep fascia is a much more densely packed and stronger layer of fascia. Deep fascia covers the muscles in connective tissue aggregations which help to keep the muscles divided and protected. Deep fascia can create tight knots or connective adhesions which act as trigger points which can cause pain.

The visceral fascia lies between deep fascia and the major organs of the body. It is more flexible than deep fascia, and the body allows for space around it so that the organs can move freely. Like deep fascia, visceral fascia can also form fibrous knots and adhesions which can also cause areas of pain.

All of the connective tissues contain varying concentrations of cells, fibers, and interfibrillar ground substance. “The ground substance is a watery gel composed of mucopolysaccharides or glucosaminoglycans such as hyaluronic acid, chondroitin sulfate, keratin sulfate, and heparin sulfate. These colloids, which are part of the environment of every living cell, allow the easy distribution of metabolites, and form part of the immune system barrier, being very resistant to the spread of bacteria. Produced by the fibroblasts and mast cells, the ground substance forms a continuous but highly variable ‘glue’ to help the trillions of tiny droplets of cells both hold together and yet be free to exchange the myriad substances necessary for living. In an active area of the body, the ground substance changes its state constantly to meet local needs. In a ‘held’ or ‘still’ area of the body, the ground substance tends to become more viscous, more gel-like, and to become a repository for metabolites and toxins.” (Myers, , 2001)

Fascial Mechanoreceptors

Fascia is densely enervated by mechanoreceptors. These include Golgi receptors, Pacini corpuscles, Ruffini corpuscles and interstitial muscle receptors.

Golgi receptors are found in myotendinous junctions, attachment areas of aponeuroses. They are responsive to muscular contraction or very strong stimulation. Stimulation results in a decrease in tonus in related striated motor fibers.

Pacini corpuscles are found in myotendinous junctions, deep capsular layers, spinal ligaments and investing muscular tissues. They are responsive to rapid pressure changes and vibrations and thus affected by high velocity or vibratory techniques. They are used as proprioceptive feedback for movement control, the sense of kinesthesia. Stimulation results in increased local proprioceptive attention.

Ruffini corpuscles are found in ligaments of peripheral joints, dura mater, outer capsular layers and other tissues associated with regular stretching. They are responsive to rapid pressure changes and vibrations, yet also to sustained pressure. They are specially responsive to tangential forces such as lateral stretch. Stimulation results in increased local proprioceptive attention and inhibition of sympathetic activity.

Interstitial muscle receptors are the most abundant receptor type and are found almost everywhere, even inside bones. They are at highest density in periosteum. Half are high threshold pressure units, which respond to heavier touch, and half are low threshold pressure units, which respond to light touch. They are responsive to rapid as well as sustained pressure changes. Stimulation results in increased local proprioceptive attention, and increase in vasodilation and respiration. Stimulation of high threshold pressure units may produce pain and increase plasma extravasation. (Schleip, 2003)

New Discoveries Regarding Fascia

Mechanoreceptors influence local fluid dynamics. Their activation triggers the autonomic nervous system to change the local pressure in fascial arterioles and capillaries. Strongly stimulated interstitial fibers can apparently also influence plasma extravasation, the extrusion of plasma from blood vessels into the interstitial fluid matrix. This changes the viscosity of the extracellular matrix. (Schleip, 2003)

The interstitial mechanoreceptors can trigger an increase in vagal tone which leads towards more trophotropic tuning of the hypothalamus. This results in global neuromuscular, emotional, cortical and endocrinal changes that are associated with deep relaxation. (Gelhorn, 1967)

Fascia is capable of spontaneous contraction. In 1996 Staubesand, a German anatomy professor, and Li, his Chinese co-worker studied the fascia cruris in humans with electron photomicroscopy and found smooth muscle cells embedded within the collagen fibers. They described a rich intrafascial supply of capillaries, autonomic nerves and sensory nerve endings. Based on these findings, Staubesand concluded that it is likely that these fascial smooth muscle cells enable the autonomic nervous system to regulate a fascial pretension independently of the muscular tonus (Schleip, 2003). Other research in Montreal demonstrated that fascia has the ability to actively contract with measurable and significant effects (Yahia et al. 1993). This is a new understanding of fascia as an actively adapting organ, giving fascia a much higher functional importance.

According to Staubesand "I believe that the most important aspect of our findings for fascial therapy work relates to the innervation of fascia. The receptors that we found in the lower leg fascia in humans could be responsible for several types of myofascial pain sensations. If you could influence these fascial receptors with your manipulation this could be of significant importance. Another aspect is the innervation and direct connection of fascia with the autonomic nervous system. It now appears that the fascial tonus might be influenced and regulated by the state of the autonomic nervous system. Plus – and this should have ramifications for your work – any intervention in the fascial system may have an effect on the autonomic nervous system in general and on all the organs which are directly affected by the autonomic nervous system. To put it more simply: ." (Schleip, 2003)

Fibroblast Functions in Connective Tissue

Perhaps because of the fibroblast's important relationship to the extracellular matrix, more attention has been paid to fibroblast–matrix interactions than to fibroblasts' interactions with each other. Several lines of evidence, however, suggest that fibroblasts are not separate cells, but rather are linked together in a reticular network extending throughout the whole body. In a recent study, researchers used a combination of histochemistry, confocal microscopy, and electron microscopy to demonstrate that mouse subcutaneous connective tissue fibroblasts do indeed form a cellular network (Langevin, 2004). The findings of this research show that fibroblasts form a cellular network in mouse subcutaneous tissue, and that the cytoplasmic processes of these fibroblasts are extensively interconnected (Figure 1).

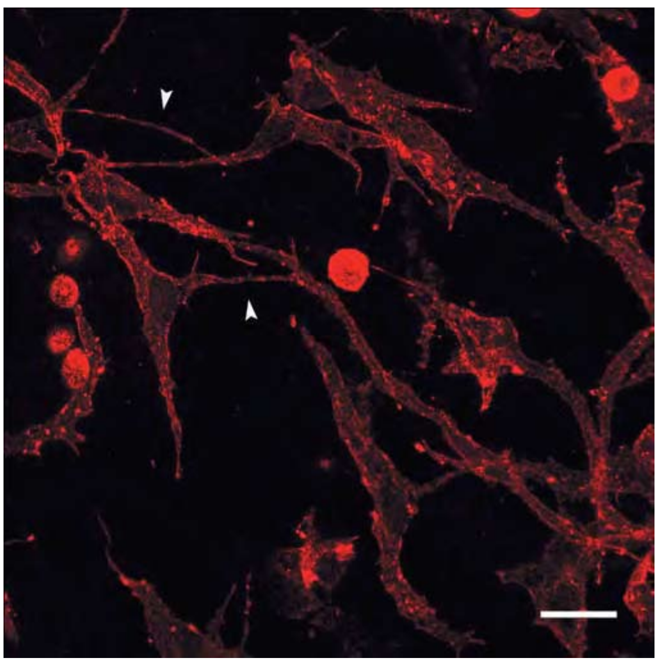

Figure 1: Mouse subcutaneous tissue fibroblast network. Tissue was fixed in 95% ethanol, stained with Texas red-conjugated phalloidin and imaged with confocal microscopy. Note the thin cellular processes present between individual cells (arrowheads). Scale bar 40 um. (Langevin, 2004)

This study's data raises the possibility that connections between connective tissue fibroblasts may involve connexins, but not gap junctions, and that fibroblasts may communicate via some form of intercellular signaling.

A unique aspect of "loose" connective tissue is its ubiquitous presence throughout the body. Subcutaneous tissue forms a body-wide "sheet" of loose connective tissue. This connective tissue sheet is itself continuous with loose connective tissue planes separating muscle, and with interstitial connective tissues surrounding all blood vessels, nerves, and organs. The significance of finding a connective tissue fibroblast network in subcutaneous tissue, therefore, is that such a cellular network indeed may permeate the entire body. Known physiological systems that transmit information signals throughout the body include the nervous, immune, and endocrine systems. The idea that connective tissue may form an additional distinct body-wide signaling system is suggested by the ancient practice of acupuncture. Acupuncture is based on the traditional theory that acupuncture "meridians" form a network throughout the body through which flows a form of movement, communication, or energy exchange termed "meridian qi" (Kaptchuk 2000). Recent evidence suggests that the acupuncture meridian system corresponds to connective tissue planes (Langevin and Yandow 2002), and that acupuncture needle stimulation sends a mechanical signal through this tissue network (Langevin et al. 2001, 2002). Connective tissue consists both of a delicate web with fine branches penetrating all tissues, and major "trunks" forming connective tissue planes and linking all parts of the body with each other. This description fits remarkably well with the definition of acupuncture meridians. "Qi cannot travel without a path, just as water flows or the sun and moon orbit without rest. So do the yin vessels nourish the zang and the yang vessels nourish the fu". (Chapter 17)

Traditionally, fibroblasts have been thought to play a mostly supportive role in connective tissue, including the synthesis of extracellular matrix constituents. In the presence of tissue injury, however, myofibroblasts have long been known to play a mechanically active role exerting tractional force within tissue and promoting wound closing (Gabbiani et al. 1978). Recent evidence also suggests that fibroblasts respond to mechanical forces even in the absence of a wound. Fibroblasts grown in tissue culture have been shown to react within minutes to a variety of mechanical stimuli (stretch, pressure, traction, shear forces) with cellular responses ranging from changes in intracellular calcium and ATP release, to signaling pathway activation, actin polymerization, and gene expression. Altered gene expression and modification of extracellular matrix composition have been demonstrated in response to mechanical signals. Change in extracellular matrix composition is itself recognized as an important mode of communication between the many cell types associated with connective tissue. Researchers have shown that the biomechanical properties of loose connective tissue are closer to that of cells than to that of high load bearing connective tissues such as tendons and ligaments. This whole tissue mechanical behavior supports the notion that fibroblasts may not be as “stress-shielded” from mechanical forces in loose compared with load-bearing connective tissues. Thus, externally applied mechanical forces in loose connective tissue are likely to have substantial effects on fibroblast mechanical signal transduction processes. The description of a cellular network within connective tissue therefore opens up the possibility that fibroblasts may participate in a body-wide signaling system responding to mechanical forces and influencing other physiological systems.

The results of these fibroblast studies indicate that the traditional view of fibroblasts as discrete cells should be modified to reflect the concept of fibroblasts forming a complex cellular network. The global nature of this network is unique to fibroblasts and suggests that these cells may have important and so far unsuspected integrative functions at the level of the whole body (Langevin, 2004).

Acupuncture Points, Meridians and Fascia

Straubesand and Li showed that there are numerous perforations of the superficial fascia layer which are characterized by a perforating triad of vein, artery and nerve. A study by H. Heine around the same time also documented the existence of these triad perforation points in the superficial fascia. Heine found that the majority (82%) of these perforations are topographically identical with the 361 classical acupuncture points in traditional Chinese medicine (Heine, 1995). The Chinese character signifying acupuncture point also means ‘hole’ (O’Connor and Bensky, 1981). This can be taken to mean that acupuncture points are locations where the acupuncture needle can gain access to deeper tissue components through this ‘hole’. “Xi and gu areas, or small and large clefts, are where the bundles of muscles meet; at this meeting place there is a depression or indentation. These places of indentation, or points, collect the qi and act as canals in providing a conduit for the flow of qi to take place” (Ni, , 1995, page 203).

Acupuncture points are located using classical guidelines which refer to anatomical landmarks and measurements to determine the approximate location, and then using palpation to find a slight depression or yielding of the tissue to slight pressure.

Acupuncture meridians are traditionally thought to represent “channels” 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). 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 (Langevin, 2002).

De Qi

Needle manipulation is performed to elicit the characteristic reaction to acupuncture needling known as “de qi.” We are taught early in our acupuncture experience that the sensation described as de qi is integral to acupuncture effect and treatment outcome. Unless the acupuncturist obtains de qi over each point used, then the acupuncture point has not been stimulated, and this means the acupuncture is of questionable value (Lewith, 1983). According to traditional teaching, de qi is essential to acupuncture’s therapeutic effect. If there is no response, i.e., no needle sensation, it is doubtful if the treatment will be effective (O’Connor and Bensky, 1981). In the process of acupuncture, no matter what manipulation it is, the arrival of qi must be achieved (Xinnong, 1981).

As stated in the “if an acupoint is accurately punctured the needling sensation will transmit, just as people travel along streets and lanes.” Thus the needling sensation transmits along certain routes to distant areas. It also states “the needling sensation must be achieved no matter how many methods are used or how long it may take”. In the it says “the de qi alone is the measure of the treatment. If the de qi does not arrive, there is no treatment”.

During needle insertion and manipulation, acupuncturists aim to elicit de qi. De qi has a sensory component, a biomechanical phenomenon which Langevin refers to as “needle grasp,” which is perceived by the patient as an ache or heaviness in the area surrounding the needle and a simultaneously occurring biomechanical component that can be perceived by the acupuncturist. During needle grasp, the acupuncturist feels as if the tissue is grasping the needle such that there is increased resistance to further motion of the manipulated needle. This “tug” on the needle is classically described as “like a fish biting on a fishing line.” Needle grasp can range from subtle to very strong, with pulling back on the needle resulting in visible tenting of the skin. During acupuncture treatments, needle manipulation is used to elicit and enhance de qi, and de qi is used as feedback to confirm that the proper amount of needle stimulation has been used.

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). When the qi arrives, the practitioner may feel a kind of moderate sinking or tight sensation under the needle tip; the patient may have a sensation of soreness, numbness, heaviness or distension around the point, or even a sensation travelling to a certain place or transmitting in a certain direction. The biomechanical phenomenon of needle grasp, therefore, is at the very core of acupuncture's theoretical construct.

De qi is widely viewed as essential to acupuncture's therapeutic effectiveness. Needle manipulation, de qi, and needle grasp, therefore, are potentially important components of acupuncture's therapeutic effect, yet the mechanisms underlying de qi and needle grasp are unknown. As a first step toward understanding the physiological and therapeutic significance of de qi, researchers quantified needle grasp by measuring the force necessary to pull an inserted acupuncture needle out of the tissues (pullout force).
They also hypothesized that pullout force is greater with two different types of needle manipulation commonly used in acupuncture practice than with needle insertion with no manipulation, and that pullout force is greater at classically defined acupuncture points than at non-acupuncture control points. These measurable effects could suggest that needle manipulation may indeed play an important role in acupuncture therapy as de qi is traditionally believed to be greater at acupuncture points.

To test these hypotheses, an experiment was performed in which normal human subjects received different types of acupuncture needle manipulation at eight acupuncture points and eight corresponding control points. 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., 2001, 2002), researchers quantified needle grasp by measuring the force necessary to pull the acupuncture needle out of the skin (pullout force). They were able to show 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., 2001), researchers measured pullout force at eight different acupuncture point locations, compared with corresponding control points located on the opposite side of the body, 2 cm away from each acupuncture point. They found that pullout force was on average 18% greater at acupuncture points than at corresponding control points. They 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.

Needle grasp has been described in acupuncture textbooks for over 2,000 years. This research constitutes a first step toward determining the biological and clinical significance of this phenomenon. For the first time, a link has been demonstrated between acupuncture needle manipulation and biomechanical events in the tissue. These biomechanical events are potentially associated with long-lasting cellular and extracellular effects.

Meridian Networks and Fascial Planes

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 stimuli, it may play a key role in the integration of several physiological functions (e.g., sensorineural, circulatory, immune) with ambient levels of mechanical stress (Langevin, 2002).

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. 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 (Langevin, 2002).

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.

Connective Tissue and De Qi

Although previously attributed to a contraction of skeletal muscle, researchers have shown that de qi, or needle grasp, is not due to a muscle contraction but rather involves connective tissue (Langevin et al., 2001a, 2002). During acupuncture needle rotation, connective tissue winds around the acupuncture needle, creating a tight mechanical coupling between the needle and the connective tissue. Further movements of the needle (either rotation or lifting and thrusting) then pull and deform the connective tissue surrounding the needle, delivering a mechanical signal into the tissue and along the tissue plane (Langevin, 2002).

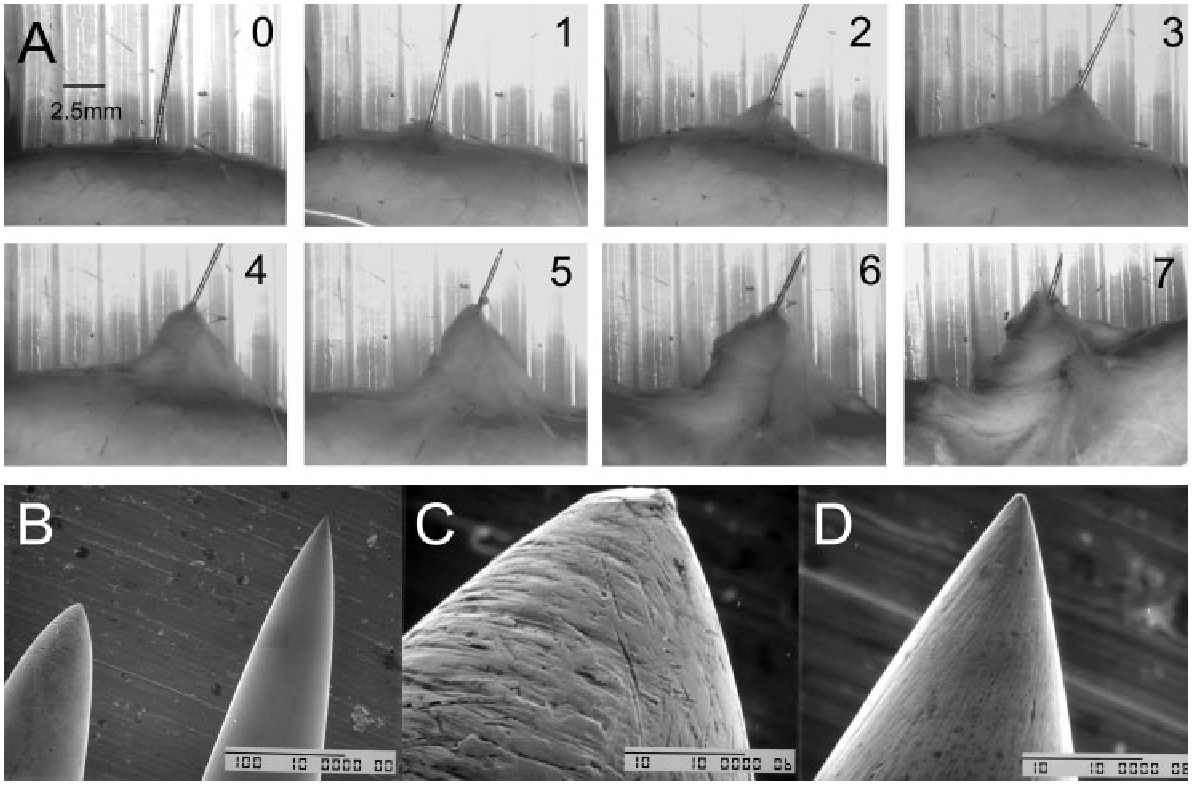

Figure 2: A: Formation of a connective tissue "whorl" with needle rotation. Rat subcutaneous connective tissue was dissected and placed in physiological buffer under a dissecting microscope. An acupuncture needle was inserted through the tissue and progressively rotated. Numbers 0 through 7 indicate 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 . C,D: Scanning electron microscopy of gold (C) and stainless steel (D) needles. Original magnification, 3,500 . The surface of the gold needle is visibly rougher than that made of stainless steel. Scale bars 2.5 mm in A, 100 m in B, 10 m in C,D. (Langevin, H. and Yandow, J. 2002)

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 2). 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. An important factor appears to be the diameter of the rotating needle. Acupuncture needles are very fine (250–500 m 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. 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 is commonly used in clinical practice. 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., 2001). The importance of establishing a mechanical coupling between needle and tissue is that mechanical signals are increasingly recognized as important mediators of information at the cellular level, mechanical signals can be transduced into bioelectrical and/or biochemical signals, and can lead to downstream effects, including cellular actin polymerization, signaling pathway activation, changes in gene expression, protein synthesis, and extracellular matrix modification. Changes in extracellular matrix composition, in turn, can modulate the transduction of future mechanical signals to and within cells. Recent evidence suggests that both tissue stiffness and stress-induced electrical potentials are affected by connective tissue matrix composition and that changes in matrix composition in response to mechanical stress may be an important form of communication between different cell types. 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, 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. 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 (Langevin and Yandow, , 2002).

Traditional Chinese Medicine Concepts and Connective Tissue Plane Correspondences

The anatomical correspondence of acupuncture points and meridians to connective tissue planes suggests plausible physiological explanations for several important traditional Chinese medicine concepts. Acupuncture meridians could correspond to connective tissue planes; acupuncture points could correspond to the convergence of connective tissue planes; qi could correspond to the sum of all of the body's energetic phenomena; meridian qi could correspond to connective tissue biochemical and bioelectrical signaling; blockage of qi could correspond to an altered connective tissue matrix composition leading to altered signal transduction; needle grasp could correspond to tissue winding and/or contraction of fibroblasts surrounding the needle; de qi sensation could correspond to the stimulation of connective tissue sensory mechanoreceptors; propagation of the de qi sensation could correspond to a wave of connective tissue contraction and sensory mechanoreceptor stimulation along connective tissue planes; restoration of the flow of qi could correspond to cellular activation or gene expression leading to restored connective tissue matrix composition and signal transduction (Langevin, 2002).

Langevin proposes 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. The anatomy of acupuncture points and meridians, thus, may be an important factor in explaining the functional therapeutic effects of acupuncture.

Langevin et al. developed a robotic computer-controlled acupuncture needling instrument allowing all movements of the needle to be programmed. Development of the programmable acupuncture needling instrument led to a series of experiments in humans and animals characterizing the effect of needle movement on tissue. These experiments showed three things;

1) Needle rotation has a pronounced effect on the amount of needle grasp, measured as the peak force necessary to pull the needle out of the skin (pullout force) as well as the torque developing at the needle/ tissue interface during rotation.

2) Needle grasp is not due to a muscle contraction.

3) Pullout force is greater at acupuncture points than at nonacupuncture control points.

Therefore, the measurement of needle forces (axial, torque) during needle movement can yield important information on the strength of the bond between the tissue and needle and on the effect of needle manipulation on the bond.

Simply measuring needle force, however, does not give information on tissue stress and strain away from the needle. This is important for a number of reasons: first, measuring how far from the needle tissue biomechanical changes can be detected will allow investigation of whether biomechanical changes are more pronounced along the path of meridians (i.e. connective tissue planes), and second, the measurement of tissue stress/ strain induced by needle manipulation will give insights into the biochemical events occurring in the tissue in response to needle manipulation.

Results of these studies found that soft-tissue displacement could be estimated using only the stimulus caused by the movement of the needle. More importantly, the tissue displacements were found to increase in amplitude by up to tenfold during rotation compared with no rotation. Needle rotation also was shown to stiffen the tissue, resulting in the absence of tissue reorganization (or, rebound) after downward displacement which was evident in the case without rotation, and causing binding of the tissue onto the needle as a result of rotation. It was also noted that rotation of the needle leads to a preferred direction of the tissue motion, especially during downward and upward motion of the needle.

This direction coincides with the orientation of the intermuscular fascia. The rotation displacement increased and the rebound displacement decreased with the number of needle rotations. The absolute value of the displacement of the tissue around the needle also increased with both downward and upward needle movement. Statistical analysis showed a significant effect of rotation on tissue displacement during downward rotation and upward needle motion as well as on rebound tissue motion after downward needle movement.

Summary

Connective tissue, or fascia, has been shown to consist of head to toe planes which relate to the traditional Chinese medicine theory of the meridian system. Connective tissue surrounds and connects all muscle, nerve, blood vessel and organ systems in the body. Fibroblasts in connective tissue have been shown to be connected, forming a body-wide cellular network. Tissue displacement caused by acupuncture needle manipulation following needle rotation may deliver a mechanical signal into the subcutaneous tissue and consequently have important effects on cellular elements (fibroblasts, blood vessels, sensory nerves) present within this tissue. This may prove to be the key to acupuncture's therapeutic mechanism and the proposed imaging technique—the key method for monitoring this effect. Imaging of the displacements occurring before and after rotation at a certain amount of revolutions of the acupuncture needle allowed for the quantitative analysis of the extent of the tissue affected by the needle when it is rotated, as is the case in the clinical practice of acupuncture. It also allowed for temporal monitoring of the tissue behavior around the needle as a result of the type of needle manipulation.

The correspondence of meridians to fascial planes, acupuncture points to to the convergence of these planes and the de qi sensation to a wave of connective tissue contraction and a sensory mechanoreceptor stimulation along fascial planes is a fascinating new way of looking at what may help to bring about the therapeutic effects of acupuncture treatments. Further research may continue to provide insights into the mechanism of the de qi response of acupuncture needle manipulations and the therapeutic response that travels along the meridian network and affects organs and distant aspect of the body from the needling site.

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