Fascia as a body-wide communication system

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c0245 Fascia as a body-wide communication system

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A single-celled paramecium swims gracefully, avoids predators, finds food, mates, and has sex, all without a single synapse. "Of nerve there is no trace. But the cell framework, the cytoskeleton might serve."

Sherrington, 1951

s0010 Introduction

p0010 This chapter begins with some evolutionary considerations regarding communication in the fascia and other components of the extracellular matrix and within the cells that maintain them. These considerations lay a foundation for exploring the nature of non-neural and nonhormonal communications in the mammalian organism, as well as how the fascia interacts with the brain and therefore with consciousness.

p0015 When we think of communication in the human body we usually first think of nerves and synapses. The purpose of the above quotation is to remind us of the existence of evolutionarily ancient communication systems that are present in single celled organisms that are entirely lacking in nerves or synapses. How does a single-cell creature, such as a paramecium, lead such a sophisticated life? How does it hunt living prey, respond to lights, sounds, and smells, and display complex sequences of movements without the benefit of a nervous system? Bray (2009) proposes that cells are built of molecular circuits that perform logical operations, as electronic devices do. He also suggests that the computational properties of cells provide the basis of all the distinctive properties of living systems, including the ability to embody in their internal structure an image of the world around them. These concepts, which are supported by the information to follow, account for the adaptability, responsiveness, and intelligence of cells and organisms. These properties also extend into the connective tissue terrain surrounding all cells in the mammalian organism.

Prokaryotes – organisms lacking a cell nucleus or any other membrane-bound organelles, even those as simple as flagellated bacteria – are likewise capable of sensing and responding to various environmental stimuli and moving toward or away from them as necessary for their survival. In this historical and evolutionary context, the nervous system is seen as a relatively new "invention" that functions in cooperation with an older communication system that has had a much longer period of evolutionary refinement – the body-wide communication system that is the topic of this chapter. p0020

Because of the relative ease with which the nervous system can be studied, and because of its obvious importance, the brain has been studied with a vast array of analytical tools, and we know enough about it to fill many books and journals. However, one does not have to dig very deep into this literature to find that there are many unanswered questions. For example, the recent discovery that the connective tissue cells in the brain also form a communication system has returned the whole of neuroscience to the drawing board. In mammals, connective tissue cells called glia (the Greek word γλια means "glue") constitute some 50% of the volume of the brain. Decades of research have required revision of the traditional view that glial cells function purely for mechanical and nutritional support. We now know that glial cells interact p0025 morphologically, biochemically, and physiologically with neurons throughout the brain, modulate neuronal activity, and influence behavior (Castellano López & Nieto-Sampedro 2001; Koob 2009). A new cutting edge branch of both neuroscience and fascial research has been born, based on the relationship between connective tissue cells and neuronal processes. Those who study the fascia as an all-pervasive system, as will be defined below, will recognize that one of the most vital relationships in the body has to be the relationship between the connective tissue and the nervous system.

p0030 Some biologists regard the modern mammalian cell as a microorganism (e.g., Puck 1972). Mammalian cells contain miniature "musculoskeletal systems" composed of microtubules (the "bones" of the cell), microfilaments (the "muscles" of the cell), and other molecules that can act as a sort of "connective tissue" within the cell. These cellular components enable cells to change shape and to migrate from place to place. In recent years it has been discovered that bacteria also contain a number of cytoskeletal structures that are homologs of the three major types of eukaryotic cytoskeletal proteins, actin, tubulin, and intermediate filament proteins (summarized by Shih & Rothfield 2006).

p0035 The cytoskeleton is often regarded as the "nervous system" of the cell. The extracellular coats of the "primitive" microorganisms evolved into the mammalian extracellular matrix. Specifically, the extracellular sugar polymer coatings of individual bacteria, viruses, and protozoa extended the "reach" of these ancient organisms into their environment and formed the oldest and most pervasive information and defense system in nature. The connective tissue is the modern expression of these ancient cell coats.

p0040 This chapter is an exploration of the concept that these ancient communication systems persist throughout the modern mammalian organism and that their existence helps explain a number of phenomena that are difficult to account for by neural mechanisms. The inquiry has been guided and inspired in large measure by conversations with a broad range of bodywork, energetic, and movement therapists who have daily and remarkable encounters with these systems and who have therefore developed a keen curiosity about their nature.

s0015 The fascia

p0045 Findley and Schleip (2009) have defined fascia broadly to include all of the soft fibrous connective tissues that permeate the human body. Their definition has the important feature of blurring the arbitrary demarcation lines between various components of the connective tissue so that we can view the fascia as "one interconnected tensional network that adapts its fiber arrangement and density according to local tensional demands." Pischinger (2007) describes the fascial system as the largest system in the body as it is the only system that touches all of the other systems. Finando and Finando (2011) summarize evidence that the ancient acupuncture meridian system shares many structural, functional, and clinical characteristics with the fascial system. Specifically, like the acupuncture meridian system, the fascia may be viewed as a single organ, a unified whole, the environment in which all body systems function. There is a virtually one-to-one correspondence between the therapeutic approaches to the fascia and to acupuncture. For example, Pischinger (2007) states that needle puncture produces a reaction in the entire intercellular–extracellular matrix. The diversity of conditions that respond to acupuncture treatment may be explained by a review of the recently understood properties of the fascia. The involvement of the fascia in dysfunction and disease is pervasive. It is believed that, to some extent, the fascia will necessarily be involved in every type of human pathology (Paoletti 2006; Pischinger 2007). The fascia is the one system that connects to every aspect of human physiology. Langevin (2006) and Langevin and Yandow (2002) suggest that the fascia is a metasystem, connecting and influencing all other systems, a concept with the potential to change our core understanding of human physiology.

These are valuable perspectives as they help p0050
address the increasing interest in whole-systems phenomena that distinguish holistic manual therapies from methods that focus on parts rather than wholes. Experience often shows that formerly intractable health issues are resolved by taking a broader view of a patient's problems. Stated differently, "There are no local problems" (Spencer 2007), and the corollary, "There are no local treatments."

Along with these holistic perspectives come ques- p0055
tions such as:

> How do we account for the unitary nature of a living organism: the way it responds as a whole to any stimulus – as if every part of it knew what every other part is doing?
>
> Ho (1994)

p0060 and:

> How is it that an organism behaves as a whole, and not just a collection of parts?
>
> Packard (2006)

p0065 These issues are related to the theme of this book, since much of the success of modern manual therapies stems from a willingness on the part of practitioners to unwind a patient's entire traumatic history, including all of the resulting compensations, which is very different from treating a current complaint.

p0070 Moreover, the way the interconnected fiber systems of the fascia adapt to both local and global forces takes us to one of the key unsolved issues in medicine and biology. This issue is the mechanism by which an organism develops from an embryo into an adult, and the equally important mechanism by which the adult organism references the embryonic formative processes when needed to restore the original structure after injury or disease. While there may be an impression that the mechanisms involved in morphogenesis are well known, they are not. Biological patterns persist in the face of changes in physical activity and trauma, but previous widely-taught ideas of how this is accomplished have been discovered to be inaccurate:

- u0010 DNA is *not* the blueprint of the organism.
- u0015 Ontogeny (morphogenesis or the developmental history of an organism) does *not* recapitulate (repeat) phylogeny (the evolutionary history of a species).
- u0020 The growth of an organism is *not* brought about by a set of linear cause and effect events like the construction of an automobile on an assembly line.
- u0025 Differentiation is no longer viewed as a one-way street, i.e., that once a cell has become "committed" to become, say an intestinal cell, it cannot revert to the undifferentiated state.

p0095 To thoroughly explore wound healing, the human body's capacity to adapt to and recover from stress and trauma and other essential biological phenomena, we extend the definition of fascia to include the denser parts of the connective tissues, cartilage and bone, whose fiber systems are continuous with the fascial elements in the soft tissues. The fiber systems in the fascia are embedded in a polyelectrolyte ground substance, and what distinguishes bone from soft tissues is the ossification of the ground substance. The fiber systems within bone are continuous with those in the soft tissues, for example at the places where tendons and ligaments insert into bone.

Tracing the kinetic chain through the living matrix s0020

Since our exploration will also go beyond gross anatomy to the level of tissues, cells, organelles, nuclei, DNA, and other molecules, we introduce an even more encompassing concept, the **living matrix**. The living matrix includes the connective tissue and fascial systems as defined above as well as the transmembrane proteins (integrins and adhesion complexes), cytoskeletons, nuclear matrices, and DNA. Figure 2.5.1 illustrates the living matrix concept. p0100

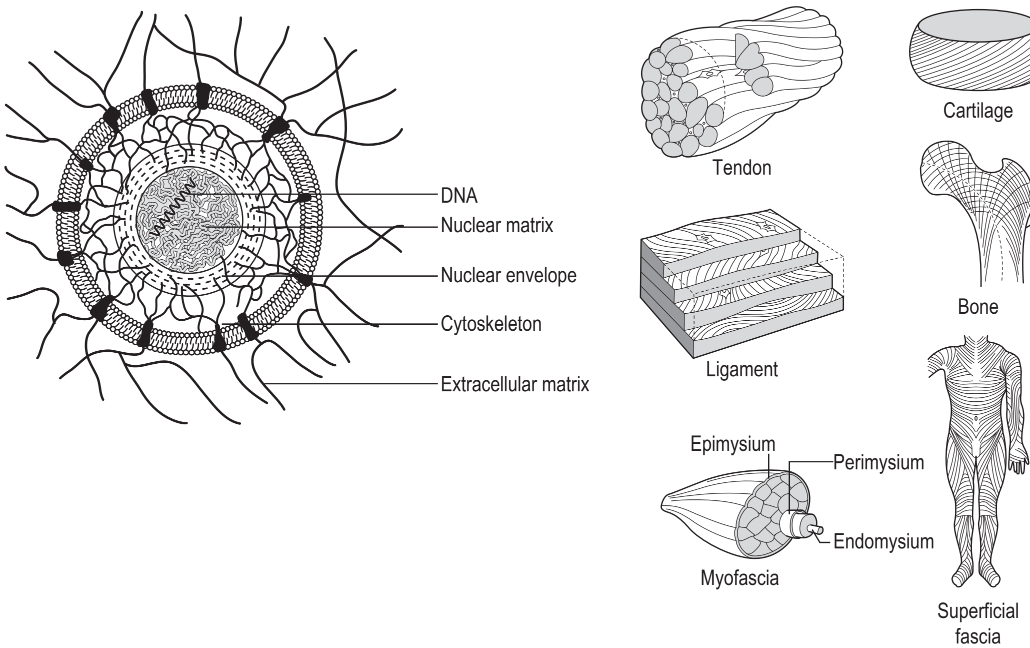
We can trace the molecules of the kinetic chain through the living matrix. The kinetic chain is an interconnected tensional network within the living matrix. All movement, of the body as a whole or of its smallest parts, is created by tensions carried through the living matrix. In laying out the following sequence of connections it must be recognized that some parts of the network have been studied more thoroughly than others. p0105

We begin with the tilting of the head of the myosin molecule, widely regarded as the origin of all muscular movements. This tilting causes movement of the myosin filaments with respect to the actin filaments. The actin molecules in turn exert tension on the filaments of the Z disk. The Z disk in turn connects to the muscle cell surface (sarcolemma) and to collagen molecules in the endomysium. In this way, tensions developed within the sarcomeres are conducted to the surrounding endomysium. These tensions, as well as those conducted at the musculotendinous junctions, are further conveyed by tendons to the bones. The functional anatomy is complex, however, as has been carefully reviewed by Huijing (2007). p0110

As the title of this chapter suggests, it is of interest to explore the possibility that the body-wide fascial network, the kinetic chain, and other components of the living matrix may serve additional roles beyond conducting tensions. One such role emerges when we explore the mechanisms by which the body adapts to the demands imposed upon it. p0115

Regulation of fascial architecture s0025

Wolff's Law (1892) is frequently mentioned as a key mechanism in the adaptation of the structure of the body to the ways it is used, abused, and traumatized: p0120



f0010 **Fig. 2.5.1** • The living matrix concept.

> The form of the bone being given, the bone elements (collagen) place or displace themselves in the direction of the functional pressure and increase or decrease their mass to reflect the amount of functional pressure.
>
> Cited in Bassett (1968)

p0125 We now know that Wolff's Law applies to more than bone – it is relevant for virtually all of the connective tissues, including tendons, ligaments, and so on. We can ask precisely what is the mechanism of Wolff's Law: precisely what connects "functional pressure" (tensions and compressions) with anatomical structure? The question is important beyond musculoskeletal mechanics. It is a key question in morphogenesis, since cellular migrations during development and during wound repair exert "functional pressures" on surrounding tissues that are important in determination of the "final form" of the tissues. Chen and Ingber describe how mechanical forces transmitted through the system ultimately reach the cytoskeleton and nuclear matrix, where they can produce biochemical and transcriptional changes by mechanochemical transduction (Chen & Ingber 2007).

p0130 Several additional signaling mechanisms have been explored to explain the connections between "functional pressure" and tissue structure. Each of these signaling mechanisms involves a particular form of energy conducted through the living matrix and/or through the associated water and fluid phases of the connective tissue. We begin with the role of electrical fields, then move on to light and sound.

Electrical fields and the piezoelectric effect s0030

The collagen fibers and fiber bundles of the myofascial system are to a high degree associated in parallel arrays that give them their great tensile strength and flexibility, while at the same time giving them a high degree of crystallinity. This is a property of soft tissues that is not always taken into account. The crystals in the living matrix have little resemblance to familiar mineral crystals such as quartz or diamond. The hardness of mineral crystals arises because the units (atoms and molecules) of which they are composed are roughly spherical and are packed tightly together in very strong polygonal arrays. In contrast, the organic crystals comprising the myofascial system are composed of long, thin, flexible filaments such as actin, myosin, collagen, and elastin. The result is flexible rather than rigid crystals. In fact, they are best described as liquid crystals. p0135

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> Liquid crystallinity gives organisms their characteristic flexibility, exquisite sensitivity and responsiveness, and optimizes the rapid noiseless intercommunication that enables the organism to function as a coherent coordinated whole.
>
> Ho (1997)

p0140 Highly ordered systems of this kind have special properties that have been studied by physicists for a long time. The biological significance of these crystals was emphasized by Szent-Györgyi (1941):

> If a great number of atoms is arranged with regularity in close proximity, as for instance, in a crystal lattice, the…electrons… cease to belong to one or two atoms only, and belong to the whole system…A great number of molecules may join to form energy continua, along which energy, viz., excited electrons, may travel a certain distance.

p0145 This statement introduced the important discovery, now confirmed, that proteins are semiconductors, and laid the foundation for the new field of electronic biology or solid-state biochemistry. Very few scientists appreciated the significance of this development. The barrier seemed to be unwillingness among most biologists to investigate the biological significance of quantum physics. Fortunately this situation has changed dramatically, and Szent-Györgyi's seminal work in molecular electronics and semiconduction in collagen is finally being recognized (Hush 2006).

p0150 Another important property of liquid crystals is piezoelectricity. When put under compression or tension, these materials develop electric fields. Deformations of bones, teeth, tendons, blood vessel walls, muscles, and skin all give rise to weak electric fields, which is thought to be a result of the piezoelectric effect. The piezoelectric constant for a dry tendon, for example, is nearly the same as that for a quartz crystal (Braden et al. 1966).

p0155 There is some disagreement as to whether the electric fields produced by deformations of connective tissues are entirely due to the piezoelectric effect. Another mechanism that could contribute to the electrical properties is the streaming potential (Bassett 1968).

p0160 There has been interest in the biological significance of these electrical effects. It appears that every movement made by the body generates electric fields due to the compression or stretching of bones, tendons, muscles, etc. In addition, electric fields occur as a consequence of nerve conduction and the depolarization of the muscle cell membranes. It has been proposed that all of these electric fields spread through the surrounding tissues, providing signals that inform the cells of the nature of the movement, loads, or other activities occurring elsewhere in the body. Cells such as fibroblasts and osteoblasts are thus able to adjust their activities in maintaining and remodeling the tissues according to the loads they are carrying. This is thought to be the mechanism of Wolff's Law, and the process by which movement and exercise maintain the skeleton, while long periods of bed rest or space travel in zero gravity conditions lead to loss of bone mass. Bodywork, energetic, and movement therapists of all kinds are familiar with the fact that tendons become thickened and hardened in response to chronic stress. They are also familiar with therapeutic methods that lessen the tensions in the myofascial network, by relaxing chronically tightened muscles and softening dense regions, particularly at the places where the tendons insert into the bones.

Athletes, musicians, dancers, and other perfor- p0165
mers experience the progressive adaptations of structure, function, motion, and energy that occur when an activity is practiced again and again. An extreme example is the body-builder, who through the stimulus of constant exertion, brings about a dramatic alteration in body form. Not only do the muscles increase in size and strength, but the other components of the myofascial system increase as well. The delicate skill of the concert violinist is an example of the same phenomenon – the gradual perfection of form and motion as the body adapts to the way it is used. It is thought that the orderly and concerted changes in structure just described, coordinated by the communications between the various tissues and the cells, are, at least in part mediated by electric fields produced, by the piezoelectric effect, streaming potentials, and other activities related to motor control. A stimulus for the research was the discovery by Dr. Robert O. Becker and others that weak electrical currents can facilitate the healing of bone fractures.

While a success with a therapeutic approach does p0170
not necessarily prove the theoretical mechanism that the approach is based upon, there is no question that clinical application of weak electrical fields can stimulate osteogenesis to the extent that the method has become widely used for treating nonunion and delayed union of bone fractures, even in bones unhealed for as long as 40 years (Bassett 1995).

Precisely how do electrical fields generated during p0175
motor activity get from their sources to nearby fibroblast or osteoblast cells, and thence to the cell

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nucleus where protein synthesis is regulated? Bassett (1995) summarized a cascade of activities that crosses the cell membrane, moves through the cytoskeleton to the nucleus and DNA. Physiologists regularly view charge transfer as the movements of charge carriers such as sodium, potassium, and chloride ions, as in other physiological processes. It is likely that other charge carriers and other forms of energy are involved as well. Light and sound may also be involved.

p0180 Interest in light emission from the fascial liquid crystals is supported by the discoveries of Fröhlich (1988), who demonstrated from both theoretical and experimental perspective that when the energy levels in these liquid crystals reach a certain point, the molecules begin to vibrate coherently, leading to the emission of coherent light. These light emissions have now been documented.

s0035 Light

p0185 Light or biophotons constitute yet another form of energy that is generated within the body and that moves through the living matrix. The modern era of biophoton research, from 1974 onwards, began with the work of Fritz-Albert Popp and his colleagues in Germany. During the past 30 years, Popp and colleagues around the world have demonstrated conclusively that living systems absorb and emit coherent biophotons. There are now about 40 groups, in a dozen or so countries, researching the theory and practical applications of this research, using state of the art techniques.

p0190 From this research we now know that all organisms, including humans, emit a glow that is too faint to be detected with the eye, but that can be measured precisely with photomultipliers that amplify weak signals millions of times. The intensity of this biophotonic glow is some tens of thousands of photons per square centimeter per second. Bischof (2005) calculates that this glow corresponds to the light of a candle seen from a distance of 15 miles. Biophotons range in wavelength from 200 to 800 nm, i.e., from the ultraviolet through the visible spectrum to infrared light. These emissions should not be confused with chemical bioluminescence, which is much stronger and has entirely different properties and origins. In contrast to chemical bioluminescence, biophoton emission increases in intensity hundreds or thousands of times before death of cells, and then ceases upon cell death. Injury to cells stimulates the production of biophotons. The coherent biophotonic light is not steady, but changes with any change in the activity of the organism. Biophoton output changes during the cell cycle, and is influenced by any change in the physiological state of the organism. A recent discovery is that biophotons are emitted from acupuncture meridians when points are stimulated with different methods used by acupuncturists (Schlebusch et al. 2005).

Popp has summarized years of biophoton research with the concept of *Gestaltbildung*: cell coordination and communication. With biophoton emissions, Popp provided an answer to the question of morphogenesis as well as *Gestaltbildung*: p0195

- Photonic communication enables every cell to know what every other cell is doing. u0030
- Weak light emissions orchestrate the body. u0035
- Emissions occur at the quantum level. u0040

For those interested in the diverse roles of fascia and connective tissue in whole-body communication, an important point of this section is that the liquid crystalline domains within the connective tissues are strong emitters and sensors of biophotons. p0215

Muscle sounds s0040

It is well known that contracting muscles produce sounds that can easily be recorded with standard microphones (e.g., Oster & Jaffe, 1980; Stokes & Cooper 1992). The recording of the acoustic myogram provides a simple, noninvasive, portable measure of the skeletal muscle that can be used for monitoring muscle fatigue, controling prosthetic devices or diagnosing pediatric muscle disease. It is instructive for readers to listen to their own muscle sounds. This is done simply by filling a bathtub to a depth that will immerse the ears when lying face up in the tub, taking care not to immerse the nose. Clenching the teeth or moving other facial and even neck muscles will produce rumbling sounds that can be heard with the ears under water. Those with sensitive hearing may be able to hear sounds produced by voluntary contractions of other muscles in the body. The point is that muscle contractions produce sounds that can be conducted through the tissues. Whether or not these sounds have regulatory significance seems to be unknown. p0220

The recognition of muscle sounds adds another dimension to our considerations of the regulatory significance of information transfer through the living matrix. The reason is that sounds and any other forms p0225 of mechanical vibration will cause crystalline connective tissues to produce oscillating electrical fields of the same frequency as the sounds because of the piezoelectric effect. Hence, after considering just two forms of energy, electricity and sound, we are seeing some of the ways the energies interact.

s0045
Conclusions

p0230 The information summarized in this chapter is intended to introduce the reader to some of the possibilities of non-neural transfer of energy and information in the human body and the role of the fascia in these phenomena. Much of the evidence for these phenomena is circumstantial, and science, unlike the law, does not reach definitive conclusions on the basis of circumstantial evidence. It is challenging to study the phenomena discussed here because traditional measurement techniques do not apply. In contrast to the nervous system, one cannot simply insert a microelectrode into the fascia and establish the nature of the informational processes taking place. The author suggests that it will soon be possible to explore information processing in fascial systems, and entirely new perspectives on fascia and manipulative therapies will follow.

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