

Connective Tissue Energetics-Part 1¹

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"The fascia is the place to look for the cause of disease and the place to consult and begin the action of remedies in all diseases."

Andrew T. Still, 1899

INTRODUCTION

Those who study the anatomy of the body in relation to the various "hands-on" therapies are familiar with the myofascial system and its mechanical properties. Injuries damage or displace fascial planes, limit range of motion, and cause pain. A variety of techniques facilitate the healing of such injuries.

The presentation introduced by this essay will focus on the cellular and molecular processes involved in injury repair, and the ways these processes are controlled. Experience shows that expert therapists from all schools and philosophies benefit from a deeper understanding of the phenomena underlying injury repair.

The presenter's approach is multidisciplinary, drawing upon recent research in a wide variety of scientific and clinical fields.

THE BIOPHYSICS OF HEALING

Healing involves remarkably intricate processes, including the coordination of activities taking place in many of the systems in the body. An individual cell is never isolated—it must

know about the activities of other cells. A cell does not do anything unless it receives a control signal, which it then obeys very precisely: divide, secrete, grow, move, etc. Scientists have isolated many different kinds of signaling systems, and more are being discovered. At any instant, a cell is listening to hundreds of signals.

If an injury is serious enough, tissues and organs a distance from the damaged region may become involved, e.g. in the manufacture of essential cells and molecules. Moreover, fascinating processes enable other tissues to take over the functions of a damaged part during the repair process, and then give up these temporary roles when recovery is complete. An understanding of injury repair must take into account the wealth of communications that coordinate and integrate essential activities.

Theory and practice indicate that any therapy that brings the visible parts of the body into alignment, or that restores flexibility and mobility, will, at the same time, facilitate vital communications and thereby have beneficial effects upon the health of

the fascial systems. As A.T. Still pointed out, nearly a century ago, "Here we could spend an eternity with our present mental capacity, before we could comprehend even a superficial knowledge of the powers and uses of the fascia in the laboratory of animal life."

In discussing regulations and communications, a biophysical perspective is invaluable. The reason is that communication requires information and information comes as mobile packets or quanta of energy. A growing number of biophysicists are exploring the "languages" of vital communications, and their discoveries have significance for all therapeutic approaches.

Discussing this subject inevitably leads to areas that have been confusing or controversial in the past. The confusions have existed because some healing traditions (e.g. acupuncture) have referred to energetic phenomena that could not be measured and that therefore were suspected of lacking validity.

Modern research, using sophisticated measuring devices, has enabled scientists to detect and measure and study some of the invisible forces shaping the human body, forces that seemed mysterious in the past. Controversies and skepticism about these energies have perpetuated simply because of a lack of information.

A SYSTEM OF SYSTEMS

In describing the ways the body responds to injury, and to clinical interventions, it is useful to look at the relations of the myofascial system to the other connective tissue systems in the body. For example, nerves are everywhere surrounded by their own connective tissue sheaths, called perineurium. Together the various glial and Schwann cell coverings form an all-pervasive connective tissue system that follows all of the nerve trunks to their terminations throughout the body. Figure 1 shows this whole system.

The perivascular systems is another form of connective tissue that branches and re-branches into every nook and cranny of the body. Bones

are covered with periosteum; organs, glands, and the digestive tract are surrounded by connective tissue, and so on.

There are mechanical and physiological connections between these different connective tissue systems, so that, taken together, they form a larger "system of systems" extending throughout the body. For example, damage to a layer of fascia can lead to pain, and this demonstrates that the connective tissue system and the nervous system are connected. The connective tissue system of systems is all-pervasive—it gives all of the organs and tissues their characteristic shape, form, and mechanical characteristics.

The repair of an injury is a remark-

able process in which all of the connective tissue systems work together to restore normal structure and function. Hence, manipulation of a muscle or joint affects all of the connective tissue systems passing through that joint to some degree.

CELLULAR CONNECTIONS

An important perspective has come from studies of cell biologists. In the past, cells were viewed as relatively independent, membrane-enclosed domains, embedded within the tissues that surround them. For a long time, cells were considered to be membrane-bounded "bags" or compartments containing the enzymes and other molecules involved in metabolism. The nucleus, with its genetic material was seen as another "bag" floating about within the cellular bag (Figure 2).

Hence, while the human body contains solids, liquids, and gasses, the predominant focus of biochemistry was on events taking place in solution. The important enzymes are soluble, and metabolism was therefore described in terms of dissolved molecules diffusing from place to place inside the cell, and sometimes being secreted to the outside of the cell. Much valuable information has been obtained by looking at cells in this manner. However, three important discoveries forever altered this simple perspective:

- the cytoskeletal matrix
- connections between the cytoskeleton and extracellular matrix
- connections between the cytoskeleton and the nuclear matrix

THE CYTOSKELETON

Electron microscopy has revealed that every cell contains a sort of myofascial system of its own, consist

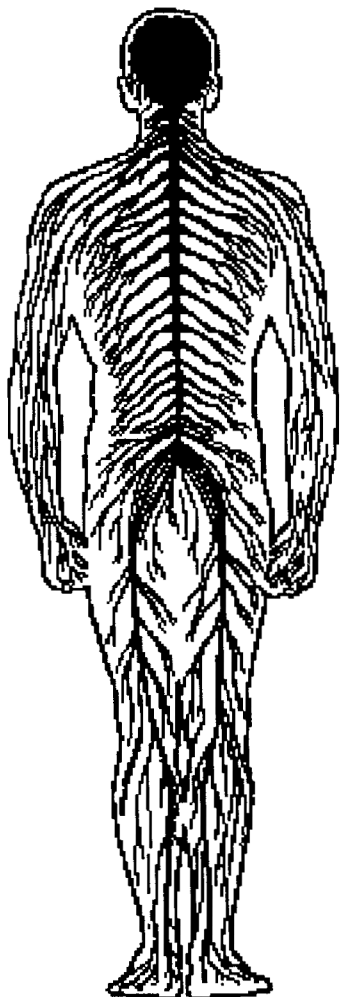


FIGURE 1.

"If a way were devised to dissolve all of the nerves in the brain and throughout the body, it would appear to the naked eye that nothing was missing. The brain and spinal cord and all of the peripheral nerves would appear intact down to their smallest terminations. This is because the central nervous system is composed of two separate types of cells; the nerve cells, or 'neurons,' and the 'perineural cells.' There are far more perineural cells in the central nervous system than there are neurons. The brain is totally pervaded by glial cells of various types and every peripheral nerve is completely encased in Schwann cells from its exit from the brain or spinal cord down to its finest terminations. Every nerve cell body and its projections of axons or dendrites is covered with perineural cells of one type or another." (Becker, 1991)

ing of "bone-like" rigid parts (microtubules), "muscle-like" contractile elements (microfilaments and related molecules), and "connective tissue-like" links (microtrabeculae). Taken together, these components have been called the cytoplasmic matrix or cytoskeleton.

Like the body as a whole, cells can change shape and move about (cytokinesis). During the past few decades, we have learned a great deal about how cells do this. Figure 3 shows a simple theory of cytokinesis based on an understanding of the cytoskeleton.

Cell movements are essential in wound healing, as different kinds of cells migrate to an injury, clean the area of any debris or bacteria, and replace damaged tissue.

THE CYTOSKELETON AND EXTRACELLULAR MATRIX ARE CONNECTED

The second important discovery of cell biology is that there are certain elements of the cytoskeleton (called glycoproteins or integrins) that extend across the cell surface and into the space around the cell (Figure 4). Many of these molecules attach to

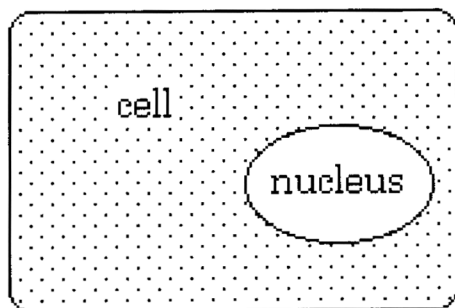


FIGURE 2.

Thirty years ago, the cell was regarded as a membrane enclosed bag containing dissolved enzymes and other molecules. The nucleus was represented as another bag within the cellular bag.

both the cytoskeleton and to the extracellular matrix or connective tissue (Oschman, 1983; Wang et al., 1993).

Obviously for a cell to move to a new location within a tissue, the transmembrane connections must be temporarily broken and then reestablished, as is shown in Figure 3.

It turns out that the same anchoring glycoprotein molecules are involved in recognition. Recognition is the remarkable process that enables cells to adhere to specific substrates or to specific cells, while not sticking to others.

A consequence of this discovery is a new perspective on the connective tissue. Not only is it a system of systems, as described above, but it is everywhere connected to the cytoskeletons of the cells throughout the body.

Mechanical manipulation of a fascial system inevitably affects the cells and molecules within, in definite and

interesting ways. The cell surface can no longer be conceptualized as a sharp boundary or barrier, distinctly separating what is cellular from what is extracellular. Important molecules extend across the membrane. We shall soon explore the meaning of this remarkable and unexpected discovery. But first, we mention another important part of the story.

THE NUCLEAR MATRIX

The cell nucleus contains an elaborate matrix of its own, consisting of the genetic material and the various molecules that regulate and repair it.

A variety of cytoplasmic filaments extend from the cell membrane to the nuclear envelope. Some of these are shown in Figure 4.

THE LIVING MATRIX

From a conceptual point of view we now recognize that what we usually refer to as "connective tissue" is actually a part of a more extensive,

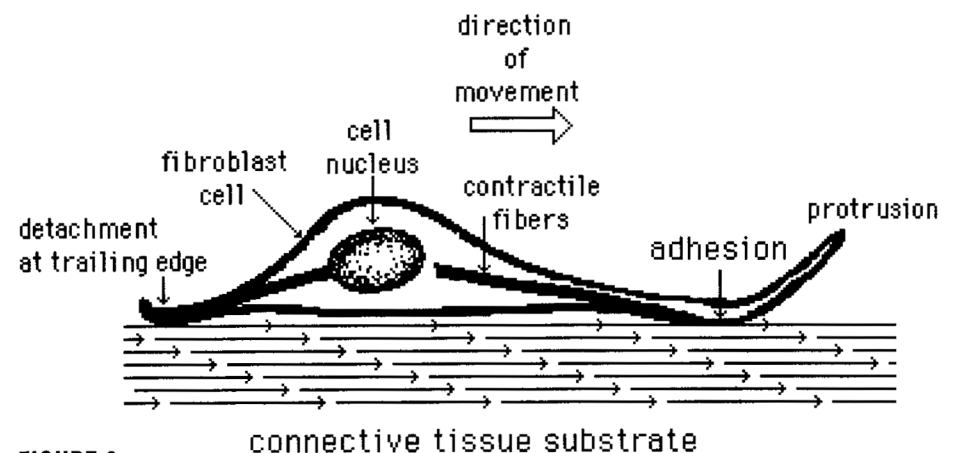


FIGURE 3.

Fibroblasts and white blood cells can crawl about within the body. The mechanism by which they move is now well understood. A cytoskeletal "motor" composed of contractile proteins exerts a force against a point of adhesion to the connective tissue substrate. The cell migrates by successively contracting against the adhesion site, detaching at the trailing edge, extending protrusions that reattach at the leading edge, and repeating the process. The diagram is based on Lackie, J.M., 1994. Cell motility. In Kendrew, J., editor, *The Encyclopedia of Molecular Biology*, Blackwell Science, Oxford, Figure C29, page 175.

continuous, and system-wide framework or living fabric composed of various kinds of fibers and filaments. It includes all of the fascial planes, and their connections to muscles, nerves, bones, and vascular tissues. It also includes the cellular and nuclear matrices of the cells contained within them. Various researchers have given different names to this global system of extracellular and cellular and nuclear systems:

- the tissue-tensegrity matrix (Pienta & Coffee, 1991)
- the connective tissue/cytoskeleton (Oschman, 1993)
- the living matrix (Oschman & Oschman, 1994)

For all therapeutic approaches, it is important to recognize that what is being contacted when one palpates the tissues of a patient is not just a specific region of the body, but an interconnected network extending throughout the body. While this is a more or less obvious statement, an awareness of the continuum or cooperative or collective properties of the living matrix can be useful to the therapist.

SOLID STATE BIOCHEMISTRY

We mentioned that for many years the focus of biochemistry was on reactions taking place in solution. The discovery of the fibrous cytoskeleton, its dynamic interconnections with the nuclear matrix inside the cell, and with the connective tissue matrix around it, has led to a new discipline of biochemistry. It is often called solid state biochemistry.

The development of this new field obviously does not reject the beautiful and profoundly important work done by biochemists and molecular biologists on the soluble enzymes and their activities. Instead, it opens up

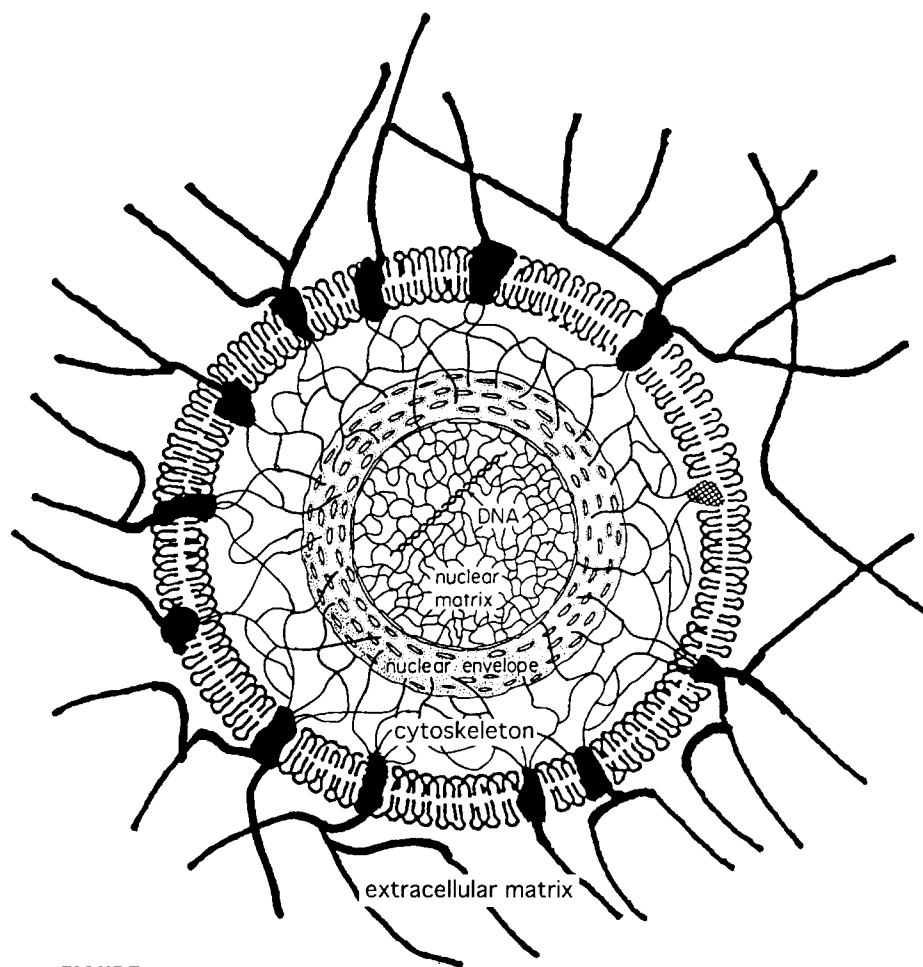


FIGURE 4.

Decades of research have revealed that every cell contains a cytoskeleton consisting of rigid, contractile and connecting elements. Glycoprotein molecules extend across the cell surface, connecting the cytoskeleton with the extracellular matrix (connective tissue). Some cytoskeletal fibers connect the cell surface to the nuclear matrix. From Oschman, 1996.

the study of additional processes taking place on and in the solid fibers and filaments that constitute living cells and tissues.

Solution biochemistry required that the molecules within the cell diffuse about more or less randomly until they bump into appropriate enzymes. Solid state biochemistry recognizes that the enzymes are associated with a molecular framework, and this enables chemical reactions to proceed in a much more orderly and rapid manner.

This conceptual advance is important to all who work with the body from the structural or biomechanical perspective. For the recent advances are giving us a new appreciation of living structure and the ways it can be approached therapeutically.

To understand solid state biochemistry it is essential to recognize the high degree of order, or regularity, or crystallinity, that is present in the body.

CRYSTALLINE ARRAYS IN CELLS AND TISSUES

An appreciation of the crystalline components of living tissues is beneficial for all therapeutic and scientific approaches to the body. We do not intuitively consider biological materials to be crystalline, because when we think of crystals we usually think of hard materials, like diamond or agate. Living crystals are composed of long, thin, pliable molecules, and are soft and flexible. To be more precise, they are liquid crystals (eg Bouligand 1978).

Crystalline arrangements are the rule and not the exception in living systems. Figure 5 gives a number of examples.

Physicists know a great deal about the properties of crystals. The information they have obtained is of considerable medical importance. For example, certain kinds of crystals are piezoelectric, i.e. they generate electric fields when they are compressed or stretched.

Physiologists are aware of this, and have studied the generation of electricity by bone for a long time. It turns out that bone is not the only connective tissue that is piezoelectric. In fact, all of the tissues in the body generate electric fields when they are compressed or stretched.

The piezoelectric effect is partly responsible for these electric fields. Another source of such fields is a phenomenon known as streaming potentials. The relative contribution of these two ways of generating electric fields in tissues is a matter of some discussion (e.g. MacGinitie 1995).

The important point is that when a bone or cartilage is compressed, when a tendon or ligament stretches, or when the skin is stretched, as at a joint, minute electric currents are set

up. These currents are representative of the forces acting on the tissues involved. In other words, they contain information on the precise nature of the movement taking place.

The physiological importance of the piezoelectric and other electrical properties of tissues is that it provides a theoretical framework for understanding how the body adapts to the ways it is used. It has long been recognized that bones and other elements of connective tissue are constantly remodeling in response to the loads imposed upon them. The electric fields produced during movements are widely considered to provide the information that directs cells such as osteoblasts, osteoclasts, and fibroblasts to lay down or resorb collagen and thereby reform the tissues so they can adapt to the loads they are required to support. This concept dates to Wolff (1892):

"The form of the bone (or other connective tissue) 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."

SOLID STATE PROPERTIES OF MOLECULAR ARRAYS

The beginnings of solid state biochemistry can be traced to a landmark paper by Albert Szent-Györgyi published in 1941:

"If a great number of atoms be arranged with regularity in close proximity, as for example in a crystal lattice, single valency electrons cease to belong to one or two atoms only, and belong instead to the whole system. A great number of molecules may join to form energy continua, along which energy, namely excited electrons, may travel a certain distance."

Szent-Györgyi (1941)

Many years later, Szent-Györgyi summarized how he reached the above conclusion:

"It was at an early date that I began to feel that the wonderful subtlety of biological reactions could not be produced solely by molecules, but had to be produced partly by much smaller and more mobile units which could hardly be anything else than electrons. The main actors of life had to be electrons whereas the clumsy and unreactive protein molecules had to be the stage on which the drama of life was enacted. Electrons, to be mobile, need a conductor, which led me to the conclusion that proteins have to be electronic conductors. Toward the end of the 1930's theories began to appear about the submolecular structure of condensed matter. This opened the possibility of electronic mobility in proteins, and thus in 1941 I proposed that proteins may be conductors."

Szent-Györgyi (1978)

The importance of Szent-Györgyi's statement is that it recognizes a fundamental process that must be taking place within the crystalline domains of cells and tissues. The process involves certain electrons that are free to move about within the crystal lattice. These electrons are therefore capable of conducting energy and information throughout the whole system. The system described above, the living matrix, then, becomes an energetic and informational continuum.

Solid-state physics recognizes several types of materials with respect to their electronic conduction. There are conductors, which can conduct electricity; there are insulators, which cannot; and there are intermediate materials, semiconductors, that can conduct electricity to some extent. While Szent-Györgyi implied that the proteins in the body are conductors, research soon revealed that they are actually semiconductors.

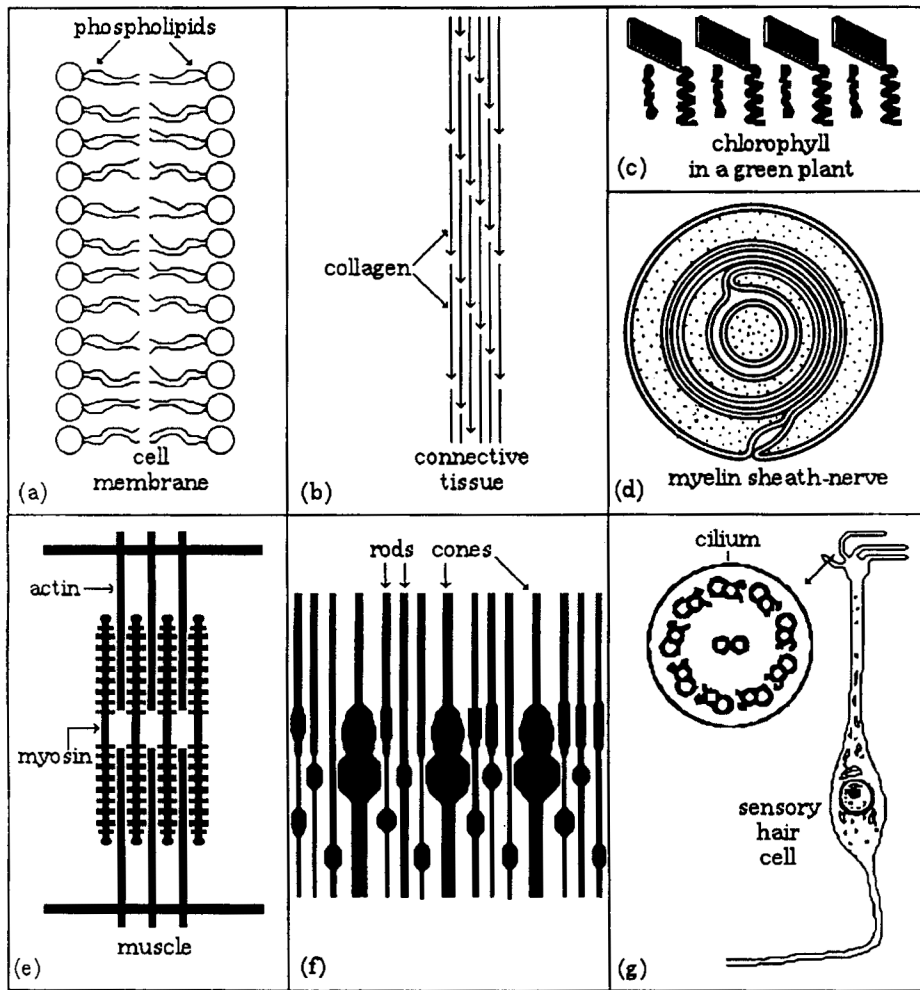


FIGURE 5.

Crystalline arrangements are the rule and not the exception in living systems. a) Arrays of phospholipid molecules form cell membranes. b) Collagen arrays form connective tissue. c) Arrays of chlorophyll molecules in the leaf. d) the myelin sheath of nerves. e) The contractile array in muscle is composed of actin and myosin molecules organized around each other. f) the array of sensory endings in the retina. g) arrays of microtubules, microfilaments, and other fibrous components of the cytoskeleton occur in nerves and other kinds of cells. The example shown here is the cilia of sensory organs such as those responsible for detecting odors and sound.

After a period of great skepticism, during which it appeared that Szent-Györgyi's 1941 statement was entirely wrong, there emerged a new field of research on the electronic and other solid-state properties of molecules. This research continues today. Virtually all of the molecules in the body are semiconductors. It has been found that electrons are not the only entities that travel about within the

molecular arrays in living systems. A variety of other charge or energy or information carriers are also present. The table lists some of them.

energy and information carriers in the living matrix:

- electrons
- holes
- phonons
- photons

- excitons
- protons
- solitons
- polarons
- conformons

In considering the living matrix as a whole system, it is important to recognize that its constituents are everywhere coated with a layer of water. This water is not ordinary water, because its properties are modified in important ways by its close association with the molecules comprising the living matrix continuum. There is evidence that the water associated with the living matrix forms a continuous system of its own, with important roles in regulation and communication. The "messages" conducted through the water system are carried by protons. This is called "proticity" to distinguish it from electricity.

Discussions of these important discoveries are found in technical journals of physics and electronics. Biologists who are aware of this research have learned a great deal about the ways living systems process energy and information at the molecular and atomic levels. Solid-state biochemistry is developing new and important explanations for aspects of regulation that have been difficult to explain in the past.

A COOPERATIVE, COLLECTIVE, OR SYNERGETIC SYSTEM

A current trend in science is to look at living systems as cooperative or collective or synergetic systems (e.g. Haken & Wagner, 1973; Haken, 1983; Fröhlich, 1988). In essence, this is a search for new and unexpected properties that arise in systems as a consequence of the ways parts are put together. Again, Szent-Györgyi (1963) stated the situation in a memorable fashion:

"If Nature puts two things together she produces something new with new qualities, which cannot be expressed in terms of qualities of the components. When going from electrons and protons to atoms, from here to molecules, molecular aggregates, etc., up to the cell or the whole animal, at every level we find something new, a new breathtaking vista. Whenever we separate two things, we lose something, something which may have been the most essential feature."

The continuous solid molecular framework of the human body can be looked at in different ways. Superficially, we can see a myofascial system that enables the body to move from place to place. Closer inspection reveals muscles ensheathed in layers of fascia. These layers connect to tendons, ligaments, cartilages, and bones. The whole system is directed by electrical impulses traveling through nerves. It is oxygenated and nourished and detoxified by blood traveling through a vascular system. It's parts are continuously maintained and repaired by cells that can migrate about within it.

To explore and understand these systems in their totality, we begin by recognizing that the study of relationships provides a totally different perspective than study of individual parts. One consequence is that the "system of systems" or "living matrix" is not only mechanically interconnected, it is energetically and informationally continuous. Stated simply, the structural framework of the body is simultaneously an energetic and informational framework.

With this essay as background, the presentation will discuss the nature of the mechanical and energetic and informational phenomena taking place within the living matrix, and its practical clinical significance. The explanation is facilitated by an

understanding of the tensegrity concept.

TENSEGRITY

Tensegrity is the architectural concept developed by R. Buckminster Fuller that underlies geodesic domes, tents, sailing vessels, and various stick-and-wire sculptures and toy models. A tensegrity system is characterized by a continuous tensional network (tendons) supported by a discontinuous set of compressive elements (struts). Ingber and his colleagues at Harvard Medical School have shown how tensegrity is involved in the regulation of cell and tissue architecture (Ingber, 1993a,b).

Tensegrity provides a conceptual link between the structural systems and the energy-informational systems we have been discussing. The body as a whole and the various parts, including the interiors of all cells and nuclei, are tensegrity systems.

A simple tensegrity system is shown in Figure 6. The tensegrity system of a rabbit is shown in Figure 7. This remarkable diagram was obtained by representing each muscle-tendon combination as a single straight line.

When applied to the myofascial system, the tensegrity concept helps explain the ability of the body to absorb impacts without being damaged. Mechanical energy flows away from a site of impact through the tensegrous network. The more flexible and balanced the network, the more readily it absorbs shocks. This is important in understanding

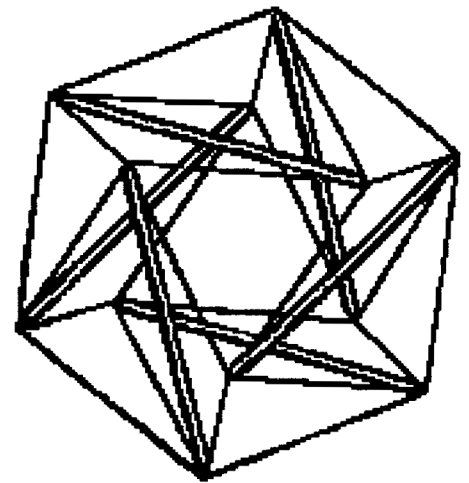


FIGURE 6.

A tensegrity system consists of a continuous network of tensile elements (called tendons) and a discontinuous system of compression members (called struts).

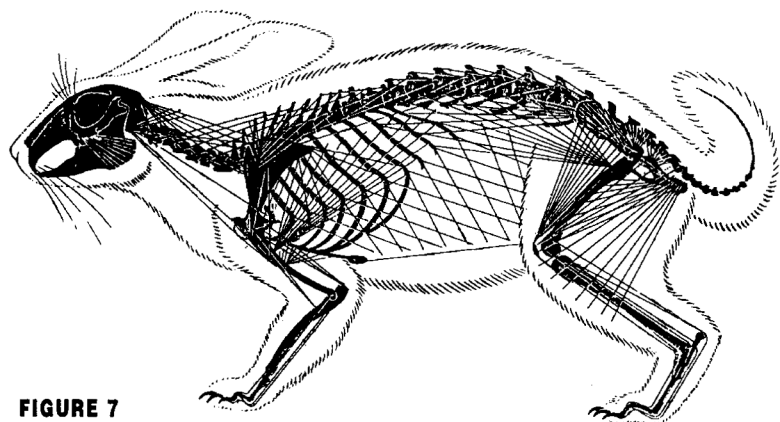


FIGURE 7

A drawing of a tensegrity system of a rabbit, created by replacing each muscle-tendon unit with a single straight line. From Young, J.Z., 1957. *The Life of Mammals*. Oxford University Press, New York. Reproduced by permission of Oxford University Press.

how flexible and well organized fascial relationships can reduce the incidence of injury to athletes and other performers.

Tensegrity also accounts for the fact that inflexibility or shortening in one tissue influences structure and movement in other parts. While a therapist may focus on improving flexibility and/or mobility of a particular part of the body, the effects can and do spread to other areas. This is in part due to the tensional integrity of the system, but it also due to the fact that the tensional system is a vibratory continuum. This can be demonstrated with a tensegrity model by plucking one of the tendons. This will cause the entire network to vibrate.

Since the tensegrity network is simultaneously a mechanical and a vibratory continuum, restrictions in one part have both structural and energetic consequences for the entire organism. Structural integrity and vibratory or energetic or informational integrity go hand in hand. One cannot influence the structural system without influencing the energetic system, and vice versa.

Donald E. Ingber and his colleagues have brought both tensegrity and solid-state biochemistry concepts into biomedicine by describing how physical forces exerted on molecular scaffolds regulate the biochemical pathways involved in determining biological patterns. His work is important to the therapist because it describes how the various kinds of manipulative therapies influence biochemical processes in important ways (Ingber, 1993a,b; Wang et al., 1993). □

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J.L. Oschman received degrees in biophysics and biology from the University of Pittsburgh. He has conducted research on physiology and cell biology at Case Western Reserve University in Cleveland, Ohio, Cambridge University in England, the University of Copenhagen, the Marine Biological Laboratory in Woods Hole, Massachusetts, and Northwestern University in Evanston, Illinois, where he served on the faculty and directed the electron microscope laboratory. He has served on the editorial board of the Journal of Membrane Biochemistry. After researching cell and tissue water transport, Dr. Oschman turned his attention to understanding the scientific basis for various kinds of "hands-on" structural, energetic, and movement therapies.

Important in this work were contacts with Nobelest Albert Szent-Györgyi and his colleagues at Woods Hole, and Dr. Ida P. Rolf, the founder of Structural Integration (Rolfing®), and her colleagues at the Rolf Institute and Guild for Structural Integration. He has written and lectured extensively on structural and energetic aspects of medicine at a variety of schools around the U.S., including the Rolf Institute, the Guild for Structural Integration, the New England School of Acupuncture, and various massage schools. In 1990, he was given a Distinguished Service Award by the Rolf Institute for his contributions in stimulating research on Rolfing.