Techniques in Orthopaedics®
18(1):67–73 © 2003 Lippincott Williams & Wilkins, Inc., Philadelphia

Bioelectric Responsiveness of Fascia: A Model for Understanding the Effects of Manipulation

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Summary: Embryologically, the largest mesodermal derivative is connective tissue encompassing blood, cartilage, bone, and connective tissue proper. Collagen is a major component of connective tissue proper and more specifically white fibrous tissue. Fascia, the largest component of white fibrous tissue, contains linear sheets of collagen found in superficial, deep, and subserous layers. Collagen is piezoelectric, functioning as a transducer of mechanical and electrical energy. Electrical impulses are generated in the collagen by compressive and distraction forces within the musculoskeletal system. These impulses trigger a cascade of cellular, biomechanical, neural, and extracellular events as the body adapts to external stress. In response to internal stress, components of the extracellular fluid change in polarity and charge affecting fascial motion. This somatic dysfunction, whether caused by internal or external stress, is identified as tenderness, asymmetry, altered motion, and tissue texture changes. Somatic dysfunction is also caused by visceral somatic relationships mediated at the level of the spinal cord. Specific patterns of somatic dysfunction in the paraspinal connective tissue are related to specific organs and act as diagnostic markers. Osteopathic manipulative treatment is a manually applied procedure used to treat somatic dysfunction. Through the application of compressive and distraction forces, the physician identifies altered patterns of motion in the fascia. Physicians trained in osteopathic manipulative techniques are able to normalize the somatic dysfunction and in so doing encourage healing. Physicians able to integrate osteopathic manipulative treatment into standard medical and surgical care have an advantage in meeting the needs of their patients. **Key Words:** Piezoelectricity—Embyologic plasticity—Somatic dysfunction—Osteopathic manipulative treatment.

In the many years of my practice, I have come to appreciate the true gift my patients bring: challenge. They challenge my understandings of health and disease, forcing me to reexamine my own paradigms and treatment practices: embryology, physiology, and anatomy appreciated through studies in biomechanics, holograms, lasers, and quantum physics. New understandings emerge of diagnoses and treatment regimens and the balance between health and disease. The integration of research from disciplines outside of medicine offer the clinician an unparalleled perspective on health and disease. This article explores some of these relationships in the hope of stimulating new understandings.

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CONNECTIVE TISSUE: THE FOUNDATION

Connective tissue is a major derivative of the mesodermal germ cell layer in the embryo. As the name implies, it connects with mesodermal, endodermal, and ectodermal derivatives as differentiation of organs and systems occurs. This special property of connective tissue allows it to act as an intermediary both embryologically and in the fully developed individual. There are four groups of connective tissue: connective tissue proper, cartilage, bone. and blood. Together they form the support structure for homeostasis that allows for normal function in the body.

A special property that connective tissue maintains throughout life is *embryologic plasticity*.[10] This property

allows differentiated connective tissue cells to dedifferentiate to a polypotential root cell and redifferentiate into another type of connective tissue cell. This process is triggered by the needs of the tissue. Histologically, traumatized tissues have contained islands of cartilage or bone in tendons or muscles. Once thought to be developmental mishaps, these are now recognized as expressions of the connective tissue's embryologic plasticity. This illustrates that in the face of traumatic biomechanical stress, connective tissue responds by changing its cell type to meet the demand on the tissue.

Many studies have been done on limb regeneration, demonstrating that when placed in an electric field, amputated rat limbs showed dedifferentiation of marrow cells and redifferentiation into muscle, tendon, and cartilage cells that grew in an organized fashion.[1] Other studies used negative electric current, silver ions, and the creation of neuroepidermal junctions to stimulate limb regrowth. These experiments demonstrate this healing ability exists to a limited degree in mammals and is controlled by the presence of specific negative electrical activity in the stump. This healing current stimulates electrically sensitive connective tissue cells that are embryologically plastic.

Limb regrowth in children has been documented in digit amputations. If in a child 11 years or younger, a digit is severed cleanly beyond the distal interphalangeal joint and left open to heal, multitissue regeneration occurs, repairing all components of the fingertip in approximately 3 months. In individuals older than 11 years this response is limited.[2] Even when placed in negative currents and with neuroepidermal connection, the adult has limited ability to sustain this healing activity long enough to regenerate more than centimeters of tissue. There is something different in the adult and in the proximal digital tissue of a child that prevents full regrowth. Stem cell research is focused on trying to understand and unlock this healing potential. In-depth discussion of these issues is outside the scope of this article.

Connective tissue types have characteristic cells and extracellular matrix. The principle cells are fibroblasts, fat cells, mast cells, fixed macrophages, plasma cells, and leukocytes. The extracellular matrix contains proteoglycans, mucopolysaccharides, and fibers of collagen, elastin, or reticulin. Other important molecules found in the matrix are mucin, chondroitin sulfate, keratin sulfate, heparin, and hyaluronic acid.[5] Each type of connective tissue is distinguished by its fiber's cells and matrix.

The cells of connective tissue are mobile, allowing migration of cells to locations to meet the needs of homeostasis. This ameboid motion is exemplified by the fibroblasts, macrophages, and white blood cells. This motion is triggered by positive or negative chemotaxis, drawing these cells along a gradient and directing the cells into and out of the area of need. This movement allows tissues to respond to changes in their environment, both internal and external, by releasing chemotactic factors, creating a gradient, and activating the movement of necessary connective tissue cells, facilitating the clearing of debris and the repair of injured tissues. This demonstrates the pivotal function connective tissue plays in the maintenance of homeostasis.

HOMEOSTASIS: DYNAMIC BALANCE

Homeostasis is both a state of equilibrium and the process by which this balance is maintained. It is a dynamic, ever-adapting, and changing series of events responding to internal and external environmental changes. The internal environment is the extracellular fluid (ECF), which contains all organs, tissues, and cells. The external environment is the aggregate of complex events outside our body that affect us. It is the challenge of homeostasis to recognize all events, external and internal, communicate needs for adaptation throughout the organism, and direct responses both internally and externally. Nothing is isolated.

Homeostasis in the ECF involves diffusion, gradients, absorption, secretion, modification of substances, excretion, metabolism, and catabolism. These complex activities involve hormones, nerve impulses, gases, nutrients, ions, and electrical potentials. Every cell contributes to and benefits from homeostasis through the ECF. In this respect, all cells are connected, and alterations in cellular relationships and functions are communicated throughout the ECF. Here, motion is imperative to life and stasis results in death.

Disease occurs when one or more systems fail to maintain their part in homeostasis. It begins as a clinically undetectable change in ECF and progresses until clinically detectable signs and symptoms appear, making the diagnosis apparent.[9] The goal of the clinician is to detect the disease and institute appropriate treatment as early as possible. This will limit the amount of damage to the systems and organs as well as enhancing the body's healing capabilities.

There is a great deal of research into viscerosomatic and somaticovisceral reflexes at the level of the spinal column.[11] These studies demonstrate how very small levels of cellular damage in end organs produce predictable patterns of detectable responses in the paravertebral musculature. The response in the paravertebrals is generated at the level of the spinal cord receiving the visceral afferents. The spinal cord segment augments the response

through the release of neurotransmitters, thus producing a much larger response in the paraspinals when compared with the amount of cellular damage in the end organ. With the resolve of the end organ cellular damage, the somatic response ceases. Osteopathic literature documents these patterns as reliable and reproducible, enabling the teaching of the viscerosomatic reflex patterns as physical diagnostic markers.[14] To the skilled diagnostician who is trained to recognize these paraspinal reflexes, earlier detection of internal disease is possible.

Other studies demonstrated that noxious paraspinal stimuli trigger end organ cellular dysfunction.[2] The relief of the noxious stimuli and the correction of the musculoskeletal dysfunction restore the end organ cellular function. Long-standing somatic input to the spinal cord causes increasing loads of cellular damage in the end organ that may not resolve with the removal of the somatic stimuli.[8] When altered or impaired function of related components of the somatic system made up of skeletal, arthrodial, myofascial structures and related vascular, lymphatic, and neural elements occurs it is called *somatic dysfunction.* In light of these concepts somatic dysfunction has both diagnostic and therapeutic implications. In a world driven by technology, physical palpatory diagnostic skills give the clinician access to homeostasis and the interrelatedness of the internal and external environments. Altered structure dictates adaptive function, and altered function dictates adaptive structure.[9]

FASCIA: SPECIALIZED CONNECTIVE TISSUE

Connective tissue proper consists of six basic types.[5] Each type is designed to provide a specific function in the support of organism integrity through structure, function, and ultimately homeostasis from the gross to the cellular. In this sense, it is aptly named.

1. Areola tissue: loosely packed, readily deformed and distended. It binds tissues and organs together, allowing freedom of motion between structures. It collects inflammatory and effused substances from organs and cells. It forms a continuous subcutaneous, submucous, and subserous tissue throughout the body. Within the loosely arranged collagen and elastin fibers travel blood vessels, nerves, and lymph vessels.
2. White fibrous tissue: very dense, linear collagenous fibers with tensile strength. It connects bones and muscles, forms investing membranes that protect organs and structures, and creates supportive pathways for nerves, blood vessels, and lymph vessels. Nerves and lymph vessels terminate in this tissue, facilitating information exchange on gross and fine motion of the musculoskeletal system. Developmentally, the pattern of linear fibers is given direction by responding to tensile mechanical forces in the growing embryo.[10] This response of collagen to mechanical forces is maintained throughout life and is discussed in more detail later.
3. Yellow elastic tissue: moderately dense with a matrix high in elastin fibers. This tissue provides elastic support to diverse tissues such as the vocal cords, blood vessels, trachea, and bronchi.
4. Mucous connective tissue: embryologically the jelly of Wharton in the umbilical cord and, in the adult, the vitreous humor of the eye. Mucin is the major component of the matrix.
5. Retiform connective tissue: the base of mucous membranes and the internal framework of organs. Fine reticulin fibers mix with white fibrous fibers to create the structure of lymphoid and adenoid tissue.
6. Basement membrane: supportive tissue for epithelium of mucous membranes and secreting glands.

Connective tissue acts as a barrier, communicator, protector, and a reactor. It supports and forms the body framework as adipose, bone, cartilage, and discs. It directs and limits planes of motion in the component parts of the musculoskeletal system with fascia, tendons, ligaments, and capsules. It protects organ structures while allowing contiguous organs and tissues to function independently. It reacts to trauma in the tissues by precipitating platelet aggregation, clot formation, and tissue repair through the ECF, and it directs the deposition of hydroxyapatite crystals in bone. It is ubiquitous.

Fascia is the largest component of white fibrous tissue. It has three layers: superficial, deep, and subserous. Developmentally, it is a continuous sheet enveloping and compartmentalizing the body. This continuity communicates local and regional events throughout the fascia. Fascial integrity is essential in the maintenance of posture, locomotion, and response to mechanical stress. The subserous fascia covers, supports, and lubricates organs. The deep fascia forms compartments for cavities, organs, and structures. The superficial fascia is related to the dermis, forming a protective covering on the body. Fascia is universal. The unique design of the fascia provides the framework in which the ECF coordinates homeostasis. No disease escapes notice and no cure occurs without the assistance of the fascia.

Disruption and distortion of the fascia triggers a repair process directed at correction of damage and strengthening of tissue. Repair is mediated by the release of chemotactic factors activating the congregation and proliferation of fibroblasts. The fibroblasts coat the injured

area with a fibrin matrix. Collagen is then deposited in a linear fashion. The fibrin matrix and collagen fibers are deposited along lines of mechanical tension in the tissue.[7] If neurologic integrity is compromised or the tissue is immobilized, dense connective tissue is formed. Edema and disruptions in circulation and lymphatic drainage also cause fibrin and collagen to be deposited in a thick and haphazard scar. These thickened areas impede normal function of the linear sheets of fascia, causing stiffness, changes in range of motion, pain, and further edema.[7] This process increases the tissue scarring in a vicious, self-perpetuating cycle. Chronic alterations in fascial integrity impede the normal function of the ECF, with consequences to the health of the whole organism. Movement is essential to the appropriate, functional repair of fascia.

The following healing concepts apply to all connective tissue when injured:

1. Linear fibrin and collagen is deposited in response to tension in the tissue.
2. Immobilization causes collagen and fibrin to be condensed and haphazard.
3. Motion improves circulation, exchange of lymphatic fluids and metabolites, and encourages the normal distribution of fibrin and collagen
4. It is essential that motion, whether passive or active, be introduced into traumatized tissue as soon as possible

The safe introduction of motion depends on multiple factors: integrity of the tissues, the amount of traumatized tissues, concomitant diseases or internal injuries, surgical interventions, infections, cooperation of the patient. and the skill of the physician or therapist. Physicians skilled in a variety of osteopathic manipulative treatment (OMT) techniques are able to address these issues and integrate OMT into standard medical and surgical care.[3,6,8,14] Physical therapists trained in the treatment of trauma are a wonderful adjunct, as are occupational and recreational therapy. A word of caution: Overly aggressive interventions are counterproductive in the treatment of traumatized patients. Care should be taken to ensure that any treatment or therapy respects the limits of the injured tissues. Exceeding these limits creates an additional traumatic event. Chronic somatic dysfunction resulting from iatrogenic trauma layered on already traumatized tissue is the most difficult dysfunction to treat.[9]

PIEZOELECTRICITY: ENLIGHTENING PROPERTIES

Fascia, as well as all connective tissue, is adaptive to changes in internal and external environments. Using the concepts of plasticity, elasticity, and viscosity, fascia responds to changes in form while maintaining function. Plastic deformation allows a formed or molded tissue to preserve its new shape. Elastic deformation is a recoverable reshaping of a tissue, and is dependent on the intact elastic function. Viscosity is the capability of a solid to yield continually under stress with a measurable rate of deformation. In intact fascia, these properties coupled with the tensile strength of linear collagen makes this tissue an excellent biomechanical reactor and protector. When traumatized, these properties serve as a tissue memory of the stress that can be recognized as altered sensation, range of motion, tissue texture, and asymmetry of the structures involved.

Physical laws of adaptability apply to fascia. *Hooke's Law* states that stress applied to stretch or to compress a body is proportional to the strain or change in length thus produced, as long as the limit of elasticity of the body is not exceeded.[12] Applying this law allows physicians to palpate, examine, and collect physical diagnostic findings on the integrity of many organs and systems. Diagnosing somatic dysfunction entails the systematic application of mechanical pressures and motions while monitoring the tissue response. Alterations in normal and predictable motions, symmetry, tissue texture, and tenderness alerts the physician to somatic dysfunction.[14] This law also applies when the forces of OMT are used in the treatment of the identified somatic dysfunction. The response in intact fascia to mechanical stress is not haphazard. It is predictable, detectable, and, when dysfunctional, it is treatable.

Wolff's Law of Bone Transformation[12] states that every change in the function of a bone is followed by certain definite changes in internal architecture and external conformation in accordance with mathematical laws. Function dictates structure. Every change in the form and the function of a bone is followed by certain changes in its internal architecture and secondary alterations in its external conformation. Structure dictates function.

Studies investigating Wolff's Law noted that if a long bone is placed under mechanical stress, the areas of compression became electronegative and the areas of tension or distraction became electropositive. This causes bone to be redistributed to the area of compression and away from the area of tension. This demonstrates that a bioelectric gradient is formed in bone in response to stress. The electronegative charge in the compressed bone stimulates osteoblast activity, and the electropositive bone stimulates osteoclast activity, allowing the remodeling of the bone.

Studies in the 1950s in Japan by Yasuda and Fukada

and in America by Bassett and Becker demonstrated that bone is piezoelectric. Piezoelectricity is a current produced by a substance that transforms mechanical stress to electrical energy. Piezoelectric substances act as transducers able to discharge electrical current when physically stressed and, when placed in an electric current, vibrate at a frequency dependent on its crystal lattice structure. Further studies identified *collagen* as the piezoelectric substance in bone.[2]

Further experiments demonstrated that the piezoelectric potentials are different from the healing negative potentials of bone growth. The piezoelectric potentials are short in duration and convey a message to the osteocytes only in response to physical stress. The healing current of bone growth is internal at the marrow and sustained. Both demonstrate the use of bioelectric currents to communicate the needs of the tissue, one in response to external stress and the other to correct internal damage.

Becker and Seldon[2] clarified the total process of Wolff's Law. They discovered that when mechanically stressed, collagen in bone produces a biphasic signal, negative with stress and positive with release. This stress–release signal is rectified to a direct current at the junction between the apatite and collagen in the bone. The strength of this signal indicates the amount of stress, and the polarity changes identify the direction of the stress. This signal triggers the osteocyte activity, allowing the bone to remodel to adapt to the mechanical stress. The electronegative signal also caused the linear alignment of collagen perpendicular to the lines of compressive mechanical stress. This alignment of the collagen becomes the base for ossification.

Collagen is the source of stress-related action potentials through its piezoelectric nature as a transducer. Collagen communicates the presence, location, direction, and strength of the stress by producing a biphasic electric current. Studies of bone remodeling by Becker et al.[2] demonstrate that the current created between the collagen and apatite is facilitated by copper ions. This link allows the bone to act as a transducer of mechanical events into electric signals. The produced electronegative field precipitates new collagen in a linear organization at the site of stress. The biphasic pulse triggers osteocyte activity and the resulting remodeling of the bone.

Further experiments by Becker et al. document that electrical changes in collagen of the periosteum triggers the embryologic plasticity of fibroblasts as the guide for healing in fractures. Disruption in the collagen of the periosteum creates a current that affects the charge of the cell membrane of fibroblasts. This cell membrane charge signals changes in the deoxyribonucleic acid and ribonucleic acid, resulting in cell dedifferentiation into a primitive cell. These cells then differentiate into the cells needed during the healing process.

These studies demonstrate how collagen is the ultimate communicator between biomechanical events, bioelectric changes, cellular function, and the ECF. It does so through its piezoelectric properties and allows the physician the opportunity to harness this power in the treatment of patients.

OMT: A BIOELECTRIC MODEL

The fascia, as discussed earlier, is a fibrous connective tissue. It contains linear collagen fibers in sheets that envelop muscles, viscera, blood vessels, and nerves. Its collagen content, relationship to the ECF, and ubiquitous expanse drew Dr. Still to describe this tissue as "the ground in which all causes of death do the destruction of life."[13] Still's fascination with the fascia in health and disease is quite evident in his writings. Just as his contemporary, Julius Wolff, he was determined to understand healing and disease. Both of these great men focused their attention on the musculoskeletal system and directed those who followed them to do the same. Still, in his practice and his teaching, emphasized the principles that the body is a unit, structure and function are interdependent and interrelated, the body has innate healing properties, and through diagnosis and treatment of the musculoskeletal system the preceding are accessed. He emphasized that any rational treatment plan is based on a thorough understanding of these principles. There is an emphasis in osteopathic medicine on the importance of integrating palpatory findings in the musculoskeletal system to the whole clinical picture. No system is isolated, no diagnosis is exclusive, and no treatment is insulated, in health and disease.

Fascia responds to biomechanical stress, through its collagen fibers, by producing microelectric potential changes. These changes communicate the biomechanical events through electrical changes in the ECF to cellular, neural, vascular, and lymphatic components. These stress-generated potentials are predictable and precise, whether traumatic or intentional. Palpation introduces compressive and distraction forces into fascial tissue that responds in predictable patterns of motion produced by adaptations to the mechanical stress. Alterations in normal patterns and ranges of motion are diagnostic parameters. Abnormal patterns of motion are recognized as restrictions to motion and ease of motion. The asymmetric motion and position of components of the musculoskeletal system are also readily identified through palpation. Responses in the ECF and surrounding structures to adaptations to stress-generated potentials produce acute

and chronic tissue textures and areas of tenderness or pain. In systemic disease or alterations in ECF electrical potentials, changes in the biomechanical integrity of the fascia occur. Areas of congestion, swelling, laxity, stiffness, and pain are produced. Palpatory findings are used by the skilled physician to identify somatic dysfunction. Integrating an understanding of the patterns of viscerosomatic and somaticovisceral relationships adds a deeper dimension to the palpatory examination.

The somatic dysfunction is treated by the appropriate application of OMT. OMT is generally categorized by the type of tissue treated, such as fascia, joint or muscle; by activating force, such as resisted active muscle contraction or physician applied compression; and whether motion is directed toward or away from a barrier to normal motion. In all types, compressive, distraction, or traction forces are introduced into the affected tissues to resolve tenderness, restore range of motion and symmetry, and reinstate normal tissue texture and tone.

The group of techniques used for the treatment of fascial somatic dysfunction is myofascial release. These techniques apply compressive and distraction forces into the affected fascia directed toward or away from a barrier of motion. Once the barrier or point of ease is engaged, the fascia responds with a decrease in resistance and motion resumes. The fascia responds rapidly to the light forces applied by the technique. This response is viewed from the biomechanical model as the result of plasticity, elasticity, and viscosity of the fascia.

During the technique, the fascia releases its restrictions in stages and leads the physician through a pattern of motion. This pattern of motion may not remain in the same direction or plane of the initiating force. The biomechanical model does not fully explain this motion. Viewing this from the bioelectric model, the response of the fascia is directed and mediated by microelectric potential changes. Internal or external trauma in the fascia leaves a pattern of bioelectric potential changes that record the direction, strength, and location as somatic dysfunction. The application of the corrective forces also produce bioelectric potentials. These induced patterns interact with the trauma pattern differently than the normal tissue. This discernible difference between the normal and dysfunctional fascia unmasks the pattern as it leads the physician along its path. The technique of activating a bioelectric response and following as the pattern releases is bioelectric fascial activation and release.

CONCLUSION

Trauma in the musculoskeletal system precipitates a cascade of events mediated by bioelectric potential changes in the collagen-laden fascia. These events have local and distant effects, ultimately affecting homeostasis. Conversely, alteration in the ECF creates bioelectric potential changes affecting fascial motion. The fascia acts as a transducer for mechanical and electrical events and as a communicator between the internal and external environment. All musculoskeletal treatment—medical, surgical, rehabilitative, or manipulative—engages these properties. Harnessing these dynamics improves diagnostic skills and provides options for treatment that will enhance the patient's ability to heal.

Applying the bioelectric model to OMT provides insight into the affects of manipulation on the cellular and systemic level. Diagnostic palpation, which introduces compressive and distraction forces into the fascia, generates bioelectric potential changes, gross and subtle motion, and alterations in tissue texture. The skilled physician is able to identify trauma and disease-altered fascia as somatic dysfunction. Once identified, the pattern, location, and type of somatic dysfunction assists in the diagnosis of visceral and somatic disease.

Treatment in the fascia also engages the same concepts. OMT is a procedure designed to address the visceral and somatic components of somatic dysfunction by normalizing motion, reestablishing symmetry, relieving pain, and restoring tissue texture. Treating somatic dysfunction enhances and supports healing and homeostasis.

It is outside the scope of this article to describe specific OMT techniques. As with any skill, education and practice lead to mastery. Many physicians are seeking training in these skills and are providing osteopathic diagnosis and treatment in their practices.[1] As more and more patients seek alternative hands-on care, the integration of OMT into your practice is an advantage for you and your patients.[4] If you are interested in educational opportunities in OMT, the American Academy of Osteopathy offers extensive physician training. To obtain a catalog of course offerings contact the American Academy of Osteopathy, 3500 DePauw Boulevard, Suite 1080, Indianapolis, IN 46268-1136 USA; phone: 317-879-1881; fax: 317-879-0563; e-mail: www.academyofosteopathy.org

REFERENCES

1. Atchison JW, Stoll ST, Gilliar WG. Manipulation, traction and massage. In: Braddom RL, ed. *Physical Medicine and Rehabilitation*. Philadelphia: WB Saunders, 1996.
2. Becker RO, Seldon G. *The Body Electric*. New York: Quill, 1985.
3. Digiovanna EL, Schiowitz S. *An Osteopathic Approach to Diagnosis and Treatment*. 2nd ed. Philadelphia: Lippincott-Raven Press, 1997.
4. Geiringer SR, Kincaid CB, Rechtien JR. Traction, manipulation and massage. In: DeLisa JA, ed. *Rehabilitation Medicine: Principles and Practice*. 2nd ed. Philadelphia: JB Lippincott, 1993.

5. Gray H. *Anatomy, Descriptive and Surgical*. 1901 ed. Philadelphia: Running Press, 1974.
6. Greenman PE. *Principles of Manual Medicine*. 2nd ed. Baltimore: William and Wilkins, 1996.
7. Kottke FJ, Stillwell GK, Lehman JF. *Krusen's Handbook of Physical Medicine and Rehabilitation*. 3rd ed. Philadelphia: WB Saunders, 1971.
8. Kuchera WA, Kuchera ML. *Osteopathic Principles in Practice*. 2nd ed., rev. Kirksville, MO: KCOM Press, 1992.
9. O'Connell JA. *Bioelectric Fascial. Activation and Release*. Indianapolis: American Academy of Osteopathy, 2000.
10. Patten BM. *Human Embryology*. 3rd ed. New York: McGraw-Hill, 1968.
11. Patterson MM, Howell JN, eds. *1989 International Symposium: The Central Connection: Somaticovisceral/Viscerosomatic Interaction, University*. Athens, OH: Classics Ltd, 1992.
12. *Stedman's Medical Dictionary*. 23rd ed. Baltimore: William and Wilkins, 1976.
13. Still AT. *Philosophy of Osteopathy*. Colorado Springs: The American Academy of Osteopathy, 1899.
14. Ward RC, ed., et al. *Foundations for Osteopathic Medicine*. Baltimore: William and Wilkins, 1997.