Fascia:Perspectives from 40 years as a Clinician and Scientist
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I am a physician in physical medicine and researcher who is crazy enough about research to have obtained my PhD during my residency program. As my wife will verify, I live, breathe, and dream research and, according to my mother, at age three I stood still for 45 minutes in the warmth of the winter sunlight streaming in through our dining room window, holding a jar of honey, proclaiming "I doing exerment [experiment]". The budding scientist in me was studying changes in the viscosity of a fluid with application of heat. I am still doing much the same thing 60 years later. Now I also am a manual therapist with a half-time clinical practice as a Certified Advanced Rolfer™. I share with you my perspective on fascia from my 40 years and both a scientist and a clinician.

I experienced Rolfing® Structural Integration in 1970, before attending medical school, and have carried the perspective on fascia developed by Dr Rolf throughout my career. Forty years ago, I studied the clinical practice and scientific basis of muscle strengthening, exercise, stretching, heat, and other therapeutic modalities that are still used in my medical specialty today. Then our resident didactic lectures got to connective tissues. From the research standpoint, all we knew was that, if you heated a rat tail, you could stretch it. I eagerly absorbed the clinical experience of my teachers, learning procedures for dealing with connective tissues developed during the polio era; but my body knew there was more.

Fast-forward 20 years. As director of Research at Kessler Institute for Rehabilitation in New Jersey, I earned the trust of the hospital leaders, who were confident that I knew my material thoroughly and well, even though they also recognized that they had no real hope of understanding it. From that vantage point, I convinced them to sponsor a training program in structural integration at the hospital in 1991, for myself and other physical therapists. The therapists began using these techniques with the traditional rehabilitation patients with good results – even publishing them (Deutsch 2000). I stayed in my research tower, except to use my bodywork training when faced with the challenge of getting Christopher Reeve off his ventilator (you can see some details in his remake of the Hitchcock thriller *Rear Window*). Even becoming a professor at UMDNJ School of Osteopathic Medicine did not dislodge me from my research perch. When I had the opportunity in 2000 for a sabbatical from my academic position, however, I did not write a book or do a new research project or visit a research laboratory. I chose to expand my horizons by setting up a clinical practice as a bodywork practitioner, and have maintained a half-time practice as an Advanced Rolfer ever since.

The fields of acupuncture, massage, structural integration, chiropractic, and osteopathy all present clinical hypotheses with fascia as a central theme. Yet many practitioners are unaware of the scientific basis for evaluating such hypotheses, and few know of the sophistication of current laboratory research equipment and methods

In real bodies, muscles hardly ever transmit their full force directly via tendons into the skeleton, as is usually suggested by our textbook drawings. They rather distribute a large portion of their contractile or tensional forces onto fascial sheets. These sheets transmit these forces to synergistic as well as antagonistic muscles. Thereby they stiffen not only the respective joint, but may even affect regions several joints further away. The simple questions from musculoskeletal textbooks regarding "which muscles" are participating in a particular movement thus become almost obsolete. Muscles are not functional units, no matter how common this misconception may be. Rather, most muscular movements are generated by many individual motor units, which are distributed over some portions of one muscle, plus other portions of other muscles. The tensional forces of these motor units are then transmitted to a complex network of fascial sheets, bags, and strings that convert them into the final body movement.

Similarly, it has been shown that fascial stiffness and elasticity play a significant role in many ballistic movements of the human body. First discovered by studies of the calf tissues of kangaroos, antelopes, and later in horses, modern ultrasound studies have revealed that fascial recoil plays in fact a similarly impressive role in many of our human movements. How far you can throw a stone, how high you can jump, how long you can run, depends not only on the contraction of your muscle fibers; it also depends to a large degree on how well the elastic recoil properties of your fascial network are supporting these movements.

Mechanotransduction

The living cell is a mechanical structure with a force balance between compression bearing microtubules and tension bearing bundles of actomyosin filaments. The cells are anchored to the extracellular matrix by clusters of integrin receptors which connect extracellular proteins to intracellular actin associated molecules. These receptors also serve to sense physical forces outside the cell and transmit that information through mechanical connections throughout the cell to the nucleus as well as multiple locations in the cell. This cytoskeleton provides both mechanical structure and direction to biochemical reactions within the cell. The cell can thus convert external mechanical signals into internal biochemical reactions (Ingber, 2010). The physiological effects of physical forces have long been recognized by clinicians – for example tension and skin aging, compression and bone formation, shear stress and vascular remodeling. With the deciphering of the human genome, it remains to develop a comprehensive theory which incorporates three dimensional geometry and physical forces to explain the folding, assembly and function of biosynthesized molecules (Fredberg et al., 2009).

What does this mean for the clinician?

A better understanding of mechanochemical control mechanisms may let us correct mechanical loading or mechanochemical signaling in adult conditions. Use of the experimental methods developed may allow us to explore the effects of externally applied forces such as repetitive stress disorders or manually applied therapies. Many clinical therapies use externally applied forces based on empirical observations (some ancient), but rarely if ever are these treatments anchored in the biomechanical environment of the cell. Recent developments in medical diagnostic imaging may allow direct observation of this biomechanical context.

Fibroblasts

Fibroblasts synthesize, organize and remodel collagen, depending on the tension between the cell and the extracellular matrix. At low tension, the fibroblast in a resting state with low synthesis of collagen matrix assumes a morphology of a small cell body with dendritic extensions connected to other cells by gap junctions. When placed in a high tension matrix the fibroblasts assume a larger cell body of lamellar shape, and increase their collagen synthesis and cell proliferation. They can also further differentiate into myofibroblasts from this lamellar state. Each fibroblast can remodel nearby collagen matrix, and this local remodeling can spread throughout the matrix to result in large scale matrix contraction. By exerting traction on the matrix, the fibroblast can either cause motion of the collagen or movement of the fibroblast through the matrix (Grinnell, 2008). Fibroblasts produce and degrade matrix proteins, with an indirect effect on matrix stiffness. They can also differentiate into myofibroblasts which can contract and increase matrix tension. By changing shape, the fibroblast can affect stiffness and viscosity of connective tissue within minutes, consistent with the mechanotransduction models of microtubule network expansion and actomyosin generated tension proposed by Ingber. The fibroblast may also remodel cell matrix contacts in the direction of tissue stretch to reduce tension (Langevin et al., 2011).

What does this mean for the clinician?

Connective tissue actively regulates matrix tension in response to stretch as a normal, dynamic physiological process. Understanding how cells respond to forces can lead to potential treatments to decrease fibrosis in cases where the forces remain high. Yet to be explored are techniques to increase fibrosis in tissues which are too lax.

Microscopic fascial anatomy

The deep fascia is a highly vascular structure with a superficial and a deep layer, each with an independent rich vascular network of capillaries, venules, arterioles, and lymphatic channels. The presence of mast cells in deep fascia suggests a protective role similar to other connective tissues. The deep layer has few elastin fibers but does have myofibroblasts suggesting contractile ability. Any active contraction would need to be controlled by a nerve supply, and indeed one finds myelinated and unmyelinated nerve axons, and Schwann cells. The deep fascia is not just a tough barrier structure of collagen and elastin, but is a metabolically active vascular layer which provides gliding and protective functions (Bhattacharya et al., 2010). Deep fascia has parallel longitudinal collagen bundles and rudimentary elastic laminae, giving it both high tensile strength and elasticity. At the junction between the deep fascia and the muscle, without any special secretory cells, the fascia is able to maintain a lubricating layer of hyaluronic acid. However, when the epimysium is disrupted the overlying fascia does not remain distinct and does not create a gliding layer over the scar (McCombe et al., 2001). This is consistent with more recent findings that while hyaluronic acid is a lubricant, breakdown products of this large molecule are themselves tissue irritants.

What does this mean for the clinician?

Fascial layers are able to produce a lubricant, hyaluronic acid, which allows sliding between the fascia and neighboring muscle. The architecture of the fascia allows continuity of nerves, blood and lymph vessels between the sliding tissues. With trauma to the muscle, the overlying fascia no longer produces the sliding layer of hyaluronan. Anatomic and clinical studies will be necessary to identify and improve methods to maintain sliding after tissue trauma.

Interstitial fluid flow

Dynamic mechanical stresses have long been recognized as important in the maintenance of supporting structures such as bone and muscle. Less well recognized is the need for stresses and pressure gradients to maintain function in all living tissues. In soft tissues interstitial flow is primarily driven by plasma leaving the blood capillaries, and that pressure gradient in turn is affected by large movements of the skeletal system and smaller motion from arterial pulsation, respiration and organ motion. This slow interstitial flow can have a direct mechanical effect on cells, as well as transporting proteins and other components of the biochemical environment. Increased interstitial flow stimulates fibroblasts to differentiate into myofibroblasts, increase production of collagen and other factors associated with fibrosis (Rutkowski and Swartz, 2006). All organs in the body must be viewed in the context of the surrounding blood and lymphatic vessels as well as the loose connective tissue which has four main components:

1) a network of collagen fibers which is the primary 3 dimensional scaffold for the blood vessels
2) elastin microfibrils
3) ground substance including hyaluronan
4) interstitial fluid.

There are interesting and surprising research findings on interactions among these elements. Connective tissue cells directly exert tension on both the collagen and the elastin fibers through β 1 integrin mediated contraction. This restrains the fluid retaining capacity of the ground substance which is normally underhydrated. While hyaluronan levels tend to remain stable, it is not a static tissue but rather has both rapid synthesis and turnover. Finally, the interstitial fluid depends on the fluid flux across the capillary and the removal through the lymph system. In humans the extracellular fluid volume is 15 L, with normal blood plasma volume of 3 L, and 6–10 L passes through the lymph system each day with resulting turnover of extracellular fluid every 48 h (Reed and Rubin, 2010). Collagen displays piezoelectric properties and this was invoked 50 years ago from studies of dried bone as a mechanism to explain the remodeling of bone in response to stress. However, when investigators began studying wet bone, they found the remodeling was directed by streaming potentials from the movement of fluid through the rigid bone channels (canaliculi connecting with Haversian canals) (Ahn and Grodzinsky, 2009).

What does this mean for the clinician?

Therapies designed to locally increase edema such as Chinese cupping may increase the adaptability of the fluid flow adjustment systems by temporarily increasing fluid flow. Therapies designed to reduce lymphedema must take into account the tissue changes which take place with prolonged decrease in interstitial flow, including the increased tissue compliance or “overstretching” of the interstitial matrix. Organs must be viewed in the context of the surrounding connective tissues and distant blood and lymphatic fluid flow, and specific organ pathology cannot be fully understood or treated without taking those tissues into account.

Any discussion of fascia must always return to the observations on its function made by the greatest fascia clinician of all, Dr. A.T. Still. More than 100 years ago, he started the profession of osteopathic medicine. The more we learn, the more we appreciate his conclusion “This life is surely too short to solve the uses of the fascia in animal form.” Dr. Still spent years studying and experimenting before he opened the American School of Osteopathy in Kirksville in 1892. His philosophy of osteopathy was based upon the concepts of body structure and health maintenance rather than disease. Dr. Still recognized the importance of fascia in health, and recent research has shown that many of his ideas about fascia are valid.

The study of fascia best starts with A.T. Still’s actual words: “How to find causes of diseases or where a hindrance is located that stops blood is a great mental worry to the osteopath when he is called to treat a patient. The patient tells a doctor "where he hurts," how much "he hurts," how long "he has hurt, ' ' how hot or cold he is…An osteopath, in his search for the cause of diseases, starts out to find the mechanical cause. He feels that the people expect more than guessing of an osteopath. He feels that he must put his hand on the cause and prove what he says by what he does; that he will not get off by the feeble-minded trash of stale habits that go with doctors of medicine. By his knowledge he must show his ability to go beyond the musty bread of symptomatology…

“I know of no part of the body that equals the fascia as a hunting-ground. I believe that more rich golden thoughts will appear to the mind's eye as the study of the fascia is pursued than of any other division of the body. Nevertheless, one part is just as great and useful as any other in its place. No part can be dispensed with.

“In every view we take of the fascia a wonder appears. The part the fascia takes in life and death gives us one of the greatest problems to solve. It surrounds each muscle, vein, nerve, and all organs of the body. It has a network of nerves, cells, and tubes running to and from it; it is crossed and no doubt filled with millions of nerve-centers and fibers which carry on the work of secreting and excreting fluids vital and destructive. By its action we live and by its failure we die. Each muscle plays its part in active life. Each fiber of all muscle owes its pliability to that yielding septum-washer that allows all muscles to glide over and around all adjacent muscles and ligaments without friction or jar. It not only lubricates the fibers, but gives nourishment to all parts of the body. Its nerves are so abundant that no atom of flesh fails to get nerve- and blood- supply therefrom...

“I write at length of the universality of the fascia to impress the reader with the idea that this connecting substance must be free at all parts to receive and discharge all fluids, and to appropriate and use them in sustaining animal life, and eject all impurities, that health may not be impaired by dead and poisonous fluids. A knowledge of the universal extent of the fascia is imperative, and is one of the greatest aids to the person who seeks the causes of disease. The fascia and its nerves demand his attention, and on his knowledge of them much of his success depends…

“When you deal with the fascia you are doing business with the branch offices of the brain, under a general corporation law, and why not treat these branch offices with the same degree of respect? The doctor of medicine does effectual work through the medium of the fascia. Why should not you relax, contract, stimulate, and clean the whole system of all diseases by that willing and sufficient power you possess to renovate all parts of the system from deadly compounds that are generated on account of delay and stagnation of fluids while in the fascia?” Still 1902, 1910.

For many years both amateur and professional athletes have looked to exercise physiologists and trainers for ways to improve and maintain their performance, and avoid injury. Forty years ago, there was research relating to building muscle strength through concentric and eccentric exercise, with isometric, isokinetic and isotonic exercises as the building blocks spaced over various repetitions and intervals. This was followed by research about muscle loss with inactivity, and exercise to combat that loss, made particularly important by the space program. Muscle biopsies showed slow twitch and fast twitch fibers, with little conversion of fiber types from one to the other. When changes in force generated by muscles were seen in a matter of days, long before there was any demonstrable change in muscle fiber size, this was attributed to changes in the innervations and activation of the muscle. At the end of the day, however, all these studies led to the same conclusion: to improve performance in a specific activity (as opposed to strength in an isolated muscle), the best training is that activity itself, which involves motion of the whole body.

At the same time, models of movement based on muscles and bones were challenged by the reality of motion which could not be explained. In the low back, lumbar fascia needed to be added to the model to account for movement capabilities. The running ability of Oscar Pistorius, the double amputee excluded from the regular Olympic games for fear that his bilateral below knee prostheses gave him an artificial advantage over athletes with normal calf muscles, shows that lower leg muscles are not sufficient or even necessary forces in propelling the human body. Studies of storage of energy in tendon and other connective tissues showed their importance in human gait – it turns out the normal musculoskeletal locomotor system in humans is indeed slightly better (92-95% energy returned from the tendon) than his spring based prostheses (91%), although the mechanics of gait are quite different (Weyand 2009). And in animals such as the Kangaroo, energy storage in tendons is critical in maintaining the repetitive patterns of locomotion (Alexander 2002).

It rapidly gets very complicated. There are nerves in the motor cortex of the brain which directly communicate with muscles via a single synapse in the spinal cord. Fortunately, we do not have to use these often, or we would spend forever figuring out how to move. We have patterns of movement which we are born with, and others which we learn through repetition, and we generally rely on these automatic patterns to accomplish our daily activities. Remember how many months it took you to learn how to walk the first time? You may not, but your parents do. And we don't ordinarily forget these patterns, even after many years of disuse. How many of us have forgotten how to ride a bicycle? If you have a stroke which interferes with movement patterns, learning to walk the second time around goes quicker.

The "fascial system" consists of a body-wide tensional network of fascia. There is a continuity of fibrils from the extracellular matrix through the integrin receptor and the cell membrane to the nucleus. Manual massage after exercise can be seen to activate the force conducting pathways to the nucleus, followed within hours by changes in gene transcription (Crane 2012). It is a useful concept to think of the body as a fascial network with connections to muscles and bones, rather than the more traditional view of a musculoskeletal system with fascia connections. This suggests that the contraction of the trunk muscles prior to use of the superficial muscle slings may not be just stabilizing the trunk – rather, it may be taking the slack out of core fascial layers to allow "pre-stretch" and energy storage for release later. Golfers and martial artists know the power in proper trunk rotation.

There are clear differences in mobility of tissues around the joints – with some people being more flexible than others. However, flexibility is not always a uniform function, and the astute clinician will find patients with flexible elbows and tight hamstrings, and vice versa. Indeed there are some rare muscle disorders characterized by certain tight and other loose joints (Voermans 2009) Stretching results in short term changes in viscoelastic properties of the muscle and tendons with decreased muscle performance lasting a few minutes (Mizuno 2014) . If we return to the notion that fascial tissues store energy for release during activities, we come to the logical conclusion that stretching these tissues to the point where their energy absorbing properties are permanently altered will result in reduction in energy release and subsequent performance. The mechanical interactions among muscle, tendon and fascia in humans have developed over many thousands of years to allow us to adapt to a wide range of activities, and we are just beginning to understand these to be able to direct such adaptation by specific exercises and activities which differ from the final desired task.

Skeletal muscle clearly responds to loading by hypertrophy and other adaptations which increase its capacity for force generation. Extending this concept to connective tissue explores loading in the context of adaptation or overloading pathology. For certain occupations, specific cycles of work/rest can be identified as tolerated or leading to functional loss. Again, task specificity is paramount. Adult tendons show little change or remodeling in the adult, unless there is wound healing to be repaired. But to put this into perspective, connective tissue turnover every two days is found in the tiny fibers connecting a muscle to the nearby arteriole, which pull open the nitric oxide receptors and increase blood flow to the contracting muscle (Hocking 2008)

A broad range of physiology and biochemistry factors need to be taken into account to understand the basis for the broad spectrum of clinical applications purporting to affect the "fascial organ." Some factors are specific to fascia. Others, such as work hardening, are general properties of hardening by plastic deformation which have been used with copper, steel and other metals for thousands of years.

Guidera's (2012) paper "Cervical fascia: a terminological pain in the neck" concisely summarizes, "There is considerable confusion surrounding the terminology and interpretation of cervical fascia and its associated potential spaces…There is a clear need for consistent evidence based definitions and terminology, incorporating results from recent scientific studies using modern anatomical techniques and cross sectional imaging, and clinical investigations." We would do well to be guided by A.T. Still's insightful clinical observations of fascial functions as we add anatomic precision, using the terms suggested by Langevin (2009) for specific layers and structures. And "fascia" may graduate from being a connective tissue, a cellular and extracellular matrix filler between defined structures, to become regarded as a connective structural system with well defined functions from the embryo to the adult (and for food scientists, beyond death).

I can speak from my perspective as a physician in physical medicine and researcher who is also a bodywork practitioner. Forty years ago the study of physical medicine and rehabilitation included muscle strengthening, anatomy, exercise physiology, and other aspects of therapeutic modalities. What was notably less present in the scientific and medical literature was how to understand and treat disorders of the fascia and connective tissues. After several decades of severe neglect, fascia is developing its own identity within medical research and is being found to play an important role in health and pathology.

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