Journal of Bodywork & Movement Therapies (2014) 18, 259–265

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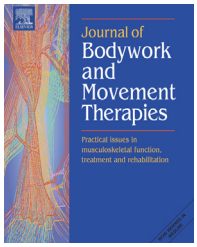

FASCIA SCIENCE AND CLINICAL APPLICATIONS: EDITORIAL

Does fascia hold memories?

KEYWORDS
Tissue memory;
Fascial mechanisms;
Fascial contraction;
Fascial treatment;
Bodywork;
Fascial release

Summary The idea that tissues may possess some sort of memory is a controversial topic in manual medicine, calling for research and clinical exploration. Many bodyworkers, at some point in their practice, have experienced phenomena that may be interpreted as representing a release of memory traces when working on dysfunctional tissues. This feeling may have been accompanied by some type of sensory experience, for the therapist and/or the patient. In some cases, early traumatic experiences may be recalled. When this happens, the potency of the memory may be erased or eased, along with restoration of tissue function. Hence the questions: can memories be held in the fascia? And: are these memories accessible during manual fascial work?

Modern research has proposed a variety of different interpretations as to how memory might be stored in soft tissues, possibly involving other forms of information storage not exclusively processed neurologically (Box 1).

Neuro-fascial memory

Early investigations of fascia showed that it is well innervated (Stilwell, 1957), especially by afferent free nerve endings, including nociceptive ones (Yahia et al., 1992). Irritation of these primary afferent nociceptive fibres can initiate the release of neuropeptides, which in turn may alter the normal tissue texture of the surrounding connective tissue, through their interaction with fibroblasts, mast cells, and immune cells (Levine et al., 1993). This process may trigger a number of both local and global responses: connective tissue remodelling, inflammation, nervous system sensitisation (Langevin and Sherman, 2007), pain – possibly evolving into persistent pain (Melzack et al., 2001), eventually followed by an adaptive response of the whole organism (Willard, 1995). Thus, under certain dysfunctional conditions, a neuro-fascial interaction may be responsible for the setting of a local tissue "memory" (peripheral sensitisation – Nickel et al., 2012), followed by a corresponding spinal facilitation (Baranauskas and Nistri, 1998). This may lead to a possible global effect through the involvement of higher centres (Nijs and Van Houdenhove, 2009) and of autonomic and endocrine pathways (Cortelli et al., 2013). Changes not only of neural pain-signaling mechanisms might follow, involving the function of somatosensory and cognitive/affective areas in the brain (Staud et al., 2007).

Fascial treatment may access such memories and obtain therapeutic effects. For instance, in indirect types of fascial techniques, the unloading of the tissues may cause a consequent decrease of neural input and mechanical load through the fascial structures, possibly unloading muscle spindles while loading Golgi tendon organs (Van Buskirk, 2006). This may change the pattern of sensory input to the facilitated spinal cord area, quieting the nociceptors (Kakigi and Watanabe, 1996). Local and spinal cord level autonomic reflexes would be stilled, particularly the sympathetic drive which may have encouraged vasoconstriction and diminished lymphatic flow. This may encourage more normal pumping action of the muscles and improved fascial sliding motion (Tozzi et al., 2011).

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http://dx.doi.org/10.1016/j.jbmt.2013.11.010

Word box 1. **Neural memory and morphic fields: a theoretical model**
Initially, memory traces were thought to be stored as patterns in specific areas of the brain: so that electrical stimulation of these areas could activate sequential records of 'memories' (Penfield, 1975). However, the same recollections could also be evoked by stimulating the brain at different sites, as well as different recollection being produced by repeatedly stimulating the brain at one site. Therefore, it seemed that rather than being confined to a specific location, memories are diffused throughout the brain. A new interpretation was then advanced suggesting the possibility that the brain may store memories as interference patterns, in a holographic-like manner (Pribram, 1969). According to this theory, memory, including that of pain (Ray et al., 2013), is to be found not in the patterns of neural activity of a specific brain region, but in the interference patterns of nerve impulses that crisscross the entire brain in the same way that laser light interferences crisscross the entire area of a film containing a holographic image. It is suggested that this phenomenon may be extended throughout the organism, via the neuro-fascial interactive function, involving a process of encoding memories in the connective tissues in a holographic-like manner. The brain (and maybe all connective tissues?) may then be able to compare stored holographic patterns with newly acquired ones, directly through "adaptive resonance", allowing rapid processing of recognition and learning (Marcer, 1992).

Along this line of thought, Sheldrake's theory goes further. He basically proposes that memory is maintained in morphic fields: potential organizing patterns of influence, extending in space and continuing in time. "Memory is inherent in all organisms in two related ways. First, all organisms inherit a collective memory of their species by morphic resonance from previous organisms of the same kind. Second, individual organisms are subject to morphic resonance from themselves in the past, and this self-resonance provides the basis for their own individual memories and habits" (Sheldrake, 1988). In this way, a sort of "phylogenetic memory" is constructed. Obviously, this theory represents a radical alternative to the conventional idea that memories are encoded as material traces within the nervous system, or in body tissues in general. The idea has even been advanced that such collective memory field can be holographically stored in the surrounding environment, accessible by the brain (and possibly by the rest of the body) just as a radio tunes in to music from surrounding electro-magnetic fields (Laszlo, 1995).

Fascial memory

Memories in the body may be also encoded into the structure of fascia itself. Collagen is deposited along the lines of tension imposed or expressed in connective tissues at both molecular (Gautieri et al., 2011) and macroscopic level (Sasaki and Odajima, 1996). Mechanical forces acting upon the internal and/or external environment, such as in postures, movements and strains, dictate the sites where collagen is deposited. Thus, a "tensional memory" is created in a particular connective tissue architecture formed by oriented collagen fibres. This architecture changes accordingly to modification of habitual lines of tension, providing a possible "medium term memory" of the forces imposed on the organism. However, this type of signalling may be altered in pathological conditions, such as locally decreased mobility due to injury or pain (Langevin, 2006). In cases of functional strain or mechanical stress through collagen bundles, known physiological responses involve fibroblast mechano-chemical transduction, and modulation of gene expression patterns (Chiquet, 1999), together with inflammatory and tissue remodelling processes of the collagenous matrix (Swartz et al., 2001). Furthermore, the release of substance P from nerve endings, particularly driven by the hypothalamus following emotional trauma, may alter the collagen structure into a specific hexagonal shape, referred as "emotional scar" (Heine, 1990). The entirety of this phenomenon may be interpreted as a highly structurally and functionally specific process of encoding memory traces in fascia.

Extracellular matrix and tissue memory

In addition, this ability seems to be present not only in the collagen network but also in elastin fibres and in various cells throughout the connective tissue: fibroblasts, mast cells, plasma cells, fat cells. Since these are relatively durable and long-lasting cells, they may represent a kind of "long-term memory" of the ground substance. "The existence of a cellular network of fibroblasts within loose connective tissue may have considerable significance as it may support yet unknown body-wide cellular signaling systems." (Langevin et al., 2004). The ground substance, in turn, provides a non-genetic memory complementary to the genetic one by ensuring a consistent set of signals to the cells. In fact, while genes may provide information to the ground substance on "how to", the ground substance may define for the cell "what to", shaping individual patterns of metabolism, development, growth, repair and behaviour (Lu et al., 2011). This microenvironmental memory, underlying most pathobiochemical events, has been indicated to be dependent on matrix turnover and, as such, to be erasable via fibroblast induction and maintenance (Tan et al., 2013). The extracellular matrix may play a crucial role in sensing, integrating and responding to the "physical and chemical environmental information either by directly connecting with the local adhesion sites or by regulating global cellular processes through growth factor receptor signalling pathways, leading to the integration of both external and internal signals in space and time" (Kim et al., 2011).

Epigenetics and tissue memory

Epigenetics is the study of changes in gene expression or cellular phenotype, caused by mechanisms other than changes in the underlying DNA sequence. Epigenetic regulation of gene expression occurs due to alterations in chromatin proteins independently of the germline. This alteration of chromatin architecture produces consequent changes of accessibility of genes and of their expression that are preserved during cell division (Arnsdorf et al., 2010) and is therefore heritable. In this sense, epigenetic modifications represent a sort of "family memory", implicated in the control of several cellular processes including differentiation, gene regulation, development and genomic imprinting. Epigenetic changes, including DNA and hystone methylation, might also cause a stable fibroblast activation, capable of altering immune function, thus producing inflammatory responses that may underlie the development of chronic diseases (Ospelt et al., 2011). Epigenetic regulatory pathways may in turn explain differences in phenotypes between subgroups of patients and also between subsets of fibroblasts within the involved joints (Sánchez-Pernaute et al., 2008).

As far as manual therapy is concerned, evidence suggests that mechanical signals are crucial regulators of cell behaviour and tissue differentiation by affecting gene regulation at the epigenetic level, through an heritable reduction of DNA methylation (Arnsdorf et al., 2010). This process may regulate extracellular matrix composition, inflammation, angiogenesis and fibroblast activity involved in tissue repair and function (Bavan et al., 2011).

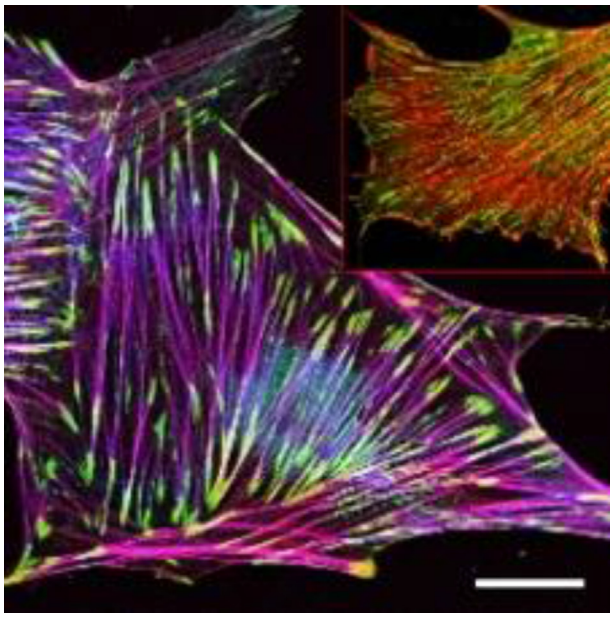

Figure 1 Myofibroblast morphology differs on stiff and rigid culture substrates. Myofibroblasts cultured on rigid plastic surfaces and soft polymer substrates (inset) were immunostained for polymerized actin (red), α-SMA (blue) and FAs (vinculin, green). On rigid plastic, myofibroblasts develop thick stress fiber bundles that incorporate α-SMA (purple color) and that insert at sites of large supermature FAs. On soft polymer substrates large FA cannot develop and α-SMA is not recruited to stress fibers (red). Note that both cells are displayed at the same magnification. Bar: 50 μm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this editorial.) From Wipff and Hinz (2009) with permission.

Microtubules, gel-sol transformation and tissue memory

Even sub-components of the cytoskeleton, such as microtubules, seem to be capable of storing information and somehow being capable of retaining memory traces. In fact, microtubules may act like computers, storing memories in the form of "information strings" (Hameroff et al., 1988). They are polymers made up of polarized monomeric subunits, known as tubulin. Information may be stored through different orientations of tubulin monomers. In addition, proteins known as microtubule associated proteins (MAP's) may encode information to the microtubule, by changing their position of attachment. For instance, the neural MAP's have long been noted for their enhancement of tubulin assembly and microtubule stability (MacRae, 1992), influencing microtubule spatial organization and interaction with cellular organelles, thus offering a record of cytoskeletal organization and cell function at the time of assembly. Interestingly, the information stored on a microtubule can be erased by depolymerizing it back into its monomeric units. Pressure and temperature change may cause microtubules to depolymerize or fall apart (Tanaka, 1981). Possibly, this mechanism may underlie the changes in tissue viscoelastic properties as well as in the colloidal consistency of the ground substance after fascial treatment. Research suggests that an increase in the sliding of the tissue layers, together with a decrease in pain following manual fascial work, may be the result of a transformation of the ground substance from its densified state (gel) to more fluid (sol) state (Findley, 2009). This change in viscosity seems to increase the production of hyaluronic acid, together with the flow within the fascial tissue: to improve drainage of inflammatory mediators and metabolic wastes (Schultz and Feltis, 1996); to decrease chemical irritation of the autonomic nervous system endings, and nociceptive stimuli to somatic endings (Lund et al., 2002), therefore resetting aberrant somato-visceral and/or viscero-somatic reflexes (Kuchera and Kuchera, 1994). Manual therapy may then activate an 'erasing process' via a gel-sol transformation of the matrix causing a reset of dysfunctional memories, possibly stored in the fascia.

Fascial contractility and tissue memory

Another way in which fascia may encode memory traces is through its contractility and related reflexive spinal activity and central control. After the discovery of myofibroblasts in the connective tissue (Gabbiani, 1998), the presence of alpha smooth muscle actin in the structure of myofibroblasts has also been demonstrated (Hinz et al., 2004), together with its responsiveness to mechanical stress (Figure 1, Wipff and Hinz, 2009). This supported a plausible capacity of fascial contractility in a smooth muscle-like

manner and its potential influence on musculoskeletal dynamics (Schleip et al., 2005) as well as on resting muscle tone (Klingler et al., 2007).

In addition, the evidence of intrafascial smooth muscle cells and autonomic nerves supports the hypothesis that a fascial pre-tension may be regulated via autonomic activity, independent of muscular tonus (Staubesand and Li, 1996). Thus, since fascia appears to be organized in tensile myofascial bands, that comprise a single continuous structure (Myers, 2000), the repercussion of an intra-fascial restriction may be body-wide, and may potentially create stress on any structures enveloped by, or connected to, fascia. Dysfunctional memory might therefore be imprinted by the development of fibrous infiltration and cross links between collagen fibers at the nodal points of fascial bands, together with a progressive loss of elastic properties. Consequently, these changes in myofascial tissue may alter the activity of related superior centres accounting for both sensory integration (Schabrun et al., 2013) and motor control (Tsao et al., 2008).

A therapeutic touch may subsequently produce stimulation of pressure-sensitive mechanoreceptors in the fascial tissue followed by a parasympathetic response (Schleip, 2003). Under parasympathetic influence, a change in local vasodilatation and tissue viscosity, together with a lowered tonus of intrafascial smooth muscle cells, may occur. Finally, in response to the proprioceptive input, the central nervous system may change muscle tone, allowing the therapist to follow myofascial paths of least resistance to the point where correction of dysfunctional matrix cross-linking is achieved (Cantu and Grodin, 1992).

Chemical memory

Another mechanism by which fascia may store memories is via chemical messages. A variety of substances are constantly transmitting innumerable messages throughout the body, including peptides whose messages are relayed through receptors in target cells (Pert, 1997). Depending on the precise external or internal stimulus a particular 'information substance' will flow through the body and bind to specific receptor sites. When this binding occurs, particular feelings are perceived encoded with a given memory. Such chemical messengers act reciprocally on the brain and the rest of the body, thanks to the denser presence of their receptors in the limbic (emotional) portion of the brain (Pert et al., 1998). The body might therefore be conceived as a single organ with full sensing capabilities, where any tissue may store emotional memories based on the specific receptors they possess, and the nature of the chemical messages they receive (O'Connor, 2005).

Manual fascial work may produce beneficial effects on chemically induced memory via a main pathway: the anandamide effect on the endocannabinoid system. The latter being an endorphin-like system constituted of cell membrane receptors and endogenous ligands (McPartland et al., 2005). This system influences fibroblast remodelling, and may play a role in fascial reorganisation, in diminishing nociception and reducing inflammation in myofascial tissues. Cannabinoids are also linked to cardiovascular changes, smooth muscle relaxation and possibly mood changes through their role on the central nervous system (Ralevic et al., 2002). Fascial tissue work may also produce the enhancement of cytokine pools (Willard et al., 2010) from actively proliferating fascial fibroblasts. Such fascia-derived cytokines may be delivered systemically, even in distant sites to that treated, via intrafascial blood flow (Bhattacharya et al., 2005), possibly reducing oedema, increasing range of mobility, decreasing pain (Meltzer and Standley, 2007) and removing fibrotic materials (Dodd et al., 2006), even at sites distant to those where the manual treatment is applied.

Tensegrity, vibration and tissue memory

According to the tensegrity model, the whole body is a three-dimensional viscoelastic matrix, balanced by an integrated system of compression-tensional forces in dynamic equilibrium.

In this vision, bones are the non-touching rods, that play the role of compression struts, embedded in a continuous connecting system (the tension system), that is the myofascio-ligamentous tissue in the body (Levin, 1990). Thanks to its hierarchical organization, any applied force can influence any part of the entire system, from cellular to the whole-body, and vice-versa, via a non-linear distribution of forces, in such a way that local stimuli invariably lead to global reorganization (Chen and Ingber, 1999). This structural and tensional continuity provides the basis for the continuum communication model: cytoskeletons of epidermal, vascular, connective tissue, and nerve cells, together with the extracellular matrix, form an electromechanical semiconducting matrix that can generate and communicate coherent vibratory signals throughout the body (Pienta and Coffey, 1991).

This system may be largely responsible for the rapid intercommunication that enables the body to function effectively as a coherent whole. It has been suggested that all the major constituents of living organisms, including collagens and proteoglycans, may be liquid crystalline in form (Giraud-Guille, 1992). In particular, fascia presents crystalline collagen strands with dielectric and electrical conductive properties that make them very sensitive to mechanical pressures, electromagnetic fields, pH, and ionic composition (Leikin et al., 1993). In fact, collagen fibers display a polarity within their molecular structure, and can therefore generate piezoelectricity. Application of an electric stimulus causes mechanical motion (vibration) while application of physical force (tension, compression, or shear) generates electricity (Lee, 2008). Collagen fibers are arranged in highly ordered, crystalline arrays and this semiconducting system produces coherent oscillations that move rapidly throughout the living matrix (Searle and Williams, 1992).

Therefore, fascia seems to combine the property of a sol-liquid conductor and of a crystal generator system, which can generate and conduct direct currents as well as vibrations. A consequence of such communication is that every process occurring anywhere in the organism produces a characteristic pattern of vibrations that travel widely, distributing regulatory information (Oschman, 2009). Every time a cell changes its shape or metabolism, every time a muscle contracts, a neuron synapses, or a gland secretes, the frequency of transmission of such vibratory signals changes throughout the system. The system is therefore

instantly informed of events occurring elsewhere in the network. Some theories hypothesize that the totality of such vibratory messages throughout the matrix may constitutes a "body consciousness" functionally interconnected with the "brain consciousness" of the nervous system, via the crystalline liquid medium of the ground substance (Ho and Knight, 1998). Memories related to diseases, dysfunctions, pain, infection, injuries, surgeries, physical and emotional trauma may be stored within this system, influencing the normal informational pattern either locally or globally, altering the properties of the fabric, distorting resulting vibrations. In this way, consciousness may be influenced by memories stored in soft tissues.

From a therapeutic perspective, it has been demonstrated that manual low frequency oscillations can induce muscle relaxation, provoking a significant change in motoneuron excitability (Newham and Lederman, 1997). In addition, both primary and secondary nerve endings exhibit sensitivity to vibration and sinusoidal oscillation (Bach et al., 1983), with a build up in amplitude of response when oscillations near the resonant frequency are applied. A slow rhythmic pendular swing has been shown to cause an inhibitory effect on vestibular nuclei, resulting in muscle relaxation, by inducing a psychogenic relaxation (Ayres, 1979). Vibration has been demonstrated to be a critical epigenetic factor on regulating the microenvironment of the extracellular matrix, thus provide a basis for reducing tissue adhesions and improving function (Kutty and Webb, 2010). Finally, oscillations may promote intercompartmental fluid flow through hydraulic mechanisms (Lederman, 1997) as well as have a possible modulating effect on spinal excitability (Kipp et al., 2011) and on the pain gate in the central nervous system (Coghill et al., 1994). These beneficial effects on the nervous system function following a vibratory treatment may be also due to an increase of endoneural blood flow (Lythgo et al., 2009).

Water and memory

Water molecules and their behaviour in living tissues may also account for the ability of fascia to store memory. The collagen tissues of the body are embedded in layers of structured water molecules. Research suggests that interfacial water plays a key part in protein folding - the process necessary for cells to form their characteristic shapes (Sommer et al., 2008). When associated with protein structures, water can demonstrate a tendency to behave in a crystalline manner, and to be influenced by properties that make up the cell, exhibiting structural organizations that differ from what is termed "bulk" water (Pollack et al., 2006). The polarized water and ions surrounding proteins (including collagen) are highly ordered, forming chain-like filaments that hold the proteins together, via hydrophilic interactions of hydrogen-bonds (Leikin et al., 1993). This system constitutes a hydrogen-bonded network that can support rapid jump conduction of protons (Sasaki, 1984), much more rapidly than conduction of electrical signals by the nerves. In other words, protein motions generate vibrational deformations of peptide bonds, which will involve polarization waves along the proteins, accompanied by proton conduction in the structured water shell. Thus, as dielectric system, the organism may exhibit coherent vibrations as result of metabolic pumping, where electromagnetic and electromechanical forces interact (Fröhlich, 1982). Weak signals of mechanical pressure or electricity may therefore be readily amplified and propagated by a modulation of the proton currents or coherent polarization waves in the liquid crystal continuum (Mikhailov and Ertl, 1996). This system may account for a fast-responding, "short term memory" of the ground substance, a memory that is dynamically distributed in the structured collagen-bound water network, self-reinforcing circuits of proton currents (Ho and Knight, 1998).

Furthermore, liquid water on its own, includes coherence domains where all molecules oscillate in unison in tune with a self-trapped electromagnetic field, at a well-defined frequency (Del Giudice and Tedeschi, 2009). The coherent oscillations produce an ensemble of quasi-free electrons, able to collect noise energy from the environment and transform it into high-grade coherent energy in the form of electron vortices. This high-grade energy may activate the biomolecules resonating with water's coherence domains. Therefore, flows of matter, energy, information and memory can be spread and stored over the organism due to self-trapping, induced by the correlated coherence domains of interfacial water.

Bodyworkers may therefore gain their results by freeing tissue memories stored in the watery body content. The interplay of calcium ion concentration and unbound water oscillations may increase following manually applied fascial work, so promoting interstitial fluid flow (Lee, 2008). This may in turn stimulate fibroblast proliferation and collagen production/alignment (Hinz et al., 2004), thanks to the coupling of the electrical-vibrational continuum with the mechanical tensegrity structure of the connective tissue-intracellular matrix.

Hypothesis

There is increasing evidence that organisms may communicate between cells and tissues by electromagnetic radiations, phonons and photons. Biophotons are believed to be emitted from a coherent photon field within the living system (Popp et al., 1992) that may work as an energy (and possibly as a memory) storage field. It appears then that the body matrix, as a continuous physical and energetic system, is capable of conducting message units in the form of electrons, vibrations, protons, photons, phonons. It is therefore an informational network that distributes regulatory signals throughout the body, coordinating cellular and extracellular activities involved in growth, morphogenesis and regeneration (Ho et al., 1994).

A yet more interesting possibility is that the liquid crystalline continuum may function as a quantum holographic medium, recording the interference patterns of local activities interacting with a globally coherent field. Holographic memory is distributed globally and yet can be accessed and recovered locally. Possibly during bodywork, the interaction of vibrational, biomagnetic and bioelectric fields between therapist and client may allow an exchange of information about the history and the present status of the living matrix (Oschman and Oschman, 1994). The information encoded in

cell and tissue structure and activity may be read holographically, by tuning to the appropriate frequencies. This may even lead to a recall of past traumas and of an array of related sensations. The result may be the restoration, balancing, and tuning of resonant vibratory circuits.

In light of what has been discussed in this editorial, it is suggested that a possibility may exist that manual therapy might affect various forms of memory, producing profound tissue changes from subatomic to global effects.

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21 September 2013

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