Human Resting Muscle Tone (HRMT)**:** Narrative Introduction and Modern Concepts

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Abstract   Human resting muscle (*myofascial*) tone (HRMT) is the passive tonus or tension of skeletal muscle that derives from its intrinsic (EMG-silent) molecular viscoelastic properties. The word *tone* has been used to convey varying clinical and physiological features that have led to confusion and controversy. HRMT is the vital low-level, passive tension, and resistance to stretch that contributes importantly to maintaining postural stability in balanced equilibrium positions. In contrast, *co-contraction* of muscle is an active neuromotor control that provides greater levels of tonus for increased stabilization. Functionally, HRMT is integrated with other passive fascial and ligamentous tensional networks of the body to form a biotensegrity system. This review aims to achieve better understandings of HRMT and its functional roles.

Nature is frugal and Man's adaptations to gravitational forces and erect postures seemingly evolved mechanisms in skeletal muscle tissues to economically enhance stability. Normal passive muscle tone helps maintain relaxed standing body posture with minimally increased energy costs (circa 7% over supine), and often for prolonged durations without fatigue. Available data infer *polymorphic* variations in normal myofascial tone. However, few quantitative studies have been performed to establish normal frequency distributions of degrees of myofascial tone. Clinical experience indicates that persons with certain symptomatic musculoskeletal conditions may have palpably increased resting muscle firmness or hardness (EMG-silent), such as that of the upper trapezius in tension-type headache, and the lumbodorsal extensors (*hartspann*) in degenerative lumbar disc disease and ankylosing spondylitis.

In summary, resting skeletal muscle tone is an intrinsic viscoelastic tension exhibited within the body's kinematic chains. It functions inseparably from fascial (i.e. myofascial) tissues and ligamentous structures. Thus, HRMT is a passive *myofascial* property which operates within networks of tensional tissues, i.e., *biotensegrity*. This passive tension is the CNS-independent component resulting from intrinsic molecular interactions of the actomyosin filaments in sarcomeric units of skeletal muscle and myofibroblast cells. The overarching CNS-activated muscle contractions generate far greater tensions transmitted by fascial elements. Interdisciplinary research on HRMT and its biodynamics promises greater effectiveness of clinical practitioners and productivity of investigators, which warrants priority attention.

Introduction

A systems level understanding of the human body is more complex than defining characteristics of isolated parts of a cell or the organism. Aristotle perceptively propounded, *"the whole is greater than the sum of its parts"* (Aristotle)*.* Emergent concepts from systems approach to applied research often require integration of many fields of thought. We review the mainly neglected area of human resting muscle (myofascial) tone (HRMT). The aim is to update current concepts and to stimulate critical discussion for better understandings in the future.

Life is movement and muscle has been studied almost entirely in its activated state

Following Hippocrates, Claudius Galen, a second century physiologist, empiricist philosopher and writer, is often considered the most important contributor to medicine. He had particular interest in types of body movements. Galen considered muscle *tone* as belonging to the fourth type of movement in which static resistance is generated; an example being a shield held against a striking sword (Galen). Such description of muscle tone generated in static resistance is more accurately described as an *action,* produced by muscle co-contraction and controlled by the nervous system (Sherrington, 1919).

Tone and tonus [G. *tonos,* tone, or a tone] are general terms which have been used for multiple meanings since antiquity, and often interchangeably. For instance, 100 years ago, Fraenkel and Collins (1903) outlined two uses. The first was a histological application describing the general state of the tissues, such as vascular tone, nerve tone, skin tone, general tone etc. Their second use exclusively applied to muscle tonus**.** They described it, 'to represent the result of a purely neural phenomena.' This neural focus of muscle tone was intensified by the extensive experimental work of Sherrington's group (1906, 1915, 1919, & 1947; Denny-Brown, 1929a,b).

Muscle tone has received considerable neurophysiological attention over the years, but it has mainly been viewed as a manifestation of *stretch reflex* neuromotor control (Denny-Brown, 1929a,b; Walsh, 1992; Simons & Mense, 1998). Relatively little research has been done on *resting* muscle tone. In the early 20th century, Sir Charles Sherrington (1852 – 1952) investigated decorticated and spinal-transected experimental specimens, rather than intact animals or humans. In his early work, Sherrington (1906) suggested a role for skeletal muscle *reflex tonus* in maintaining postural attitude. Later (1915), he wrote 'a fairly literal meaning attaching to the term 'tonus' is, of course, mechanical tension. In this sense it fits well the slight, steady, enduring tension so characteristic of muscles in their state of reflex tonicity.'

Sherrington concluded that muscle tone resulted from *reflex* neurogenic mechanisms (Sherrington, 1919 & 1947), based upon his models which interrupted central *inhibitory* pathways of muscle contraction. Post-surgical recovery, the animals displayed generally exaggerated neurogenic reflexes. Stretch reflex mechanisms were overly-generalized as the cause of all muscle tonus (Walsh, 1992; Simons & Mense, 1998). Diligent review of Sherrington's writings did not reveal a statement referencing the role of passive (non-reflex), mechanical,

viscoelastic tonicity of skeletal muscle. Even today, Sherrington's experiments have promulgated the common belief that neurogenic reflex mechanisms are responsible for all forms of muscle tone, including resistance to slow passive stretch in fully relaxed normal persons. Many modern textbooks still consider muscle tone as entirely reflex in origin and resulting from a myotatic *(a stretching)* reflex in the muscle spindles.

Table 1
Papers Affirming Human Resting Muscle Tone (Chronological Sampling)*

1934 - **Fenn WO, Garvey PH.   J Clin Invest 13: 383-97.**

1941 - **Hoefer PFA.   Arch Neurol Psychiat 46: 947-72.**

1951 - **Clemmesen S.   Proc R Soc Med 44: 637-46.**

1953 - **Ralston HJ, Libet B.   Am J Physical Med 32: 85-92.**

1960 - **Joseph J.** *Man's Posture. Electromyographic Studies.* **Thomas, IL**

1962 - **Morris JM, Benner G, Lucas DB.   J Anat 96: 509-20.**

1966 - **Stolov WC.   Arch Phys Med Rehabil 47: 156-68.**

1972 - **Donisch EW, Basmajian JV.   Am J Anat 133: 25-36.**

1986 - **Hnik P.   Biomed Biochim Acta 45: S139-43.**

1992 - **Walsh EG.   *Muscles, Masses and Motion.* London, Mac Keith**

1992 - **Davidoff RA.   Neurology 42: 951-63.**

1994 - **Hagbarth K.   Scand J Rehab Med, 30 (Suppl): 19-32.**

1998 - **Simons DG, Mense S.   Pain 75: 1-17.**

2007 - **Loram ID, Maganaris CN, Lakie M.   J Physiol 584: 661-75.**

2007 - **Loram ID, Maganaris CN, Lakie M.   J Physiol 584: 677-92.**

*Full titles in the reference list

Notable literature affirming human resting muscle tone (Table 1)

The classical CNS-activated stretch reflex theory of muscle tone predominates in the literature. However, it overlooks clinical and experimental research supporting resting muscle tone (EMG-silent) in *intact* animals and humans, as cited in Table 1 (titles are included in the reference section). The absence of EMG evidence of muscle contractile activity of normal resting muscle (Table 1) has indicated that such clinically recognized tone is caused by intrinsic viscoelastic properties (Walsh, 1992; Simons & Mense, 1998). For example, Clemmesen (1951) was a pioneer exponent of passive muscle tone, in both static and movement functions. He specified that EMG-silent passive tone assists and resists active movements, contributes to synergists and antagonists, and counteracts inertia and external forces, including those of gravity.

Since the 1940's, increased clinical use of electromyography (EMG) has confirmed that normal, fully relaxed muscles do not have reflex activation, being EMG-silent. However, proper experimental conditions require that the subject's positioning needs to be comfortable and in equilibrium-balanced postures and relaxed to the fullest extent. Superimposed EMG activity can often be observed under other static or passive testing conditions, as previously reviewed (van der Meche & van Gijn, 1986). *Passively* moved normal skeletal muscles are also EMG-silent, when the subjects are fully relaxed, unlike Sherrington's animals. However, low-level EMG activity may be observed under certain intended *passive* experimental settings, as when measuring resistive torque during isokinetic motion of the ankle joint. Such extraneous contractile activity can a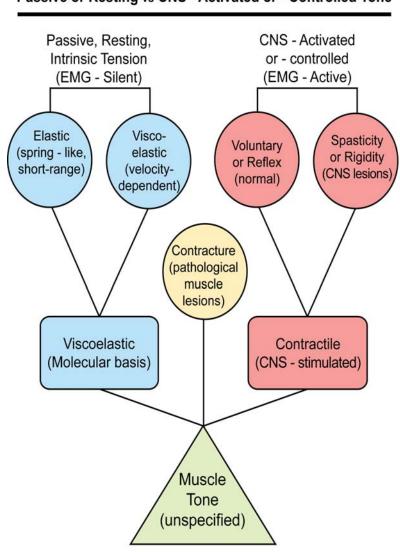mount to circa 2% of a maximal voluntary contraction (MVC) (Mahieu et al., 2007; Gajdosik et al., 1999). However, when calf muscle tone is measured under even more relaxed static experimental conditions, it is EMG-silent, and its inherent stiffness can maintain stance in defined balanced posture (Loram et al., 2007a,b).

Importantly, both the subject and the tested muscle must be in a state of full relaxation in evaluating HRMT, since its intrinsic tension (without extraneous contractions) is only about 1% maximal voluntary contractions (Woledge, 2003). The absence of such standardized relaxed testing conditions has led to contradictions in studies.

Experimental research evidence for passive muscle tone and its categorization

Space limitation does not permit detailed review of experimental evidence for low level tension in isolated, denervated muscle. Briefly, D. K. Hill (1968) applied slow small stretches (~ 0.2 % isometric length) to a resting, denervated frog sartorius. He inferred that a small elastic part of resting tension is due to interaction of thick myosin and thin actin filaments. He called the *initial* tension on small passive stretch, as "short-range elastic component (SREC)". The passive tension was labeled 'filamentary resting tension (FRT)'. It was estimated to be about 150g per 100g of muscle tissue (Hill, 1968). Thus, it would constitute about 1% of MVC (Woledge, 2003). Subsequent molecular research has demonstrated that myosin head cross-bridging to actin filaments in muscle is the intrinsic force generator for active as well as resting tension (Campbell & Lakie, 1998; Sugi, 2003). The components of passive or resting, as opposed to CNS – activated or – controlled, muscle tone are summarized in Figure 1.

Figure 1

Passive or Resting vs CNS - Activated or - Controlled Tone

Passive, Resting, Intrinsic Tension (EMG - Silent)

- Elastic (spring - like, short-range)
- Visco-elastic (velocity-dependent)

CNS - Activated or - controlled (EMG - Active)

- Voluntary or Reflex (normal)
- Spasticity or Rigidity (CNS lesions)

- Contracture (pathological muscle lesions)

- Viscoelastic (Molecular basis)
- Contractile (CNS - stimulated)

- Muscle Tone (unspecified)

Legend to Figure

Simplified components of intrinsic passive vs CNS-activated muscle tone, to help clinically differentiate the respective mechanisms causing detectable tension/stiffness (modified from Simons and Mense, 1998). Contracture, which results from pathological lesions of muscle, restricts extensibility and is considered to be EMG-silent. Terms are briefly described in Table 3, extracted from Panjabi (1992), and are included in Simons and Mense (1998). The passive resting viscoelastic tone is estimated to be circa 1 % maximum voluntary contraction (MVC), which helps maintain stability in balanced equilibrium postures (see text). The EMG-silent resting tone must be differentiated from extraneous contractions or co-contractions (EMG active) which are CNS-activated or -controlled. The passive *elastic* component is short-range (circa 0.2% of resting isometric muscle length). It was labeled "short-range elastic component (SREC)" by Hill (1968). Longer passive stretchers have *viscoelastic* physical properties.

Review of JBMT papers referring to muscle tone

The concept of HRMT is novel and has not been well incorporated into current patient assessment or management. This review is intended to begin a dialogue concerning resting muscle tone. We examined all past issues of JBMT, and those statements referring to muscle tone were extracted from relevant articles. The information was integrated and synthesized in order to understand the varied viewpoints. No statement was found that explicitly defined or endorsed HRMT. Also, no statement contradicted the validity or utility of HRMT. Thus, we conclude that the concept of HRMT had not been formally addressed in JBMT, and that it is now worthy of critical attention.

Many general mentions were found on muscle tone. However, the functional role of resting or passive tension (EMG-silent) was not critically addressed as opposed to CNS-activated tone or extraneous contractions. Notably, some authors emphasized that gravity was an important force that needed to be addressed in movements or postures. However, the energy efficient passive viscoelasticity of the body was not raised as an evolutionary adaptation for maintaining balanced stability postures. The aim of this paper is to more explicitly differentiate passive from active muscle tone and to stimulate discussion of the clinical and functional significance of HRMT.

Text Box 1: Dr. Moshe Feldenkrais' (1904-1984) selected quotes on tone

Feldenkrais (1984) recalled a story of an Italian count challenging anyone to walk blindfolded 300 yards across the cobbled stones of the city's plaza without deviating right or left. Feldenkrais theorized that no one succeeded because of an insensible turning of the body during gait towards the heavier side. He predicted this side to be the right because of the location of the heaviest unpaired organ of the body: the liver.

Feldenkrais (1949, 1972) noted that the standing body is most ready for translation at short notice, if its center of gravity is maintained at the highest possible position. He also noted that practically no expenditure of energy was necessary and that this minimum is drawn from potential energy.

In the less than ideal body, Feldenkrais (1949) described rigid muscles as "short and never relax to assume their full length, and feel string-like to palpation. …"

He continued (1949), having stated, "Every joint where the two members [bones] are inclined transmits a portion only of the force applied to either of them, and acts as a dash-pot, damping all transmission of mechanical stress through the joint. The soft, wooly punch of many boxers is due to faulty hip carriage, and no amount of training can ever make the punch 'hard' so long as there are springy, flexed joints, at the instant of hitting."

Text Box 2: Dr. Ida Rolf's (1896 - 1979) selected quotes on tone

Rolf (1990a) stated that, "Man consists, more or less, of stackable units. The agents of this balance are the bones and the soft tissue (myofascia). Bones determine position in space, but bones are held by soft tissue. When the myofascia is repositioned, bones spontaneously reorient. When the tone of the soft tissue is balanced, there is a sensation of lightness in the body. The masses of head, thorax, pelvis, etc., are no

longer dragged out of true by their weight; the structure presents less resistance and gravity can "flow through." …

"In a human body, support is not something solid. Support is relationship" (1990b). ...

She continued (1990b), raising the question, "Could you translate this balance as tone? I don't know. I don't know what tone is in words, only in experience. I once equated it with span, but I don't know how to define span. When you get span in a body, you get tone**:** when you get tone, you get span. Span is a spatial thing, tone is physiological. Both words refer to balanced structure in a living body. Both tone and span indicate a readiness to act and respond that is the touchstone of a healthy body."

Text Box 3: Chiropractic & osteopathic founder's selected concepts on tone

The cover of the founder's textbook on chiropractic, Palmer (1910) reads**:** 'Text-book of the science, art, and philosophy of chiropractic, founded on tone'.

Wardwell (1992) quotes Gaucher-Peslherbe as saying, "It was the 'tonos' of the Stoics on which Palmer founded chiropractic."

Leach (2003) explains further and notes that "Palmer chose to adopt vibratory theory— that nerves vibrated normally at approximately 200 vibrations per minute, representing the tone of the nervous system" …   Further, "While Palmer's concept that nerve vibrations create tone has obviously been displaced, his hypothesis that too much or not enough nerve function is disease was a forerunner to later accepted scientific concepts of homeostasis" (Leach 2003).

Nimmo coined the term *receptor tonus control method* to describe his manual therapy, and thought this allowed the nervous system to reset homeostasis with respect to muscle tone (Schneider 2007).

The developer of osteopathy, Andrew Still (1897, 1899, 1910), wrote little on muscle tone or tonus in his three books. In a book of 268 pages, Still (1899) mentioned tone in terms of the sympathetic nervous system's role in controlling the tone of the 'non-striate muscles tissue'.
Still (1915) wrote that the cause of diseases, "can be found and does exist in the limited or excited action of the nerves that control the fluids of a part of or of the entire body. My position is that the living blood swarms with health corpuscles which are carried to all parts of the body."

Other osteopathic authors more often mentioned tone. A representative example is McConnell (1902) who made 15 citations on tone (see reference for pages). However, none of his statements described HRMT. Tone was described nonspecifically and generally (vasomotor, arterial and intestinal tone, atrophied muscles and even the capsule of the kidney).

Structural integration (SI)

Structural integration (SI) evolved from the earlier teachings of Ida Rolf (Rolf, 1977) and is now popularly referred to as 'rolfing'. It is a systematic program of postural repatterning via connective tissue manipulation (Myers, 2004a,b). The focus of SI is on the balance of the myofascial tensional structures around the skeleton (Myers, 2004a,b). However, mention was not made of HRMT and its role in helping to maintain balanced postures.

Principle of least effort

The concepts of the preceding founders on gravity and movements have led to more current approaches to manual and movement therapy. Gravity is an unseen force of constant direction and intensity which influences the principle of least effort (Hannon, 2000c), and should be considered in patient assessment and management.

Differentiating resting muscle tone from co-contractions and extraneous contractions

By definition, HRMT is a separate intrinsic component for achieving low-level energy-efficient muscle tone (Abitbol, 1988). It has been profoundly stated, 'We have never encountered poor engineering in nature' (Albrecht- Buehler, 1985). Accordingly, if HRMT truly exists, as we believe that it does (see below), then it should serve an important role. Kinesiologically, agonist/antagonist balance achieves stability and smoother movements. Balance refers primarily to myofascial tissues on either side of a joint, as they are functioning in a gravity field. Balance can occur with passive (resting) or actively contracting muscles, depending upon the resistance needed to counteract gravity or desired in intended actions or movements. Confirming the principle of least effort (Hannon, 2000a,b), the body can achieve energy-efficient, low levels of stabilization in gravity-neutral postures by the passive viscoelastic properties of muscle. The body does not need to add active co-contractions, until greater levels of mechanical stability or resistance movements are required. Extraneous contractions may reflect inefficient or tensed body posturing, at a cost of extra energy or easier fatigueability.

In regard to active and resistance movements against gravity, Irvin Korr (1909-2004) was a neurophysiologist (Chaitow et al., 2004) who recognized that the musculoskeletal system had 90% of the connections with the nervous system (Korr, 1975). He indicated that our richest and largest sensory organ is not the eyes, ears, skin, or vestibular system, but is in fact our muscles with their related fascia (Korr, 1975; Schleip, 2003a,b). Such rich CNS neuromotor control is essential for precise stimulation of muscles in active contractions and movements. Notably, this exquisite CNS-controlled system is superimposed upon the inherent passive viscoelastic properties of muscle or myofascial tissues. In a model of spine *movements*, Cholewicki & McGill (1996) and Cholewicki et al (1997) examined the theory that antagonistic trunk muscle co-activation is necessary to provide mechanical stability to the lumbar spine around a neutral posture. According to Cholewicki and McGill (1996), spine stability is greatly enhanced by co-contraction of antagonistic trunk muscles, e.g. abdominal and extensor muscles (as also reviewed in Liebenson, 2004b). Such co-contraction studies of spine stability in movement do not conflict with those of passive muscle tone stabilization in relaxed balanced stance (Table 1). Cholewicki & McGill (1995) had earlier performed biomechanical simulation studies of the relationship between muscle force and stiffness in whole mammalian muscle. The stiffness of skinned muscle fibers approximated the relatively simple-cross-bridge theory, but a complete muscle-tendon unit becomes complex and non-linear. This study emphasizes the importance of defining functionalities of integrated myofascial networks.

The osteoligamentous stability of the vertebral spine is barely sufficient to hold

the weight of the head (Lucas & Bresler, 1961). Therefore, myofascial support of the spine is required for stability. The controversial question is how much is required by passive properties vs active contractions under particular balanced vs unstable equilibrium circumstances. Unnecessary co-contraction of muscles, occurring as a result of pain, anxiety or habit, is disadvantageous (Lyttle, 1997). Extraneous muscle tension of the anterior thigh often occurs in those unable to relax (Hannon, 2006). In study of EMG-monitored voluntary quadriceps muscle relaxation, about two thirds of the subjects could not abruptly relax at various tested passive movement velocities (Ferris-Hood et al., 1996).

HRMT should be considered among biomechanics that promote stability (Table 2)

According to the conventional concepts of Panjabi (1992), the following subsystems work together to promote stability: (1) central nervous subsystem (control); (2) osteoligamentous subsystem (passive), and (3) muscle subsystem (active). The fascial system has been more recently added as a fourth stability component of the body, in terms of its known passive (Lardner, 2001) and newly recognized active myofibroblast tissues (Schleip, 2003a,b).

Fibroblasts can transform into myofibroblasts, which contain smooth muscle actin fibers, and can therefore actively contract. From a teleological perspective, it makes sense that an interspersing of smooth muscle-like cells into fascial sheets equips the organism with an accessory tension system to increase muscular tonus (Schleip, 2003a,b). Fascial smooth muscle cells enable the autonomic nervous system to regulate a fascial pre-

tension, independently of the skeletal muscular tonus (Staubesand & Li, 1997; Staubesand et al., 1997; Schleip, 2003a,b). Quantitative parsing of the myofibroblast tension into its passive vs active aspects will require further research.

Table 2
Components Governing Stability in the Musculoskeletal System*

1. The myofascial passive tonicity/tension (HRMT)
2. The fascial system passive network
3. The osteo-ligamentous system passive component
4. The muscular system active contractile response
5. The neural system control of reflex or active contractions

* Expanded from Panjabi, 1992; Lardner, 2001

From this review, it is clear that the role of passive muscle tone has not yet been adequately integrated into the conventional concepts of joint stability or optimal control of movements (see below). Although HRMT provides only circa 1% MVC, it is important in balanced equilibrium. For discussion purposes, we added HRMT as another subsystem component governing stability in the musculoskeletal system (Table 2).

Views on muscle tone and muscle grouping found in JBMT

As indicated, muscle tone involves intrinsic as well as CNS-activated tensional elements (Simons & Mense, 1998 & Fig 1). Passive tone is the component of intrinsic viscoelastic resistance of resting muscle to stretch, whereas active tone is the readiness with which the nervous system activates the muscle in response to stimuli (Basmajian &

DeLuca, 1985; Davidoff, 1993; Hagbarth, 1994; Ng et al., 1998). Hypertonicity is defined as, literally, too much muscle tone (Ng et al., 1998; Simons & Mense, 1998). Accordingly, intrinsic hypertonicity is an abnormal increase in the resistance to stretch of a resting, EMG-silent muscle. In contrast, neuromotor hypertonicity is an abnormal increase in the readiness with which the nervous system activates the muscle in response to stimuli (Ng et al., 1998).

Postural and phasic functional roles of muscles in the body have been interpreted to influence tonicity. The postural muscles are considered to be those involved primarily in maintenance of upright posture, while the phasic muscles are those primarily involved in movement (Tunnell, 1998). Janda (1978) first suggested the categorization of muscles into `postural' (tonic) and `phasic' (movement) classifications. It served as a useful way of conceptualizing several of his clinical theories (Murphy, in Bullock-Saxton et al., 2000). Certain muscles tended to easily become tight and hyperactive, and certain muscles tended to become inhibited and underactive (Murphy, in Bullock-Saxton et al., 2000). Tightness of postural muscles is common and can initiate a cascade of changes in locomotor system function which often lead to pain (Tunnell, 1998).

A clinical implication of hypertonic postural muscles is that the body mechanics in postures and movements are not optimally countering the extant forces of gravity, which we favor. An alternate viewpoint is that a muscle becomes hypertonic (increased muscle tone) or hypotonic (decreased muscle tone), as a result of certain neurological events, not because the muscle is `tonic' or `phasic' (Janda, 1978; Stokes & Young, 1984; Johansson & Sojka, 1991).

Besides resistance to passive stretch, muscle tone is often clinically assessed by its palpatory quality on compression by the examiner, i.e., its pliability, firmness, or hardness.   Boris Chaitow added to the methodology of the neuromuscular technique (NMT), by his NMT evaluation of a 'variable pressure' application. He emphasized application which 'met and matched' the tissues, but which did not overcome their intrinsic tone (Chaitow, 1996). Thus, a pioneer in NMT recognized a palpatory quality of myofascial tonicity, and considered it to be important in assessment and therapy. Another thought leader (Maitland, 1995) coined the neologism, *palintonicity* (palin, Gr. again), as in the word *palindrome*, which refers to the same meaning reading forward or backward. He described a state of even tone across the various muscles and connective tissues of our structural body (Myers, 1999).

Variable relaxation of muscle tone and effects of balance

As reviewed above, it is possible for some people standing in comfortable balance to fully relax with no EMG evidence of muscle activity (Basmajian & DeLuca, 1985 & Table 1). In a passively moved (flexed or extended) resting (EMG-silent) muscle, e.g., biceps brachii, length does not alter muscle tone (Basmajian & DeLuca, 1985). A common problem, however, is that some persons are unable to relax and often are susceptible to increasing their muscle tension at a moment's notice (Myers, 1998; Hannon, 2000b).

Most often, balance is viewed as an active process, rather than in states of gravity-neutral or balanced equilibrium. However, much of comfortable living occurs in such balanced equilibrium, e.g., being reclined, sitting, or relaxed standing. Passive muscle

tone constitutes only about 1 % of maximum voluntary contraction (MVC) ability (Woledge, 2003). However, this small tension can be sufficient for stability in quiet, gravity-neutral stance (Loram et al., 2007a,b, and Table 1).

The theoretical argument could be made that EMG silence does not *exclude* CNS control of passive muscle tone. However, such neurophysiological control is not yet documented, and such interpretation was not favored by proponents of HRMT (Table 1). The degree of postural and structural balance directly influences whether only passive muscle tone is needed to maintain stability or whether the greater CNS neuromotor control is required. Further integrated EMG and myofascial tissue tensional (stiffness) research is needed. Quantitation is needed of forces across specific joints that can be balanced by only passive vs active CNS-stimulated tone. Such quantitative studies have been done across the ankle joint in quiet, relaxed stance. They indicate that small ranges of forward tilt can be stabilized only by passive calf muscle tone (Loram et al., 2007a,b).

Standing men continuously oscillate, and their muscles are needed to correct displacements and prevent falling (Hannon, 2001a). A subtle, but important point is that minor perturbations of balanced equilibrium, e.g., heart impulses and respirations, can be stabilized by the body's intrinsic myofascial elasticity (Gallasch, 1998). Such passive *oscillations* on Earth are relatively rapid (10 Hz). In contrast, control of the greater degree of body sway (not oscillations) is under active reflex control. Sway has a lower frequency (circa 1 Hz), required by the long latency of proprioceptive CNS pathways (circa 0.120 sec). Differentiation of passive oscillations vs active reflex control of standing sway is controversial and infrequently documented (Loram et al., 2007a,b).

The biomechanics of muscle is complex and cannot be adequately reviewed in this paper. However, selected biomechanical definitions and relevant terms were published previously in JBMT (listed in Table 3) or elsewhere (Simons & Mense, 1998).

Table 3
Selected Definitions Related to Physical Properties of Muscle Tone*

Stiffness: A material's resistance to deformation

Strain: The amount of deformation that occurs as a result of the applied force

Elasticity: The property of a material to return to its original form or shape when a deforming force is removed

Viscosity: The measure of shear force that must be applied to a fluid to obtain a rate of deformation. It is time dependent

Thixotropy: The property exhibited by materials such as muscle of becoming fluid when disturbed or shaken and of setting again when allowed to stand

Viscoelasticity: The property of being both elastic and viscous

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*Extracted from Panjabi, 1992

Structural balance and achieving favorable postures

Achievement of structural balance, and, most assuredly, ease and generosity of

movement, are priority therapeutic ideals (Myers, 2004a,b). Understood in such statements, but not always stated, is avoidance of unnecessary co-contractions. Also, the energy-efficient passive myofascial tone should be utilized during gravity-neutral activities. The topic of posture, and how the individual uses their body is central to most bodywork and movement therapies (Hannon, 2000a). Upright stance is generally considered an example of unstable equilibrium. However, balanced positions may be achieved in which little force is needed to maintain stability (Hannon, 2006; Loram et al., 2007a,b). The trick of efficient postural adjustment is to have, be able to find, and actually employ, a neutral posture to which we return after an activity (Myers, 1999). Achieving an easy, relaxed alignment of the basic body segments in gravity is a fundamental body-mind integration tool (Myers, 1999).

Persons may, for various reasons, assume overly stiffened postures that require co-contractions (i.e., "military" stance). However, with education and rehabituation, natural relaxed posture gradually emerges (i.e., "at ease"). This posture conforms to the body's response to gravity (Latey, 1996), and can be maintained mainly by passive muscle tone (Table 1). Thus, the concepts of postural stability and movement instability are integral to modern musculoskeletal care (Liebenson, 2004a,b). Unstable equilibrium, as a form of dynamic response, was previously reviewed (Hannon, 2001b). Additional research is needed on the role of passive resting myofascial tone in helping to achieve and maintain stability in equilibrium postures and flexibility in peripheral joint movements (Magnusson et al., 2001).

Myofascial - Osteoligamentous connectivity of the musculoskeletal system

The upright human displays a unique interdependence between the skeleton, the extra-cellular matrix (ECM) webbing, and interstitial fluid. The neurally-controlled muscle provides the active or reflexive adaptation responses (Myers, 1997). We fully agree with this concept in movements or in static resistance. However, in gravity-neutral, balanced equilibrium, the passive myofascial tonicity provides important stability to the body. The body itself seems to work over a continuum of structural solutions to its gravitational and mechanical challenges (Myers, 2001). When such perturbations are minimal, then the low-level passive myofascial viscoelasticity (circa 1 % MVC) may be sufficient to maintain stability, especially in static, balanced postures. With movement or increased loading, the active muscle subsystem may then be more likely required (Cholewicki & McGill, 1995 & 1996; Cholewicki et al., 1997).

Myofascial continuities are key to global pattern assessment in bodywork and movement treatments. Five major lines were originally proposed and their clinical implications were earlier discussed (Myers, 1996). More recently, an alternate version was developed, based on longitudinal myofascial continuities (Myers, 2004a,b). The lead author of this review has focused primarily on the muscle-ligament-fascia systems required to stabilize the pelvis by compressing the SI joints (Masi et al., 2003a,b & 2005). The concept of *form and force closure* of the pelvis was developed by Andry Vleeming (1990a,b) and his associates (Lee, 2004). It permits better understanding of clinical conditions which result from insufficient or excessive pelvic (or other joint) stability, due to respective

hypo- or hyper- myofascial tonicity
(Vleeming, 2004).

Biotensegrity as a model of the body's balanced tensional forces

The body is a structure that depends on the balance of tensional forces to maintain its stability (Myers, 1999). Such structural model has isolated compression elements (bones) within a balanced ocean of tensional members (myofascial). The model was popularly dubbed 'tensegrity' (a contraction of "tensional integrity") structures by Fuller (1975). This architectural concept was based upon earlier Kenneth Snelson's smaller art sculptures and larger closed structural systems (http://www.nlm.nih.gov/exhibition/tour/treei.html). The term was adapted to our human body as a 'biotensegrity' structure (Robbie, 1977; Ingber, 1998; Oschman, 2000; Levin, 2002). It incorporates not only the macroanatomical tissues, but also the subcellular fibrillar and micro-tubular structures (Ingber, 2003). Within such organic structure and tensional continuity of the body, the role of HRMT can be more clearly understood. Specifically, it is the important motor generator to maintain pretensing and low-level stabilizing functions (see Text Box).

Clinically, HRMT is subtle to document and the concept has not received sufficiently critical attention. Nevertheless, one important recognized property of healthy muscle tissue is its extensibility, or the ability to lengthen (Tunnell, 1998). Passive tension ("tone") cannot be documented, unless EMG-silence is confirmed. Clinically, proper evaluation of muscle tone needs maximal relaxation of the patient in a comfortable gravity-neutral posture for the practitioner's assessment of end-feel and positioning (Tunnell, 1998).

Proper assessment of each muscle condition requires a different treatment approach (Ng et al., 1998). Accepting the biotensegrity model, tensional alterations of myofascial tissues in a particular patient could be *hypo* or *hyper* in any particular region. In the past, emphasis has been given to painful disuse and weakening of muscle. Less attention was given to hypertonicity as contributing to painful limitation of motion and secondary weakening. More recent research suggests group aerobic and stretching classes are as useful symptomatically as modern active physiotherapy, and as effective as muscle strengthening or coordination methods using training devices (Adams et al., 2002). We propose that abnormal alterations in HRMT may be an overlooked mechanical factor in a number of non-degenerative spinal conditions and deserve greater clinical assessment.

Current concepts of myofascial trigger points (MTrPs) as related to HRMT

Expressed concepts of HRMT pertain to pain-free healthy subjects without myofascial tissue restrictions in active or passive movements. Yet, evolving research on myofascial pain syndromes (MPS) and their hallmark trigger point (TrP) clinical indicator may offer basic and clinical clues to factors influencing HRMT. Simply described, MPS are regional pain disorders associated with a hypersensitive palpable nodule (TrP) in a taut band of skeletal muscle (Simons et al., 1999a). A snapping palpation of the involved muscle area can reveal an induration ("taut band") which elicits a local twitch response (LTR) (Simons et al., 1999b; Rivner, 2001). In addition, restricted ranges of motion are often found in MPS.

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Questions about MPS and TrPs that may be relevant to concepts of normal HRMT include: (1) mechanisms causing the "taut band"; (2) whether local or central factors control tension in the focal tender areas (as well as influencing surrounding muscle often perceived as feeling stiff), and (3) the EMG activity of focal points and surrounding subjectively tight muscles. Although definitive answers to these questions on MPS and TrPs are not yet available, their current concepts and basic research can help generate hypotheses and investigations pertinent to HRMT.

Focal nodularities (TrPs) within taut bands can occur following muscle injury or repetitive strains in susceptible subjects. One suggested mechanism is focal ischemia ("energy crisis component") and calcium release in contracted sarcomeric units (Simons et al., 1999c; Simons, 2008). This concept could account for the absence of motor unit *action potentials* in the palpable taut band of the TrP when the muscle is at rest (Simons et al., 1999c). However, precise and sensitive needle EMG recordings from TrPs revealed occurrences of low voltage spontaneous activity ("endplate noise") in some reports (Hubbard & Berkoff, 1993; Rivner, 2001; Kuan et al., 2008), but not in another (Durette et al., 1991). In the chronic tension-type headache (CTTH) form of MPS, spontaneous EMG activity of muscles about TrPs was not greater than in healthy matched control subjects (Couppé et al., 2007). In another study of CTTH patients, muscle tenderness as well as objective hardness were also greater than in control subjects (Ashina M et al., 1999). The above findings suggest that TrPs and surrounding muscle stiffness are local manifestations (Simons & Mense, 1998), rather than CNS reflex mediated phenomena. However, increased sensory excitability of the CNS may transform episodic headaches into the chronic symptomatic form (Ashina S et al., 2005).

The new magnetic resonance imaging (MRI) technique - magnetic resonance elastography (MRE) – was recently used to quantitatively explore stiffness of taut bands in a patient with MPS (Chen et al., 2007). The methodology is based upon shear waves generated by a vibrator bar firmly pressed on the subject's skin traveling more rapidly in stiffer than softer tissues. In the MPS patient, stiffness of the taut band was greater than that of surrounding musculature, and more so than was found in the control subject. Although the study was exploratory (Chen et al., 2007), findings support clinical observations and concepts of MPS and TrPs. This methodology may be useful in future measurements of objective stiffness of HRMT.

In other recent studies, microdialysis catheters (Ashina M et al., 2003) or fine gauge needles (Shah et al., 2005 & 2008) were used to sample interstitial fluid concentrations of inflammatory mediators in *tender points* or myofascial *trigger points* (MTrPs) using microanalytic techniques. In the controlled study of tender points in CTTH patients (Ashina M et al., 2003), no difference was found in resting concentrations of inflammatory mediators or metabolites between patients and controls during rest and static exercise. These data suggest that tender points in CTTH are not sites of ongoing inflammation. However, in the controlled studies of TrPs, at which a LTR could be elicited at a standardized location in the upper trapezius muscle, concentrations of multiple analytes were significantly higher in the milieu of *active* than *latent* TrPs, and more so than in normal subjects (Shah et al., 2005 & 2008).

These latter data support a concept of chemical mediators being released into the local tissue milieu of active TrPs. To determine whether local ischemia contributes to this process (Simons et al., 1999, pp 71-72) or a spinal cord level reflex related to LTR (Hung et al., 1995) will require further investigations. Currently, the multiple chemical mediators studied above (Ashina M et al., 2003; Shah et al., 2005 & 2008) do not seem to be important determinant factors in presented concepts of HRMT. Also, the newly applied MRE technique (Chen et al., 2007) may provide quantitative validation for alterations or polymorphisms in HRMT.

The 2007 International Fascia Congress and interface with HRMT

That landmark Fascia Congress (2007) illustrated that fascia is the soft tissue component of the connective tissue system that exists throughout the human body. It forms a whole-body, three-dimensional cell and extra cellular matrix of support, continuity, and communication (Chaitow, 2006). Importantly, fascial tissues are connected to and integrated with the musculoskeletal system to provide stability and effect movements. Fascial and muscular components are united to form combined myofascial units (Chaitow, 2006).

Within this rapidly developing scientific field, the integrated function of muscle needs to also be actively investigated as a myofascial complex. Such concept has not previously been well explored under passive states (static or kinetic), as opposed to the active contractile transmission of forces. Promising clinical and research opportunity may be expected from critical attention to and better understanding of HRMT.

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