

Muscular Strength and Chiropractic: Theoretical Mechanisms and Health Implications

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Abstract — To date, a number of studies have investigated the relationships between chiropractic care and muscular strength. Chiropractic practice philosophy states that correction of vertebral subluxation promotes health through enhancing neurological integrity. Accordingly, chiropractic adjustments aimed at reducing vertebral subluxation should also reduce neurological interference at the involved levels. A reduction of interference to the nervous system would thereby allow muscles to more fully express their functional potential, including an improvement in strength. In the present study, a focused discussion is presented relating vertebral subluxation to muscular strength. Consideration is also given to cardiovascular regulation as a result of improving neuromuscular function. This is followed by an overview of the principal factors affecting muscular strength. Finally, the relevant chiropractic literature pertaining to strength, with potential mechanisms of action, is discussed. A paradigm shift from a disease treatment model to a health enhancement model of chiropractic is afforded by presenting these concepts and conclusions in the current presentation.

Key words: *Vertebral subluxation, muscle strength, chiropractic, health model.*

Introduction

Overview

According to Stephenson's 1927 text,¹ the following must occur for the term "vertebral subluxation" to be properly applied: Loss of juxtaposition of a vertebra with the one above, the one below, or both; Occlusion of an opening (inferred to be either the intervertebral foramen or the neural canal, or both); Nerve impingement, and; Interference with the transmission of mental impulses. Evidence which supports each of these components of vertebral subluxation has been previously discussed by Boone and Dobson.²

The philosophical premise and historical foundation of chi-

iropractic is that the vertebral subluxation is the "cause of disease," from which "disease" may arise.³ Since disease is one aspect in the overall concept of health, as proposed by the World Health Organization,⁴ chiropractic education is closely linked to this concept. In that regard, the Association of Chiropractic Colleges⁵ (ACC) has established that the purpose of chiropractic is to optimize health. The ACC notes that the body's innate recuperative power is affected by and integrated through the nervous system. Subluxation as described by the ACC is "a complex of functional and/or structural and/or pathological articular changes that compromise neural integrity and may influence organ system function and general health."⁵

Nerve Root Compression Effecting Muscular Strength

While extensive reviews of subluxation theory have been presented elsewhere,⁶⁻⁹ a discussion of certain components associated with the concept of vertebral subluxation will clarify its role effecting muscular strength. The first component considered, kinesiopathology, refers to segmental spinal dysfunction that can either present as hyper-mobility or hypo-mobility of vertebral units. This is believed to alter normal joint biomechanics.¹⁰⁻¹² As a result of the chiropractic adjustment, however, the hypo-mobile vertebral motion segments are often corrected.

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Table 1. Primary Experimental and Clinical Effects of Nerve Root Compression

Clinical Effects	Experimental Effects
A. Disturbance of blood flow	Change of impulse propagation
Tissue Inflammation	Intraneuronal edema with subsequent intra neural fibrosis
Neurological dysfunction (<100 mmHg pressure)	Increased microvascular permeability of endoneurial capillaries
B. Loss of nerve function (sensory deficit and/or muscle weakness) (100-200 mmHg pressure)	Deformation of nerve fibers Displacement of Nodes of Ranvier Invagination of paranodal myelin sheaths Blockage of axonal transport

Thus, this component of the vertebral subluxation is easily demonstrable, and is often the component most readily identified with spinal dysfunction.⁷

A greater challenge is elucidation of the component of the vertebral subluxation that deals with nerve interference and subsequent consequences influencing overall health,² including muscular strength. Evidence indicates that neurological interference may result in impaired muscular function.¹³⁻¹⁴ Thus, clinically a weak muscle or reflex may be interpreted as a loss of motor function or "hypo-function" of the nerve.^{6,15} In such a case, communication from the brain or spinal cord to the tissue cell would be reduced. In this type of scenario, there are two basic types of neurological dysfunction. One type of lesion would be that often associated with loss of muscular function; i.e., nerve root compression which is referred to as a compression subluxation.¹⁶ The second form of interference causes a state of "hyper-functioning" of neural elements exhibited by spasticity or pain. This type of subluxation is often referred to as segmental facilitation.¹⁷ It is likely that both functional changes, loss of nerve function and hyper-excitability can be present at the same time in nerve roots.¹⁵

Nerve compression is historically known as D.D. Palmer's "foot-on-the-hose theory."¹³ In this theory, much like stepping on a garden hose supplying water to a plant, a subluxation compresses the spinal nerves traversing through the intervertebral foramen (IVF). Sites other than the IVF may also be involved in compression of spinal nerves; such as the back of the disc, laterally in the central canal, centrally in the cauda equina, more laterally in the nerve canal and posteriorly in the zygapophyseal joints.¹⁸ Causes of this type of compression include degenerative changes of the superior articular facets and posterior vertebral bodies, intervertebral disc protrusions, and pressure from the superior pedicle of the IVF.¹⁸⁻²⁰ The dorsal root appears to be more sensitive to smaller amounts of pressure and tension than the efferent ventral root or the nerve itself.²¹ The dorsal root

ganglion (DRG) is far more sensitive to smaller mechanical stimulation than are nerve roots, spinal nerves, or peripheral nerves.⁷ Thus, nerve roots have the potential of being compressed at many sites. The dorsal root, and in particular, the dorsal root ganglion is of great importance to the chiropractor because of its susceptibility to mechanical stimuli and its location within the IVF. Table 1 provides a summary of the experimental and clinical effects of nerve root compression.^{15,22-25}

The spinal cord may also experience adverse mechanical tension.²⁶ Leach²⁷ discusses compressive myelopathy as subluxations resulting in irritation, compression and disturbance of the spinal cord. More subtle examples of spinal cord traction could result from changes in cervical lordosis²⁶ or meningeal stretch from the dentate ligaments.²⁸

There have been a number of studies showing that in addition to mechanical insults there are also chemical causes of irritation to nerve roots. It is suggested that substances from degenerated intervertebral discs and/or facet joints may be of significance in the generation of spinal pain. Glycoprotein from the nucleus pulposus could be a direct irritant to the nerve root as well as potentially inducing auto-immune reactivity due to its notochord ancestry.²⁹ Other chemical irritants include hydrogen ions, lactic acid, histamine, bradykinin, serotonin, leukotriene B-4, potassium ions and prostaglandin E-2.³⁰⁻³¹

Other Forms of Neurological Interference

Although the nerve compression hypothesis is a part of the neuropathological component of the vertebral subluxation, spinal nerve root compression is not the only means through which neural interference may exert aberrant neuromuscular effects. As a result, there is and has been continued emphasis on the role of both sensory and motor neural activity and their interactions within the central nervous system.

In this regard, one must consider the atlanto-occipital, the

atlanto-axial, and the sacroiliac joints as examples. These joints, devoid of intervertebral foramina, still produce compression subluxations although they do not produce foraminal compression. One explanation of this mechanism found in the literature indicates that proprioceptive and afferent dysfunction (dysafferentation) also disturb the normal efferent outflow to muscles.^{6,9,32-34}

Proprioception contributes to the control of movement through reflex and central connections. In the case of proprioceptive dysfunction it is hypothesized that vertebral misalignment produces a hyper-stimulation of proprioceptive receptors in and around the articulation, as well as muscle spindles. The resulting repetition of proprioceptive signals to the CNS may cause an overload of the integrating circuits of the spinal cord. This could result in an impairment of the spinal cord, at the level of the insult, with possible effects manifested in other areas of the nervous system.^{28,35-36}

The proprioceptive somatic bombardment may also lead, through reflex, to alterations in postural tone and neural integration of postural activities. Sensory nerve fibers originating in spinal and paraspinal tissues distribute extensively within the spinal cord.³⁷ The sensory nerve fibers in the spine are known to activate projection neurons within the dorsal horn of the cord, with many of these receiving converging input from spinal, paraspinal and peripheral sensory inputs.³⁸ Proprioceptors are plentiful in spinal tissue and so both the quantity and quality of proprioception received from the periphery has important consequences relative to motor behavior. "Spinal and transcortical reflex loops establish a servomechanism which provides automatic corrections of unexpected changes in muscle length and allows compensation for undesirable irregularities in the mechanical properties of muscles by modulating limb stiffness at the subconscious level."³⁹

Central connections provide the motor control system with key information about peripheral states, which are used in volitional movement control, therefore, proprioceptive afferent data on initial limb orientation becomes an important basis for motor regulation. Proprioceptive input continues during dynamic motion and is used to regulate and trigger motor commands and muscular activity.

Proprioception has the capability of being modified by environmental constraints. Kravitz⁴⁰ found conditioned adaptation to prismatic displacement in 48 undergraduates to the wearing of a pair of goggles in 240 minutes of training by employing J. Taylor's⁴¹ alternation training technique. After training, both pointing to a visual target test and the pointing straight ahead test measured more adaptation and more after effects of adaptation when the goggles were worn than when they were not worn during testing. These results indicate that a proprioceptive adaptation effect and possibly an oculomotor adaptation effect had been conditioned. It is possible that proprioceptors are being maladapted by the presence of subluxation, and may influence muscular behavior.

Gibson, an ecological psychologist, proposed that organisms perceive the environment relevant to their capabilities for performing goal directed actions. He proposed that since organisms function in particular environments, their nervous systems are capable of detecting unique information about the environment.⁴² Therefore, the layout of the environment may provide

information that specifies or contributes to appropriate behavior for different organisms. Extrapolating this idea, in order to perform activities of daily living and other goal directed actions, people must correctly perceive *affordances*. That is, whether relevant properties of the environment can support the intended actions.⁴²⁻⁴³ From this perspective, the challenge facing an individual is to perceive whether the existing layout of the environment affords a particular mode of action. The resulting *affordance* is a function of the person's capabilities. For example, when climbing steps, the riser height of each step and the leg length of the individual will determine whether a bipedal approach versus a quadrupedal method is afforded. According to the theory, if information is picked up, perception results. If an adult fails to perceive the *affordance* of a sheet of glass by mistaking a closed glass door for an open doorway and attempting to walk through it, the person would then crash into the barrier. In this case the *affordance* of collision was not specified by the outflow of optical texture in the array, or it was insufficiently specified.⁴²

Subluxation theory also ascribes that there is a failure to accurately perceive relevant environmental information. This may result from a failure to "register" information which produces altered response patterns (adaptation). Perhaps the dictum "garbage in" equals "garbage out" in terms of the sensory/motor relationship explains why an individual fails to perceive *affordances* correctly. This misjudgment may also skew the ability to respond appropriately to challenges, thus producing changes in muscular function. Continual misjudgment may result in actions that won't be completed successfully. In contrast, assuming that there are no misjudgments, strength can affect *affordance*.

The present authors propose that the presence of a subluxation, may promote the formation of internuncial reverberating circuits at the affected spinal levels such that positive feedback from distorted afferent signals is recycled. The chiropractic adjustment may break the loop and allow the organism to reintegrate the proper sensory information allowing the body to correctly perceive itself and its environment.⁹ This reintegration may then reprogram the neural reflection of the environment in correct context, allowing for the appropriate *affordance*.

Patterson⁴⁴ suggests that the spinal cord segmental neurology and inflammation of the related area can cause and maintain a level of hyper-excitability in the spinal cord. The resulting hyper-excitability could disrupt normal muscular function. The concept used by Patterson is similar to the concept of facilitation applied to vertebral subluxation.⁴⁴ The "facilitated segment" produces a positive-feedback, gamma-motor loop in which muscle spasm may both result from and contribute to proprioceptive irritation.⁴⁵

Inputs from nociceptors may also contribute to the facilitated lesion. Nociceptors are thought to produce an initial habituation response within spinal circuits until a certain threshold is reached. At the level of threshold response, sensitization occurs and the interneuron pool produces more and more output.^{44,46} Once sensitization is reached, normal movements may greatly enhance the input to the affected spinal centers because of the decreased threshold for nociceptive activation. Upon reaching this level of hyper-excitability, neural elements have the distinct possibility of disrupting normal tissue function, including muscular strength. Abnormal joint function can change the activity

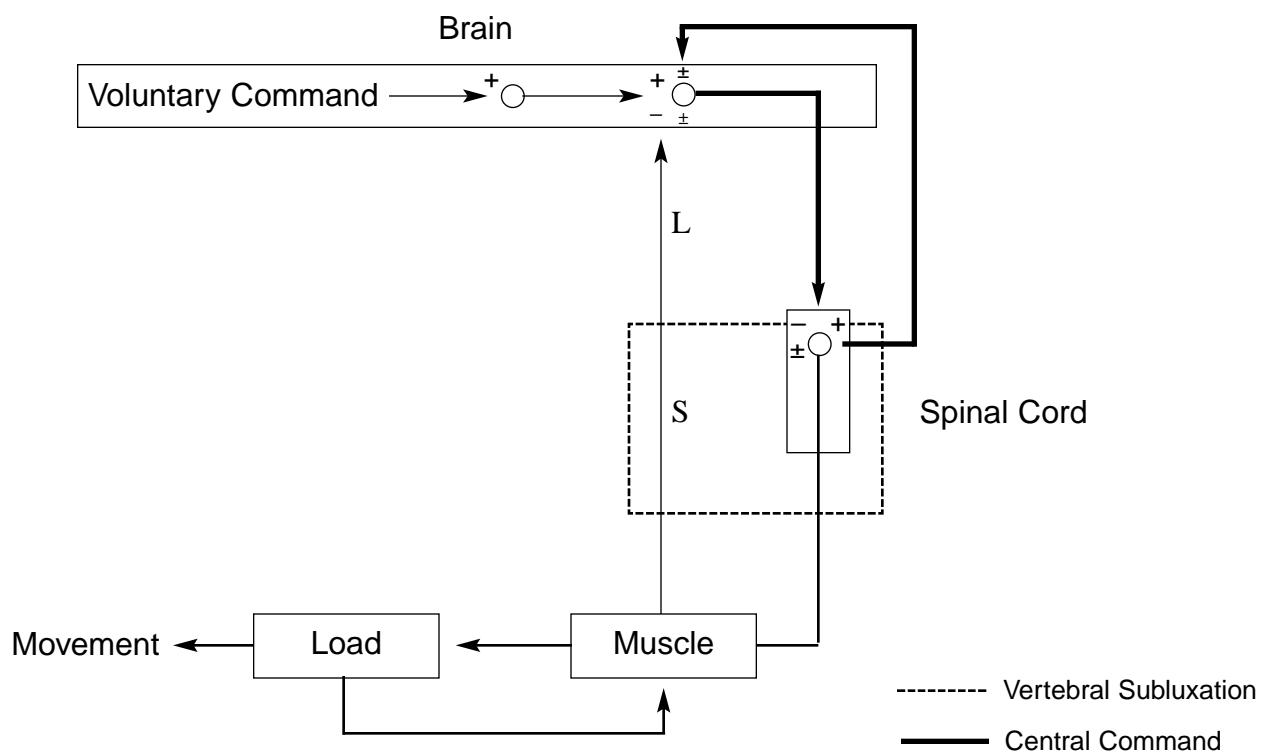


Figure 1: The interaction between the central nervous system and peripheral nervous system with respect to muscular function. Afferent input to the central nervous system is carried out by short loop feedback (S) to the spinal cord or long loop feedback (L) to the brain and brain stem. Notice that subluxation is in the position to interfere with both the short and long loop feedback mechanisms. Subluxations may also interfere with the process of central command both centrally and peripherally which can regulate cardiovascular dynamics. (Adapted from Jaweed MM and Monga TN: Neuromuscular Function Assessment. Physical Medicine and Rehabilitation: State of the Art Reviews 11: 205-237, 1997.)

of nociceptors such that nociceptor activity increases and mechanoreceptive activity decreases.³¹ Therefore, the source of spinal cord hyper-excitability (sensitization) may be attributed to nociceptors when mechanoreception decreases in the presence of increased nociception.

Removal of motion restrictions between two adjacent vertebrae is thought to have an effect by reducing stress on the zygapophyseal joint, capsule, spinal ligaments, intervertebral disc, and surrounding musculature. This in turn reduces reactive proprioceptive, nociceptive and mechanical stimuli bombardment from these structures to associated spinal segments.⁴⁸

Classically, vertebral subluxation has been thought of as osseous misalignment, that promotes occlusion of the IVF and/or spinal canal, resulting in impingement which places pressure on the spinal cord and/or nerve root (this description goes back to the writings of BJ Palmer and Stephenson). Current concepts have taken us beyond these early viewpoints such that we now realize that when a spine is experiencing improper function, all tissues are involved in a complex manner.^{7,49} Rather than view "subluxation" as if it were some extrinsic entity or process that acted on the body, it may be that the body is at the same time, the subluxated and the "subluxator."⁵⁰ "The nervous system does not simply suffer from the ill effects of a subluxation, it is an integral part of the subluxation. Sometimes, the nerve is the primary subluxation generator, other times it is muscle or vessel, and, of course connective tissue of all descriptions."⁵⁰

It is a widely accepted fact that neural integrity is a pre-requisite to muscle function. If there was interference between nerves and muscles due to the existence of subluxation, then it is logical to assume there would be less than optimal function. There is little published information, however, that links the spinal adjustment to muscle function or strength, even though it has been suggested that the adjustment may affect neural activity.⁴⁹ This is an important concept since muscle function can have a significant impact on cardiovascular function via both afferent and efferent mechanisms.⁵¹

Muscle-CNS Associations with Relevance to Muscular and Cardiovascular Performance

In humans, muscle tissue constitutes 40–50% of the body mass,⁵² considering over 430 voluntary muscles.⁵³ Because of the high percentage of afferents (40%) from muscle and peripheral nerves from other tissues, there is a potential for substantial impact on the efferent loop by way of sensory reflexes and internuncial communications. Muscles are influential not only reflexively onto themselves as evidenced by the stretch reflex, but also have important connections to cardiovascular regulation.⁵¹ Hence, assuming there is some kind of effect on the motor characteristics of muscle following chiropractic adjustments, there is also a potential impact on cardiovascular regulation by means of the same process.

According to Lantz, one of the most controversial issues in chiropractic theory is whether chiropractic intervention can prevent degeneration and restore vitality to degenerating visceral tissues.⁶ This controversy may be resolved by considering potential mechanisms that may be affected through chiropractic adjustments. This may also provide a basis for identifying the most efficacious application of chiropractic care to various clinical problems.

For example, chiropractic intervention could affect cardiovascular function through muscular events. The activity of the cardiovascular system is intimately linked to the activity of the skeletal muscular system.⁵⁴ This makes intuitive sense in that skeletal muscle activity can be a threat to homeostasis.⁵¹ Because muscle is a large proportion of body mass, it demands considerable fuel and could generate considerable heat and metabolic waste (e.g. acids, and ammonia). All of these threats, however, are averted by cardiovascular compensations which are often under emphasized. A simplified schematic of this relationship is shown in Figure 1. Though simplified, the schematic is consistent with the concept that CNS regulation of cardiovascular function reflects the integration of many physiological inputs.⁵⁴ Moreover a significant number of these inputs are related to efferent and afferent aspects of muscle function.

The primary influence of muscle on autonomic activity has been termed "central command."⁵¹ That is, all motor outflow is accompanied by a parallel, proportional, and obligatory input to cardiovascular control centers. On a perceptual level, central command posits cardiovascular responses (e.g. blood pressure) will be related to the effort exerted. Even the intention to move elicits concomitant triggers activating muscle (EMG activity) and cardiovascular responses.⁵¹ In the event that muscles are prevented from contracting because of peripheral neural blockade (e.g. local succinylcholine infusion) the attempt to contract the muscle still results in an elevation of blood pressure and heart rate.⁵¹

The original notion first proposed at the beginning of the century⁵⁵ posited a strictly feed forward mechanism. However, subsequent observations have forced a reevaluation of this type of process. Attempts at muscular contraction when blockade is induced centrally (e.g. peridural anesthesia or lower level spinal cord trauma) do not result in pressure elevations.⁵¹ This suggests that spinal cord function is involved in centrally generated cardiovascular responses (i.e. central command). As Rowell has pointed out, "motor neuron output at a given level of effort can be facilitated or inhibited by reflex feedback from contracting muscles."⁵¹ As the target of descending efferent activity, muscle fiber type and recruitment patterns will indirectly impinge on autonomic outflow because of the input to those control centers predicted by the central command hypothesis. Consequently spinal adjustments could affect cardiovascular regulation through the central command mechanism. Perhaps the clinical finding of reduced systolic and diastolic blood pressure following adjustments is in part due to central command. This hypothesis is supported by evidence that EMG activity is reduced in resting muscle following adjustments.⁵⁶⁻⁵⁷ An osteopathic controlled study also found that paraspinal EMG activity is reduced in patients following manipulation.⁵⁸

The second effect of muscle on cardiovascular function is exerted through peripheral afferent feedback. Both mechanical and metabolic information from muscle is used to coordinate

cardiovascular activity. Any change in this information produced by chiropractic interventions could be expected to manifest in altered cardiovascular responses. Due to its dependence on motor outflow, central command predicts that hyper-stimulation of motor neurons supplying the muscle would lead to heightened blood pressure and heart rate. Correction of the facilitative type subluxation could therefore be predicted to lead to a drop in blood pressure and heart rate. Conversely, correction of the inhibitory "compression" subluxation could be predicted to lead to an elevation in blood pressure and heart rate. On the basis of these occurrences, a case could therefore be made that chiropractic adjustments "normalize" cardiovascular output.

Strength Defined

Central to any discussion of strength, a definition must be included. This is a more difficult task than one might expect. For example, Wilmore and Costill⁵⁹ define strength as the maximal force that a muscle or muscle group can generate. Dorland's medical dictionary⁶⁰ defines strength as intensity or power and subclassifies muscular strength as the greatest force that can be put forth by a muscle; it is measured with either isometric, isokinetic, or isotonic exercises. Gray's Anatomy⁵² points out that "strength is usually measured on intact subjects in tasks that require the participation of several muscles; it is then as much an expression of the skillful activation and co-ordination of these muscles as it is a measure of the forces that they contribute individually. Thus it is possible for strength to increase without a concomitant increase in the true force generating capacities of the muscles involved, especially during the early stages of training." Finally, Enoka⁶¹ defines strength by the torque rather than the force exerted by the simple joint system for purely pragmatic reasons: it is much easier to measure the torque in human subjects. The measurement of force would involve either the attachment of a force transducer to the muscle tendon or a means of converting the myoelectric activity (EMG) into a measure of force. Since neither of these procedures is simple, torque may be the preferred choice.

Factors That Influence the Development of Force and Strength

However, from a clinical and observational perspective, as well as the objectives of this article, strength is taken to reflect muscular ability to produce force on an external object. In general terms there are three broad determinants of a muscle's ability to generate force: (1) neural factors, (2) muscular factors and (3) biomechanics. As well, other factors cannot be discounted such as the endocrine system, the environment, cardiovascular function and psychological factors as contributors towards strength. However, the present authors believe that these factors can be subsumed under one or all of the three main factors described. The objective is to show that chiropractic adjustments can impact on any or all of these three factors, resulting in change in muscle strength.

Neural Factors

Humans control skeletal muscle through volition. Voluntary

Table 2. Studies Examining the Influence of Chiropractic Adjustments on Strength/Tension

Reference	Subjects	Variables Measured	Technique	Major findings
Pollard and Ward ⁴⁶	15 controls 15 experimental (18-40 yr)	Unilateral isometric maximal contraction of quadriceps femoris	Gonstead side posture/L3	Significant short term increase in strength
Rebechini-Zasadny et al. ⁷²	12 volunteers (21-39 yr)	EMG of first dorsal interosseus during isometric contraction	Cervical index manipulation	Significant increase in strength
Schwartzbauer et al. ⁷³	21 male baseball players (19-23 yr)	Shoulder abduction, long jump distance, capillary counts	14 weeks of upper cervical toggle recoil adjustments	Significant improvement in abduction, long jump and capillary counts
Bonci and Ratliff ⁷⁴	5 controls 20 experimental	EMG of biceps brachii	Seated C4 pillar contact	No significant changes
Howitt-Wilson ⁷⁵	6 student controls 50 patients	Grip strength via sphygmomanometer	Thumb move at T1	21 patients had significant contralateral grip strength increase
Unger ⁷⁶	16 chiropractic patients	Hand held dynamometry on 8 sets of bilateral muscles	Category II blocking (SOT)	Significant strength increase in 15 of 16 muscles
Haas et al. ⁷⁷	47 males 21 females (31 yr)	Piriformis muscle response (RRAM); AK muscle testing	Prone thoracic crossed bilateral	No significant changes
Suter et al. ⁷⁸	17 females 1 male (30.5 ± 13 yr)	Torque, muscle inhibition and muscle activation (EMG) of knee extensors	SI joint adjustments	Significant knee extensor torque increase, decrease in inhibition and increased RMS
Shambaugh ⁵⁶	20 experimental 14 controls (40 yr)	EMG of trapezius and erector spinae at rest	Prone adjustments to T1,T3,T5 L1, L3	Significant reduction in muscle tension and cervicals
Grice ⁵⁷	6 case studies	EMG of spinal area of complaint	Various technique	3 of 6 showed marked decrease in AP, 2 increase in AM, 1 slight decrease in AM

RRAM = relative response attributable to maneuver; AP = action potentials; AM = amplitude

muscles are neurologically “wired” to the voluntary cortex of the brain. Voluntary motor control is primarily governed by the pyramidal system,⁶² the largest descending tract is the corticospinal tract (CST). Its function is to convey information concerning volitional motor activity. Approximately 80% of neurons originate in the motor cortex of the frontal lobe on the opposite side of the somatomotor activity.¹⁴ These neurons descend via the internal capsule through the brain stem on the same side of origin. At the caudal portion of the brain stem these neurons cross (decussate) to the contralateral side of the spinal cord, ipsilateral to the muscle to be activated. The descent of these neurons is via the lateral corticospinal tract. The termination of these axons is in the grey matter of the spinal cord where there is communication with the alpha motor neurons, which terminate on the skeletal muscle. Approximately 20%⁶² of the voluntary motor neurons originate in the cortex on the same side of the body as the involved muscle. These neurons descend via the internal capsule and into the brain stem on the same side they originated on. The difference is that these neurons do not cross in the brain stem but remain on the same side of the body. These neurons descend down the spinal cord in the anterior corticospinal tract and terminate in the grey matter, which communicates with the alpha motor neurons.⁶²

Motor neurons leave the spinal cord via the ventral root and join the dorsal root to form the “mixed” spinal nerve that supplies peripheral muscles. Often referred to as the final common pathway, the motoneurons are the route by which the nervous system controls muscular activity.⁵⁹ A motor neuron and all of the fibers it innervates forms a single motor unit. Once an electrical impulse reaches a motor neuron, the impulse travels the length of the neuron to the neuromuscular junction where the release of acetylcholine elicits an action potential that spreads to all muscle fibers innervated by that particular motor neuron. Several trophic substances influence neuromuscular interaction in addition to acetylcholine.⁶³⁻⁶⁴

The fourth component of the subluxation,¹ namely the “mental impulse,” is intimately linked to the “neural factors” affecting muscular strength. The mental impulse is not synonymous with action potential. It is more appropriately coupled to other modes of transmission. “Several other well documented modes of non-synaptic communication between cells, including; ephaptic transmission, volume transmission, field effects mediated by large extracellular currents, and weaker fields generated by axons during growth and repair, as well as peptide messengers postulated through psychoneuroimmunology, clearly demonstrate that other phenomena play an important role in the transmission of organizing information.”² In the case of skeletal muscle, the effects of the motor neuron are mediated in part by impulse-induced stretching of fibers. However, the remainder of the effects and those achieved by the muscle on motor-neurons, are brought about by chemical messengers.⁶⁵ Thus, neural factors affecting muscle strength consist of a wide spectrum of phenomena including the action potential as well as other modes of nerve “cross talk.”

The strength, or force of contraction of skeletal muscle, depends mostly upon the number and size of the motor units recruited by a stimulus. As well, the frequency of action potentials to that unit, and the rate at which they are activated are also important.⁶⁶ Motor units contain homogeneous fiber types and

are recruited in an orderly manner such that the motor units with smaller neurons (slow twitch-fine motor tasks) are called on before those with larger neurons (fast twitch-gross motor tasks). This is referred to as the principle of orderly recruitment.⁵⁹ As a muscle is required to exert more force in a given action, the muscle responds by recruiting more motor units at quicker speeds. The nervous system can also modulate muscular force by varying the firing rate of motor neurons. Increases in force with increased firing frequency occurs because successive twitches can summate.⁶⁷ Synchronous firing occurs when motor units are recruited simultaneously and is often implemented in power or strength events such as power lifting. Asynchronous firing occurs when some units fire while others recover and is common in endurance events. Synchronous firing allows a large force to be generated quickly, mostly through the stimulation of fast-twitch fibers.⁶¹ The collective effect of the frequency of action potentials along with synchronicity is called rate coding.

Therefore, the neural factors in control of skeletal muscle are complex in nature. For the purposes of this discussion, these factors when interfered with may result clinically in strength deficits.

Muscle Factors

Intrinsic muscular force depends on the number of motor units activated, the type of motor units activated, the size of the muscle, and the initial length when activated.⁵⁹ More force can be generated when more motor units are recruited. Fast twitch muscle fibers generate more force than slow twitch fibers because they have more total fibers per motor neuron. Similarly, larger muscles with more fibers can produce more force than smaller muscles. Pre-stretching a muscle results in stored elastic energy and when released, increases force production. Ultimately, the more cross-bridges that are in contact at once, the more forceful the muscle action.

Biomechanical Factors

The foundation of biomechanics rests upon the concepts of force and motion. Muscles are the major source of force that creates or alters the movement of a body segment or multiple segments. It follows that strong muscles are able to produce more force than weak ones. Absence of forces acting on an object equates to no motion. Forces are often described by four characteristics: (1) magnitude of force, (2) line of application of force, (3) sense, or direction along the line of applied force, and (4) point of application of force.

Humans are able to move as a result of the application of force onto anatomical levers. These levers are not modifiable, with the exception of surgery or traumatic occurrences. An understanding of the neuromusculoskeletal relationships of body levers can allow a person to be more efficient in terms of muscular efforts. Levers can be thought of as rigid bars that turn about an axis. There exist three types of levers: first class levers result when the axis of rotation is between the force and the resistance; second class levers have the resistance between the axis and the force; third class levers place the force between the axis and the resistance. Floyd and Thompson⁶⁸ describe the various types of levers in further detail.

Another important factor is the angle of pull of muscles on bone. This angle is described as the angle between the muscle insertion and the bone on which it inserts. When the line of force approximates 90 degrees to the bone it attaches to, all of the muscular force is rotational force and thus 100 percent of the force is producing movement. At all other degrees of pull angle, there is a lessened rotary force component with the addition of a non-rotary force component that is either termed stabilizing (angle of pull is greater than 90 degrees) or dislocating (angle of pull is less than 90 degrees).⁶⁸ The common activity of flexing your forearm against resistance is easier if a person begins at 90 degrees because of the more advantageous angle of pull. When one is required to operate at a disadvantageous angle of pull, an increase in strength and force is the only solution to operate efficiently. Force appears to be dependent on the speed of a contraction. During concentric (shortening) contractions maximal force development decreases at higher speeds, whereas, fast eccentric contractions allow maximal application of force.³⁹

Relationship between the Three Elements of the Ability of a Muscle to Generate Force

These descriptions indicate that there is an obvious complex relationship between the neural, muscular, and biomechanical factors that contribute to the strength of an individual's musculature. Thus the question as to whether there is evidence to support strength gains following chiropractic care must be addressed. Moreover, if so, the mechanisms by which they might occur must be described. The literature pertaining to strength changes resulting from chiropractic care provides insight into this concept. A discussion of potential mechanisms of action and implications on the general health of those receiving chiropractic adjustments is provided.

Research Investigations on Chiropractic and Muscular Function

There are three prevalent axioms evident within chiropractic. The first is that the body is a self-healing and self-regulating system. The second is that the nervous system co-ordinates and controls organ function. Finally, it follows that if there is interference to the nervous system as predicated by an existent vertebral subluxation then removal of the subluxation by a chiropractic adjustment will restore neurological integrity and promote health. Practitioners whose goal it is to detect and correct subluxation adhere to these axioms.

The traditional approach in examining the effects of chiropractic care, however, has not focused on the overall health of the individual. Rather, chiropractic investigations have tended to focus on the amelioration of symptoms or the treatment of disease states.⁶⁹⁻⁷¹ Contra to this perspective however, is the admonition by the World Health Organization relative to the definition of health, which is; the optimum physical, social, and mental well-being of an individual, not merely the absence of disease or infirmity.^{4,60}

As a result of the traditional approach, many attempts have been made to investigate the effects of chiropractic care on pain and symptom management over the years. Typical pain studies tend to concentrate on the activities of the dorsal horn and its

afferent precursors. To relieve pain and suffering is an honorable goal, but there may be much more to chiropractic than back pain or neck pain. To investigate through research that chiropractic maximizes human potential, the ventral side of the cord should at least be considered more than we do now in terms of health consequences. A number of studies^{46,72-78} have been done to characterize the influence of subluxation or chiropractic adjustments on measures of efferent motor control, in particular, strength.

Subluxation theory was predicated on the work of Daniel David Palmer and his son B.J. Palmer. Although B.J. Palmer began testing this theory in the earlier part of this century, investigation of the possible motor effects of vertebral subluxation have only recently intensified.^{46,73,76-78} The inherent difficulty of studying the subluxation and its effects on neural integrity, is the complexity of the nervous system itself.

In chiropractic practice, there is anecdotal evidence that strength may be enhanced through the adjustment. The major premise of this paper is that the effects of chiropractic extend beyond symptom management. The basis for this assumption is that the vertebral subluxation is responsible for the impairment while the adjustment restores neurological integrity and enhances motor integration. Several studies have shown that muscle strength is significantly increased following chiropractic adjustment (Table 2). A few of the studies are elaborated on below.

A study by Pollard and Ward⁴⁶ stated that in fifteen experimental asymptomatic students receiving a manipulation to the L 3-4 motion segment, there was a *progressive* short-term increase in strength of the quadriceps femoris with repeated tests. The fifteen control subjects were subjected to a simulated manipulation (sham) which involved a general nonspecific, non-cavitating impulse into the soft tissues. The results of the control group demonstrated a progressive strength decrease or fatigue with repeated tests. All subjects were required to perform unilateral isometric maximal contraction of the quadriceps as measured by a force transducer. There was an overall statistically significant change between the experimental and control groups.

More recently, Schwartzbauer et al.⁷³ analyzed athletic performance in baseball players following upper cervical chiropractic care. Twenty-one male university baseball players free from physical injury completed the study, nine in the chiropractic group and twelve in the control group. The control group did not receive chiropractic care. The subluxations were determined from radiographic analysis and the Palmer toggle-recoil adjustment in side posture with a drop head piece was employed. The results showed significant improvement ($p < 0.05$) at fourteen weeks of care in muscle strength (repetitive shoulder abduction), long jump distance, and capillary counts in the group receiving adjustments.

Suter et al.⁷⁸ found that sacro-iliac joint manipulation altered muscle inhibition and strength of the knee extensor muscles in patients with anterior knee pain. Eighteen (17 women) patients with either unilateral or bilateral knee pain were included in the analysis of whom most had a history of previous intervention (surgery, physical therapy). Before and after the manipulations, torque, muscle inhibition and muscle activation for the knee extensor muscles were measured during isometric contractions using a Cybex dynamometer, muscle stimulation and elec-

tromyography. Results showed substantial muscle inhibition in the involved and contralateral legs by way of interpolated twitch technique. After correction of the SI joint dysfunction, a significant increase in knee extensor torques and a decrease in muscle inhibition were observed in the involved legs and EMG root mean square values were higher compared to pre-adjustment status. Interestingly, increased EMG activity was also evident in the legs contralateral to the SI joint manipulation in patients with bilateral knee pain.

The belief that muscle strength can be enhanced through chiropractic care suggests that the subluxation interferes with either neurological, muscle strength, or biomechanical factors or a combination of these. These same principal factors may play an integral part in the detection of subluxations. Dobson⁷⁹ recently describes how manual muscle testing (MMT) combined with specific head positioning, and other articular challenges may be used as an assessment of vertebral subluxation in the upper cervical spine. This method provides an interesting approach in detecting subluxation because it engages biomechanical factors at the same time, stressing muscular and neural factors by performing MMT. Manual muscle testing is widely used in clinical practice as a method for determining muscle weakness.⁸⁰ It may aid in the detection of subluxations,⁷⁹ and should be considered an important way to ascertain and track the patients neuromuscular status.

Discussion

In this paper the factors affecting muscular strength have been reviewed and discussed. As well, components of the vertebral subluxation associated with muscular function, and research investigations into this area have also been presented. As well, the concept of central command relative to the chiropractic literature has been presented as a means of explaining some of the cardiovascular effects seen following chiropractic adjustments.

There are two basic opposing neurological processes that can influence skeletal muscle behavior. The first is the concept of neurological hypo-functioning, or degeneration, such that the end result of the process is reduced neural activity to muscle. In terms of the vertebral subluxation, causes may include compression lesions of nerve roots, rootlets, peripheral nerves, or inhibitory adaptation responses such as neural habituation in the spinal cord. Although only partially understood, another way reduced motor output has been postulated to occur is by means of inhibitory influences from the assortment of descending pathways from various parts of the brain. The reduction of the "mental impulse" which may include neurotrophic factors, chemical mediators and other forms of transmission could also be postulated to inhibit normal muscular function. These processes imply that the end organs (ie. muscles) may not have any intrinsic pathology, but are the recipients of factors, which may be contributing to neural inhibition. The clinical findings seen in someone with alpha and gamma motor neuron inhibition from a subluxation may be similar to those with any other lower motor nerve lesion and may include: muscle weakness, absent or diminished muscle tone, fasciculations, neurogenic atrophy, and absent or decreased stretch reflexes.¹⁴

Perhaps the most common neural mechanism by which mus-

cles may be affected is the facilitation subluxation. The facilitation hypothesis has also been called the impulse-based theory because it depends on impulses from the proprioceptive nerve receptors located in spinal muscles.¹⁷ When nociceptor activity is increased and mechanoreceptor activity is decreased, the facilitation may be attributed to nociception.⁴⁷ Therefore, the facilitated nerves become sensitized by the bombardment of stimulation they almost certainly receive from peripheral receptors in muscles, tendons, ligaments, and joints.⁸¹ However, this is not to say that cutaneous receptors and interoceptors cannot also contribute to the state of hyper-excitability. Denslow et al.⁸² demonstrated that motor neuron pools in the spinal cord segments of humans related to areas of somatic dysfunction were maintained in a state of facilitation. This chronic hypersensitive state means that facilitative subluxations are hyper-responsive to impulses received from any part of the body. Clinically this facilitative type subluxation may exhibit muscle hyper-tonicity, muscle weakness, and exaggerated stretch reflexes.

Anecdotal evidence suggests that chiropractic care enhances muscular strength, although the studies by Bonci and Ratliff⁷⁴ and Haas et al.,⁷⁷ contradict this view. In the studies reviewed, a variety of muscles including those of the upper extremity, back, and lower extremity, have shown significant increases in strength following adjustments.^{46,72-73,75-76,78} However, because most of the investigations measured strength immediately after adjustments, and did not include long term follow up analysis, it is difficult to say how long these changes lasted. However, Schwartzbauer et al.,⁷³ found that at fourteen weeks of upper cervical care, strength was still significantly improved compared to controls. The effect of increased strength occurred in both males and females and in both asymptomatic and symptomatic subjects. The potential mechanisms of action of subluxation correction on motor performance have been presented throughout this paper.

Re-establishment of coherent patterns of afferent input by way of the chiropractic adjustment is theorized to eliminate neurological interference and allow the proper functioning of skeletal muscle. The present authors suggest that this is important in terms of muscular strength because of its potential to eliminate the formation of internuncial reverberating circuits caused by distorted afferent signals from the periphery (Table 3).

Ochoa states that "many adults, both ill and healthy, harbor sub-clinical local lesions of one kind or another within their peripheral nerves or spinal nerve roots. At present, many of us have or will develop clinical manifestations, such as muscle weakness and atrophy, sensory loss, or paresthesias and pains in various combinations from such lesions."⁸⁶ Evidence of the muscular weakness aspect of this statement is provided by the fact that the majority of subjects in the reviewed studies who were adjusted regardless of whether they had symptoms or not, experienced significant improvement in muscle strength.

It appears that chiropractic adjustments can positively impact all three of the factors affecting muscle strength; (1) neural factors, (2) muscle factors, and (3) biomechanical factors. Neural factors have been most discussed in this article because the nervous system controls muscular activity. The primary muscular factor that the adjustment can affect, as seen in the studies presented,⁵⁶⁻⁵⁷ is resting electrical activity, measured by surface EMG. Following adjustments there were significant reductions

Table 3. Improved Strength Following Chiropractic Adjustments

<i>Potential Mechanisms</i>
Removal of nerve root pressure ^a reversing compression effects.
Removal of motion restrictions ^b and restoration of normal joint biomechanics. ^c
Restoration of appropriate patterns of sensory input ^d by normalization of the internal state of the involved connective tissue (enhancing pliability, increased ROM). ^e
a. References 16, 83 b. References 84, 85 c. Reference 10 d. References 47, 81 e. Reference 50

in muscle activity. Since facilitative subluxations lead to hypertonic muscle patterns, the adjustment appears to normalize muscle tone (normotonic) and as a result may allow the muscle to resume a more correct length-tension relationship, thus decreasing its activity level.

The mechanical effect of the adjustment may restore biomechanical stability to the involved motion segments by increasing pliability and the range of motion of the surrounding connective tissues. Adjustments also can improve the process of central command because of reflex effects on reducing reactive afferent stimulation as well as reversing compression effects if present. This in turn implies an improved ability of the person receiving chiropractic care to more adequately regulate his/her cardiovascular system.

Athletic performance demands strength, balance, proper posture, co-ordination and flexibility. All of these components require appropriate regulation by the nervous system. As an example, one such activity that demands the above listed performance requirements is dance. Interestingly, a study investigating the relationship between spinal misalignment and dance performance indicated that spinal misalignment has a negative effect on overall dance performance relative to muscle balance.⁸⁷ This study suggests that the absence of vertebral subluxation, which would allow the body to express normal muscular balance, is a positive contribution to dance. This is concluded because chiropractic is proposed to allow the innate wisdom of the body to be expressed primarily via the neural mechanisms described, and thus all athletes, including dancers, appear to do especially well by receiving regular chiropractic care.

Highly trained athletes, however, are not the only ones who can directly benefit from gaining additional strength. Recent evidence indicates that strength is a predictor of disability in older people.⁸⁸ Research investigations regarding strength and chiropractic care did not just show improvement of strength in athletes but also, in young subjects, in subjects who had symptoms and those without symptoms. Thus, it can be surmised that appropriate chiropractic care may improve the health and quality of life of anyone with vertebral subluxation, regardless of their physical status. Further investigation is required to fully

elicit an understanding of the potential mechanisms of chiropractic care in all age groups with respect to muscular strength. However, preliminary evidence suggests that the adjustment can significantly improve short-term strength in the adult population, regardless of their physical state relative to symptoms.

Summary and Conclusions:

1. Subluxation correction has effects that extend beyond the palliative effects of spinal manipulation.
2. The benefits of improved neurological flow of information can improve the functional capabilities of both the muscular and cardiovascular systems.
3. The musculoskeletal/neurophysiological pathways that may account for the efficacy of the adjustment in eliminating fixated joints and improving muscular strength are provided.
4. Clinical muscle, and other forms of testing, should be considered an important way to ascertain the patients neuro-muscular status, and that return of muscle strength is a good indicator of the success of that approach.
5. Chiropractic care can positively impact all three of the factors affecting muscle strength; (1) neural factors, (2) muscle factors and (3) biomechanical factors.
6. Because the central nervous system has an inherent capacity to learn and adapt (ie. habituate) it may also have the capacity to learn to be sick (pathological habituation) by looking in certain deranged central neural circuits which lead to chronic disease states.⁸⁹ These pathologically habituated states can be reversed by de-habituation through modulation of the abnormal neural circuits by physical means.⁸⁹ This de-habituation according to chiropractic philosophy is the elimination of the subluxation by chiropractic adjustments allowing the mental impulse to propagate uninterrupted.

7. Enhancements in strength have a number of positive manifestations some of which are perceived and others not. The older person who has developed a possible resistance to falls or the easing of everyday tasks such as picking up a child, carrying groceries or carting your trash to the curb all enhance the quality of life for everyone. Less well appreciated is the fact that with

improved strength, these same tasks will elicit less of a cardiovascular tumult (viz. central command and afferent feedback).

8. In short, chiropractic appears to "normalize" neural integrity; it functions to promote the overall health of the individual, not just pain relief. Considering the powerful effects of the adjustment on muscle strength alone, it seems reasonable to consider the benefits of chiropractic care from the standpoint of a health enhancement model as opposed to a strictly disease elimination model. Muscles comprise a large percentage of the total mass of the body, are a significant regulator of homeostasis and are required in all movements, and contribute to the regulation of the cardiovascular response. Hence, our ability to affect muscle has profound total body effects.

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