The Role of the Spinal Dura Mater in Spinal Subluxation

ABSTRACT: This paper examines the evidence for the role of dural attachments in the biomechanical and patho-physiological manifestations of Spinal Subluxation. The scientific literature is reviewed in relation to anatomical, biomechanical, physiological and clinical considerations. The paper examines the implications of these factors in the context of "Tonal" Chiropractic models.

INTRODUCTION

The Dura Mater is the continuation of the inner layer of the cranial dura mater beyond the Foramen Magnum and brainstem. The potential role of the Dura mater in the biomechanics of the Subluxation Syndrome and the physiological and pathophysiological effects of the Subluxation Syndrome has been proposed by early authors and contemporary technique developers within the Chiropractic profession.

This paper endeavors to review anatomical considerations in relation to the Dura Mater and its biomechanical relationship with the spinal column, and suggests a potential role for the Subluxation Syndrome in exacerbating mechanical spinal cord tension, and to produce detrimental effects to the function of the nervous system.

DURAL ATTACHMENTS TO THE VERTEBRAL COLUMN

There has been some controversy in regards to the fibrous attachments that exist between the vertebral canal and the Dura Mater over many decades. This appears to be in part due to the degree of anatomical variation between individuals that have been studied. The second factor appears to be the rapid development in imaging technologies allowing greater visualization of microscopic anatomy; versus the gross dissection techniques of the past.

It would appear that early Chiropractors paid attention to this matter. Stephenson illustrated the existence of attachments of the Dura to bone other than to the foramen magnum and coccyx, to at least the posterior body of C2 (Fig. 1) (1). This may explain in part the apparent obsession of some of our pioneers with the upper cervical spine. It should also be noted that Stephenson also dedicated a chapter of his "Art of Chiropractic" to the Coccyx (2). It would appear that the importance of the caudal attachment of the spinal cord was not ignored either.

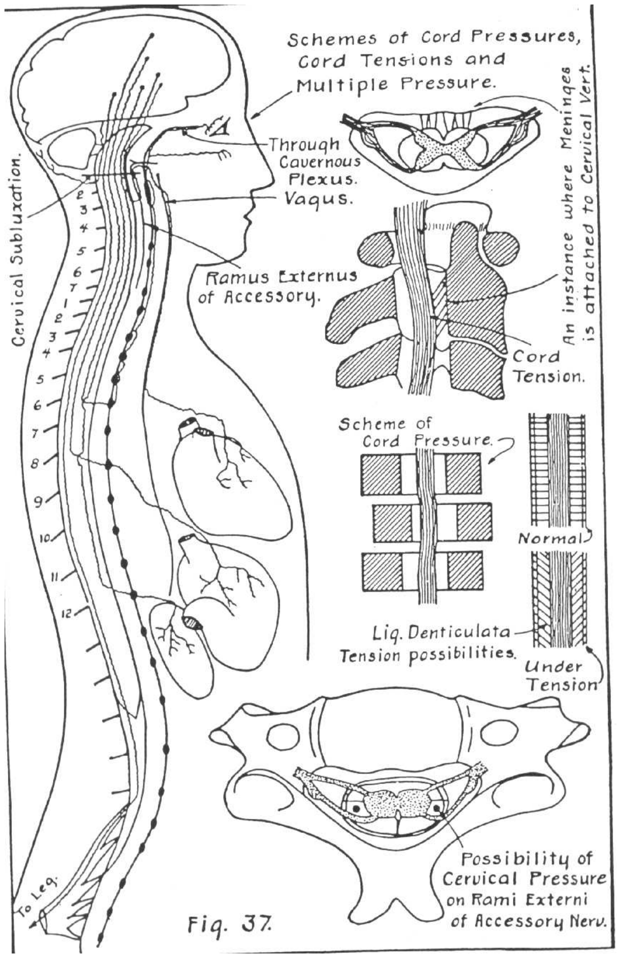

Fig. 1: Plate from Stephenson's 1927 Textbook of Chiropractic.

Academic texts through time have modified their descriptions: For example my personal copy of the third edition of Moore's clinically oriented Anatomy text states that: "The spinal Dura mater, the tough outermost covering membrane of the spinal cord, is composed of white fibrous and elastic tissue. The spinal Dura forms a long tubular sheath or Dural sac <u>that is free within the vertebral canal</u>. It is adherent to the margin of the foramen magnum of the skull, where it is continuous with the cranial Dura mater." (3)

According to the 35th edition of Grays Anatomy, "The spinal Dura mater is attached to the circumference of the foramen magnum, and to the posterior surface of the second and third cervical vertebrae; it is also connected by fibrous slips to the posterior longitudinal ligament of the vertebrae, especially near the lower end of the vertebral canal. The subdural cavity ends at the lower border of the second sacral vertebra; below this level the Dura mater closely invests the Filum Terminale of the spinal cord and descends to the back of the coccyx, where it blends with the periosteum." (4)

Passage through time has seen many expansions on the limited information provided by the teaching texts. "There are inconsistencies between the descriptions of the physical connections between the spinal cervical dura and the surrounding tissues. A study was undertaken to clarify the relationship between the spinal dura, the nuchal ligament and the suboccipital muscles. Dissections were performed on embalmed cadavers: in nine the relevant structures were removed en bloc, whereas in one a sagittal section was prepared. In all specimens it was possible to demonstrate continuity in the midline between the nuchal ligament and the posterior spinal dura at the atlanto-occipital and atlanto-axial intervals. No such attachments were found caudal to the arch of the axis. In addition, there was a connective tissue bridge between the deep aspect of the rectus capitis posterior minor muscle to the transverse fibers of the posterior atlanto-occipital membrane that extended laterally to blend with the perivascular tissue of the vertebral arteries. The present study is, we believe, the first to describe continuity between the nuchal ligament and the dura at the atlanto-occipital interspace, and confirms previous descriptions of similar connections at the atlanto-axial level." (5)

"The connective tissue attachments to the cervical spinal dura mater originating from the ligamentum nuchae (LN) and rectus capitis posterior minor (RCPM) muscle were evaluated in 30 cadaveric spines. Magnetic resonance images (MRIs) were correlated with the attachments in four cadaveric specimens. Attachments from the LN to the RCPM were also identified. The LN and the RCPM to dura attachments were found in all 30 specimens. Our results indicate that: 1) the attachments between the LN and RCPM and the dura occur between vertebrae C1-C2 and the occipital bone and C1, respectively, and that they are substantial normal anatomic attachments, 2) attachments between the LN and RCPM are usually present, and 3) the attachments between the LN and dura mater can be identified on MRI. These latter attachments may play a role in neck pain, making their MRI appearance clinically important. (6)

The attachment of dura to muscle was also confirmed by some dentists who demonstrated "a connective tissue bridge between the rectus capitis posterior minor muscle and the dorsal spinal dura at the atlanto-occipital junction". It was suggested by the researchers that such an attachment would help to maintain the spinal cord's position preventing excessive anterior displacement. (7)

Sunderland suggested that the dura also attaches to the transverse processes of the lower cervical vertebrae (C4-6). (8)

"Meningovertebral ligaments (AKA Hoffman's Ligaments) represent a heterogenous group of membranous formations, connecting the dura with the Posterior Longitudinal Ligament and other elements of the spinal canal. They prevent the dura from moving away from the bony container. These ligaments may vary from loose areolar tissue to clearly individualised ligaments and from pure midsagittal septa to more laterally oriented attachments. A double cross vault structure between the Posterior Longitudinal Ligament and the dura mater often extends from L3 to the end of the dural envelope. A retrospective study of medial and paramedial attachments in CT and MRI scans confirmed the presence of a mediosagittal structure below L3 in 35% of the cases." (9) Once again the suggestion was that these structures are a normal and necessary anatomical and biomechanical component of the spinal system.

"Meningovertebral ligaments were found in both the lumbar and thoracic regions of all cadaveric specimens. These ligaments were much more prevalent in the lumbar vertebral column but were also present throughout the thoracic vertebral column. The meningovertebral ligaments in the lumbar region were more robust as well as more frequently encountered than those found in the thoracic region. Dural sac attachments to the posterior aspect of the vertebral bodies and the posterior longitudinal ligament could act to traction the dural sac in the event of nuclear bulge or herniation." (10) The added emphasis by these authors suggested a potential role for normal anatomy to play a part in the development of neural tension, and we will examine this further later in this paper.

"In contrast to the attention paid to the structures surrounding spinal nerve roots in the intervertebral foramina, the anterior dural attachments are largely ignored, although they have been described since the last decades of the 19th century. These anterior attachments were systematically studied in a series of 30 cadaver dissections and were found to be present in almost 94% of cases. Four types of anterior attachments were observed. The most frequent form (84%) being a system of filaments that present as a double cross vault between the dura mater and the posterior longitudinal ligament extending from L3 to S3 levels. Less frequent were sagittal filaments (30%), short strong ligaments

(17%) and a median septum from L3 to the end of the dural sac (7%). No attachments were found in two cadavers." (11)

"Anterior dural ligaments connect the anterior dura to the deep layer of the posterior longitudinal ligament, but appear to be limited to the lumbar region and have been observed to have a craniocaudal orientation. Their function is reported to help in supporting and protecting the dural sac and spinal cord… The orientation of the ligaments changed from caudocranial (dura to posterior longitudinal ligament) at upper thoracic levels to transverse at the level of T8-T9 to craniocaudal at lower thoracic and lumbar levels, often with multiple ligaments being present at a single level. Ligament length varied from 0.5 to 28.8 mm and was positively correlated with vertebral level and negatively correlated with orientation… Hofmann ligaments are present at most levels between C7 and L5; although most ligaments were limited to a single vertebral segment, some were observed to cross several segments." (12)

"Among the minor soft structures of the lumbosacral spinal canal that computed tomography can visualize, the meningovertebral ligaments have been neglected. There are no specific reports on this subject, and the only knowledge we have comes from very ancient and nearly forgotten anatomical works. From our studies on cadaveric specimens, it has been confirmed that the ligaments consist segmentally of ventral and lateral fibrous bands, connecting the outer surface of the dura to the endostium of the spinal canal. The most characteristic component is the ventral one, running from the anterior wall of the dural sac to the posterior longitudinal ligament and vertebral endostium. Due to their anchoring function, the ligaments are significantly developed at the level of the dural conus (sacrodural ligaments of Trolard and Hofmann). On in vivo computed tomography studies, the ligament image appears most commonly on transverse scanograms of the lumbosacral segments as a median sagittal septum, easily identifiable when the extradural fat that it crosses is abundant. The meningovertebral ligaments may be implicated in pathological conditions of the spinal canal. They can calcify singly, though very rarely, and this process must be differentiated from degenerative marginal spurs, calcific disc herniation, circumscribed calcification of the posterior longitudinal ligament, or partial diplomyelia." (13)

So, Moore's earlier description of a spinal cord freely floating inside the spinal canal has been replaced by clearer descriptions of fibrous attachments between the dural sac and its surrounding tunnel anteriorly, posteriorly and probably even laterally. This spider web of ligaments appears to suspend the spinal cord in a relatively central location within its hosting tube. These connections could also be expected to produce a stable degree of mechanical tension between the cephalad and caudad ends of the spinal cord in a neutral posture.

Undergraduate Anatomy classes often describe the spinal cord as floating as a suspension in the Cerebrospinal Fluid; but a more accurate description may be that it is hanging within the spinal canal much like a circus tent help up by a number of guide ropes, projecting from supporting columns.

Based on the descriptions of the actual dimensions and consistency of the connective tissue attachments this author would suggest that there appears to be three levels of "strength" of these attachments:

1) The strongest and most permanent attachments around the foramen magnum and to the coccyx;

2) Seemingly consistent but slightly finer attachments of the dura to the body of C2, to the nuchal ligament at the atlantoaxial level, transverse processes of lower cervical vertebrae, and, to the posterior longitudinal ligament somewhere between L3 and S3, and;

3) Significantly finer and less consistent attachments to the body of C3, rectus capitis posterior minor muscle, and thoracic to upper lumbar posterior longitudinal ligaments.

From a Chiropractor's point of view, might this also suggest some degree of ranking of clinical significance of these spinal levels when subluxated?

DURAL ATTACHMENTS TO THE SPINAL NERVES

The dura mater also needs to allow the spinal nerve roots to escape from the spinal canal through each intervertebral foramina. "The spinal dura mater extends into the intervertebral foramina and evaginates along the dorsal and ventral nerve roots of the spinal nerves and spinal ganglia to form dural root sleeves. These sleeves adhere to the periosteum lining the intervertebral foramina and end by blending with the epineurium of the spinal nerves." (3)

"Also, a high incidence of the intradural connections between the dorsal rootlets of C5, C6, and C7 segments was found. The presence of intradural connections between dorsal nerve roots and the relation between the course of the nerve root and the intervertebral disc may explain the clinical variation of symptoms resulting from-nerve root compression in the cervical spine.” (14)

This melding of the dura into the coating of the spinal nerves would mean that sliding movement of the spinal nerve away from the spinal canal would draw the dural sheath inside the foramina with it, and that movement of the spinal cord inside the spinal canal superiorly or inferiorly would retract the spinal nerve towards itself.

DURAL ATTACHMENTS TO THE SPINAL CORD

The spinal bones connects to the dura mater; the dura mater connects to the “The spinal cord is suspended in the dural sac by a saw-toothed denticulate ligament on each side. This ribbon-like ligament, composed of pia mater, is attached along the lateral surface of the spinal cord, midway between the dorsal and ventral nerve roots. The lateral edges of the denticulate ligament are notched or serrated. The 21 tooth-like processes of the ligament are attached to the dura mater between the nerve roots. Their attachment is to the periosteum starting at the foramen magnum; the last one is between T12 and L1 nerve roots.” (3)

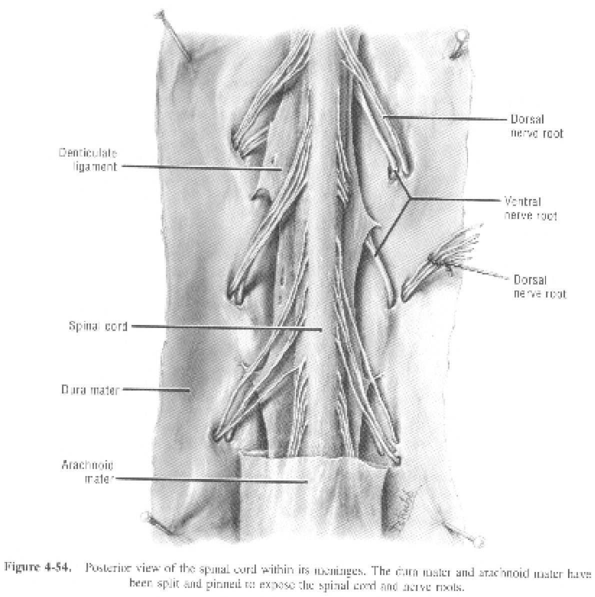

Figure 2: Gray’s Anatomy diagram of the denticulate ligaments.

The spinal cord hangs on the dentate ligament, itself attached to the dura mater, so as to avoid excessive loading on the brain stem and the pons.

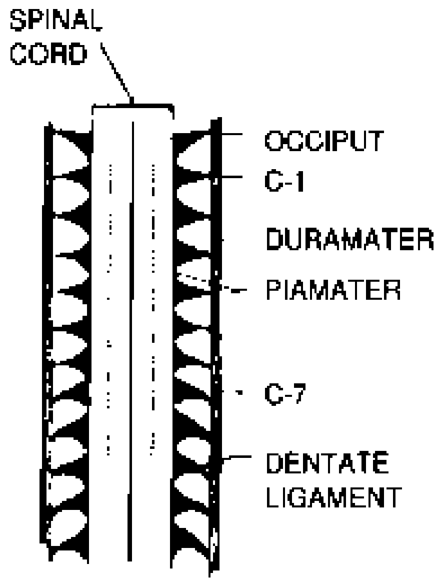

Figure 3: Diagram depicting dentate ligaments. (15)

“Changes in the form and position of the denticulate ligament during spinal movements have been demonstrated by cineradiographic techniques.” (4) Changing positions of the spinal column alter the degree of tension on the spinal cord and denticulate ligaments. In general flexion increases tension while extension reduces tension. “The spinal canal undergoes considerable changes in length between the extremes of flexion and extension, particularly in the cervical and lumbar regions. The total change is of the order of 5-7cm, and is greater on the posterior than the anterior aspects. Similarly, on lateral flexion, the canal is lengthened on the convex side and shortened on the concave.” (16)

It would appear perfectly plausible that the connection between spinal canal length changes and changes in form, position and degree of tension between the dentate ligaments and the spinal cord result from the transmission of forces from the spinal column via the dural attachments between bone, ligament and muscle as described earlier.

“The authors have determined that the ligaments are stronger in the cervical region and that they decrease in strength as the spinal cord descends. These findings are demonstrative of the denticulate ligaments being more resistant to caudal compared with cephalad stresses in the cord. Anterior and posterior motion is constrained by these ligaments but to a limited degree, especially as one descends inferiorly along the cord.” (17) Anatomically the relatively large number of dural connections to the spinal column in the cervical spine might suggest a significant role for subluxation in the cervical spine in influencing the spinal cord. Conversely the relatively greater strength of dentate ligaments in the cervical region would increase the influence of spinal cord movement on the cervical spine's biomechanics.

SPINAL CORD PRESSURE AND CORD TENSION

The potential for nerve system impingement is not a new concept. R.W.Stephenson describes clearly separate mechanisms of nerve impingement due to either "pressure" or "tension": "Impingements can occur in the spinal canal, which is also packed with the same material as the foramen. These impingements are called Cord Pressures. There are several kinds. Those due to pressure upon the contents of the spinal canal, and those due to distortion of the meninges, called Cord Tension." (1)

In the neuroscience and neurosurgical literature much attention has been paid to cord compression as the predominant mechanism for neurological insult. Concurrently the major focus of Chiropractic descriptions of Subluxation has centred on local compressive and constrictive impacts, either centrally or laterally in the spinal vault.

More recently the focus has broadened to include the concept of cord tension as a potential offender in neurological damage.

Alf Breig a neurosurgeon, coined the term "Adverse Mechanical Cord Tension" in 1978: "When the trunk is fully flexed the dura is under tension, as is also the cord, and stretching occurs. Part of this tension is transmitted from the dura mater via the dentate ligaments to the pia mater, but by far the larger component of the tension is set up directly in the cord by virtue of its anchorage at its two extremities, namely the brain stem and the cauda equina. From the biomechanical aspect the spinal cord therefore cannot be considered in isolation but must be treated as a continuous tract of nervous and supporting tissues." (16)

Hence transmission of tension in one section of the spinal cord will automatically be transmitted to the rest of the length of spinal cord. This concept offers significant implications for the potential of distant neurological effects from a localised source of spinal cord tension. Could it be that a local lesion such as a Spinal Subluxation could have more global impact through this mechanism?

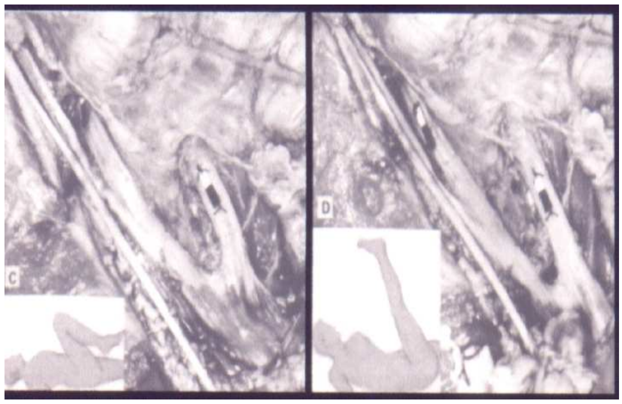

Fig 4: Dissection photo showing a Sciatic nerve tractioning away from the spine in a position know to create dural stretch. (15)

"All spinal postures will deform the neural elements within the spinal canal. Flexion causes the largest canal length changes and, hence, the largest nervous system deformations." (18) There seems to be strong consensus in the literature that flexion movements create the largest increases in spinal cord tension, while extension movements create compressive changes to the dimensions of the spinal canal. Either tendency provides compelling motivation for any chiropractic intervention to attempt to restore the spinal column to as close to the ideal neutral posture as possible.

In another study "In vivo, quasi-static distortion of the human cervical spinal cord was measured in five volunteers during flexion of the neck using a motion-tracking magnetic resonance imaging technique… To measure cord distortion and movement in living subjects… Between a neutral posture and full flexion, the entire cord (C2-C7) elongated linearly with head flexion, increasing 10% and 6% of its initial length along the posterior and anterior surfaces, respectively. Average displacement was on the order of 1-3 mm, and varied with region. Specifically, the upper cord showed caudad movement in the spinal canal, and the lower cord moved cephalad, again with larger movements on the posterior surface… The cervical cord elongates and displaces significantly during head flexion in human volunteers, offering valuable information regarding the normal milieu of the cord." (17)

"In 15 cases dynamic studies of cervical spinal cord and canal in flexion and extension were performed by magnetic resonance imaging (MRI). In addition measurements of the complete spinal cord were made in 5 cases. As compared with extension the cervical spinal canal and spinal cord lengthen 12 mm in average during flexion, whereas the spinal canal lengthens 28 mm in average, which means a difference of about 15 mm. We feel that these results indicate that adverse mechanical tension may occur in the cervical spinal cord during flexion." (19)

Mechanical cord tension created by the normal flexion movements of the spinal column is most likely a normal physiological process, within the physiological limits of the elastic properties of the spinal cord and meninges, and without pathological or clinical ramifications. But is it possible that more forceful, extreme, or sustained factors that produce increased spinal cord tension may have significant potential for harm?

ADVERSE MECHANICAL CORD TENSION

The discovery of the stretching tensioning effect of spinal canal flexion holds important implications for the aetiology of spinal cord damage from sudden whiplash type movements. It also holds clues for the potential for more chronic low-grade flexion tensioning of the spinal cord and how this may contribute to spinal cord neuropathophysiology. There are also significant ramifications for a range of therapeutic modalities.

"The simple pathoanatomic concept that a narrowed spinal canal causes compression of the enclosed cord, leading to local tissue ischemia, injury, and neurological impairment, fails to explain the entire spectrum of clinical findings observed in cervical spondylotic myelopathy. A growing body of evidence indicates that spondylotic narrowing of the spinal canal and abnormal or excessive motion of the cervical spine results in increased strain and shear forces that cause localized axonal injury within the spinal cord. During normal motion, significant axial strains occur in the cervical spinal cord. At the cervicothoracic junction, where flexion is greatest, the spinal cord stretches 24% of its length. This causes local spinal cord strain. In the presence of pathological displacement, strain can exceed the material properties of the spinal cord and cause transient or permanent neurological injury. Stretch-associated injury is now widely accepted as the principal etiological factor of myelopathy in experimental models of neural injury, tethered cord syndrome, and diffuse axonal injury. Axonal injury reproducibly occurs at sites of maximal tensile loading in a well-defined sequence of intracellular events: myelin stretch injury, altered axolemmal permeability, calcium entry, cytoskeletal collapse, compaction of neurofilaments and microtubules, disruption of anterograde axonal transport, accumulation of organelles, axon retraction bulb formation, and secondary axotomy. Stretch and shear forces generated within the spinal cord seem to be important factors in the pathogenesis of cervical spondylotic myelopathy." (20)

Could it be then possible to propose a hypothesis that a subluxation syndrome would have similar pathological potential due to biomechanical rather than anatomical factors as that of spinal cord tension especially if exacerbated by the presence of spondylotic structural space occupying lesions?

"Tethered cord syndrome (TCS) is a stretch-induced functional disorder of the spinal cord. The mechanical cause of TCS is an inelastic structure anchoring the caudal end of the spinal cord that prevents cephalad movement of the lumbosacral cord. Stretching of the spinal cord occurs in patients either when the spinal column grows faster than the spinal cord or when the spinal cord undergoes forcible flexion and extension. Research in patients and experimental animals suggests that there is a link between the clinical dysfunctions that characterize TCS and putative pathophysiological changes that accompany this syndrome. Among these changes are depression of electrophysiological activity and shifts in the reduction/oxidation ratio of cytochrome oxidase. The latter suggests that there is impairment of oxidative metabolism." (21)

Models of Subluxation cover a range of manifestations. One such manifestation is that of spinal misalignment. It may be a stretch to suggest that the degree of distortion created by this component of a Subluxation would be sufficient to create a pathological degree of spinal cord tension comparable to myelopathy or tethered cord syndromes. But, Chiropractors have long made the distinction between dysfunction and dys-function.

Another manifestation of Subluxation is kinesiopathology: Would it be plausible to suggest that spinal joint biomechanical restriction could mimic the "inelastic structure" mentioned above? Or, could there be another mechanism whereby a Subluxation syndrome could create or at least exacerbate the presence of adverse spinal cord tension?

"The role of the dentate ligaments in the pathogenesis of myelopathy secondary to disease conditions that alter the normal biomechanics of the spinal canal was studied in 14 dogs. The effects of posterior cord elevation on somatosensory evoked potentials (SSEP's) and tension requirements were compared before and after dentate ligaments section in acute experiments. At levels of posterior elevation usually within the confines of the canine canal, the dentate ligaments were the most significant element increasing tension requirements and SSEP alternations. Human cadaver studies also showed an approximate 50% reduction of force after dentatotomy. These findings suggests that after dentate ligaments section the applied tension is distributed over a longer segments of the cord with a reduction in tension and disruption of axonal conduction at the level at which the force was applied." (22)

As proposed earlier in this paper, tension in the spinal cord is transmitted from the spinal dura mater via the denticulate ligaments. This tension is transferred from the spinal column to the dura mater by the dural attachments to the spinal column described earlier. Now add a subluxation to one of the spinal segments with dural attachments to the formula and it would seem plausible that abnormal forces and tensions could be transmitted to the dura mater from this inelastic and misaligned segment. Now if we were to add other factors which increase the mechanical cord tension from a source separate to the subluxation, then would the tensile stresses be multiplied or at least exacerbated? This would implicate the Subluxation syndrome as a precipitating or at the very least as an aggravating factor in the development of adverse mechanical cord tension.

"Seventy-five patients who underwent surgical treatment for cervical spondylotic myelopathy were evaluated with respect to the operative procedure performed and their outcome. Forty patients underwent a laminectomy plus dentate ligament section (DLS), 18 underwent laminectomy alone, and 17 underwent an anterior cervical decompression and fusion (ACDF). The patients were evaluated postoperatively for both stability and for neurologic outcome... Functional improvement occurred in all but one patient in the laminectomy plus DLS group. The average improvement was 3.1 +/- 1.5 points in this group; whereas the average improvement in the laminectomy and the ACDF groups was 2.7 +/- 2.0 and 3.0 +/- 2.0 points respectively. All of the patients who improved substantially (greater than or equal to 6 points) in the laminectomy plus DLS and the laminectomy alone groups had normal cervical spine contours (lordosis). The remainder had either a normal lordosis or no curve (no kyphosis or lordosis). All patients in the ACDF group had either a straight spine or a cervical kyphosis. These factors implicate spine curvature, in addition to choice of operation, as factors which are important in outcome determination... Laminectomy plus DLS is a safe and efficacious alternative to laminectomy for the treatment of cervical spondylotic myelopathy. The data presented here suggests that myelopathic patients with a cervical kyphosis are best treated with an ACDF and that patients with a normal cervical lordosis are best treated with a posterior approach." (23)

If it is plausible to suggest purposeful severing of the dentate ligaments in an effort to reduce adverse mechanical cord tension, would not the reduction of restricted spinal joint motion that is creating an inelastic buffer for the dural attachments be a more acceptable conservative alternative? Especially when you consider that most Chiropractic techniques also aim to restore normal cervical curve.

TENSION OR COMPRESSION?

"To determine whether either of two mechanical theories predicts the topographic pattern of neuropathology in cervical spondylitic myelopathy (CSM). The compression theory states that the spinal cord is compressed between a spondylitic bar anteriorly and the ligamentum flava posteriorly. The dentate tension theory states that the spinal cord is pulled laterally by the dentate ligaments, which are tensed by an anterior spondylitic bar... The predicted stress pattern of the dentate tension theory corresponds to the reported neuropathology, whereas the predicted stress pattern of the compression theory does not. CONCLUSIONS: The results strongly favor the theory that CSM is caused by tensile stresses transmitted to the spinal cord from the dura via the dentate ligaments. A spondylotic bar can increase dentate tension by displacing the spinal cord dorsally, while the dural attachments of the dentate, anchored by the dural root sleeves and dural ligaments, are displaced less. The spondylotic bar may also increase dentate tension by interfering locally with dural stretch during neck flexion, the resultant increase in dural stress being transmitted to the spinal cord via the dentate ligaments. Flexion of the neck increases dural tension and should be avoided in the conservative treatment of CSM. Both anterior and posterior extradural surgical operations can diminish dentate tension, which may explain their usefulness in CSM." (24)

If a paradigm shift in neurosurgical thought from attempting to reduce compressive lesions to attempting to reduce tensile lesions, what would it take for the chiropractic profession to shift from predominantly compression reducing adjustive models to tension reducing adjustive models?

PATHOPHYSIOLOGY OF CORD TENSION

A number of mechanisms have been proposed for the manner in which adverse mechanical cord tension can lead to dysfunction and pathology in the central nervous system:

"Neuropathology in cervical spondylotic myelopathy. The results strongly favour the theory that CSM is caused by tensile stresses transmitted to the spinal cord from the dura via the dentate ligaments. A spondylotic bar can increase dentate tension by displacing the spinal cord dorsally, while the dural attachments of the dentate, anchored by the dural root sleeves and dural ligaments, are displaced less. The spondylotic bar may also increase dentate tension by interfering locally with dural stretch during neck flexion, the resultant increase in dural stress being transmitted to the spinal cord via the dentate ligaments." (25)

"Cervical spondylotic myelopathy (CSM) is the most common cause of spinal cord dysfunction. Despite advances in diagnosis and surgical treatment, many patients still have severe permanent neurologic deficits caused by this condition. An improved understanding of the pathophysiology of cervical spondylotic myelopathy, particularly at a cellular and molecular level, may allow improved treatments in the future. A detailed review of articles in the literature pertaining to cervical spondylotic myelopathy was supplemented by an analysis of relevant mechanisms of spinal cord injury. The pathologic course of cervical spondylotic myelopathy is characterized by early involvement of the corticospinal tracts and later destruction of anterior horn cells, demyelination of lateral and dorsolateral tracts, and relative preservation of anterior columns. Static and mechanical factors and ischemia are critical to the development of cervical spondylotic myelopathy. Free radical-and cation-mediated cell injury, glutamatergic toxicity, and apoptosis may be of relevance to the pathophysiology of cervical spondylotic myelopathy. To date, research in cervical spondylotic myelopathy has focused exclusively on the role of mechanical factors and ischemia. Fundamental research at a cellular and molecular level, particularly in the areas of glutamatergic toxicity and apoptosis may result in clinically relevant treatments for this condition." (26)

It may take a quantum leap to insinuate that a Subluxation is capable of creating the degree of advanced damage as that described in the case of full-blown CSM. However Subluxation is commonly seen as a dys-function, with the potential for initiating neural dysfunction and ultimately pathophysiology. When considering many of the discrete and diffuse presenting manifestations of chiropractic clients who receive dramatic symptomatic and functional improvements, seemingly due to the chiropractic intervention, it could be argued that these syndromes might be explained by the presence of a milder form of functional "CSM". This line of investigation may warrant further study since it is often quoted that these clients had undergone many medical investigations and procedures without conclusion or result.

PATHOPHYSIOLOGY OF AMCT

We will now summarise some models for the means by which Adverse Mechanical Cord Tension creates pathophysiology.

VASCULAR AND HYPOXIA

"In most other pathological situations in which nervous tissue is deformed there is no firm opposing surface, the deformation instead being produced by the pathological structure impinging on the cord that is stretched due to flexion of the spine. The interstitial pressure is then raised and the blood supply is put at risk." (16) "It was evident that an important cause of functional disturbance both of the axis-cylinders and the blood vessels lies in the reduction in their cross-sectional area resulting from tension." (16)

Hence the tension created in the spinal cord tissues would appear the create a wringing type effect squeezing and impinging on the vascular supplies.

"We conclude that spinal cord distraction is capable of generating cord tissue pressures that could cause a spinal cord compartment syndrome and thereby seriously impair spinal cord blood flow causing spinal cord injury." (27)

"Data obtained indicate that recovery or lack thereof is directly proportional to the intracellular calcium concentration which in turn is directly proportional to the amount and rate of tension applied to the axon. It is concluded that in most instances of acute spinal injury, disruption of cord function is a result of the effects of local cord anoxia and the increased concentration of intracellular calcium. It is proposed that implementation of therapeutic measures that restore blood flow and reduce cytosolic calcium will increase neurologic recovery." (28)

Would a chiropractic adjustment be one such therapeutic measure?

NEUROLOGICAL

"The most significant consequence of over-stretching nerve-fibres is impairment of their conductivity." (16) "..excessive tension in the cord may produce measurable changes in motor sensory and autonomic function." (16)

"Lumbar intrathecal ligaments have recently been demonstrated to randomly bind dorsal nerve roots to the dura within the lumbar vertebral column. Lengthening of the vertebral column and associated lumbar back pain experienced by astronauts is common in microgravity. This study was designed to investigate the relationship of lumbar intrathecal ligaments in spinal lengthening as a possible mechanism for back pain… The spinal cord moves in a cephalic direction approximately 2.8 mm with 4 cm lengthening of the vertebral column. During lengthening, a loss of thoracic and lordotic curvature was noted with an increase in disk height. Tension was significantly increased on the dorsal nerve roots being tethered by the lumbar intrathecal ligaments in comparison to non-tethered nerve roots during lengthening of the vertebral column… A significant amount of tension is placed on dorsal nerve roots tethered by intrathecal ligaments within the lumbar spine during spinal lengthening. These ligaments randomly bind dorsal nerve roots in the lumbar spine and may be involved in the back pain experienced by astronauts in microgravity. (29)

Much attention has been given to the potential for neurological impairment by a subluxation producing some type of impingement in the intervertebral foramen. Without denying this as a possibility, it should also be noted that adverse mechanical cord tension will not only produce the potential for neurological dysfunction within the spinal cord itself, but may also have the ability to transfer mechanical tension to the spinal nerves via the dural attachments.

BIOCHEMICAL

"A 'brain reward cascade' of neurotransmitters, when operating properly, results in feelings of well-being. If an imbalance impedes the normal flow of the 'cascade', the feelings of well-being are supplanted by anxiety, anger, or by craving substances which alleviate the negative emotions. Disruption of the 'brain reward cascade' results in Reward Deficiency Syndrome (**RDS**)." (30)

"In support of a comprehensive treatment regimen for **RDS** behaviors, we must review research establishing the vertebral subluxation complex as a primary issue in the multi-factorial expression of addictions and compulsive disorders. The foundation of chiropractic is neurological; therefore, for our purpose we re-focus on neurophysiology and neuroimmunology." (30)

"Feelings are mediated in the limbic system and are expressed through the reward cascade of neurochemicals. A number of these neurochemicals including neuropeptides are the biochemical mediators of a state of well being. Using autoradiography science has established opiate receptors are densest in the amygdala and hypothalamus (classically considered the core of the limbic system). Pert and Dienstrey (1988) expanded the limbic system (the neurosubstrate of emotions) to include the amygdala, hypothalamus, dorsal roots and dorsal horn of the spinal cord. In this regard a direct connection of the nocioceptive reflex at any level of the spine to the limbic system has been established. Moreover, we suggest it is time to accept that "every level of the spine has an intimate relationship with the limbic system's ability to process and establish a balanced brain reward cascade" (Holder and Blum, 1995). A literature review (Holder and Blum, 1995) revealed only vertebrates have an opiate receptor brain reward cascade mechanism; therefore, inspite of opioid peptides found in invertebrates, only vertebrates express a well-being state. In this instance the common denominator is the spine and spinal cord. If the spine is allowed to express itself without interference (minus subluxations), the vertebrate can express a state of well-being at its greatest potential. Consequently, the ability of the limbic system to function and express itself without interference requires a subluxation free spine." (30)

"Pert and Dienstrey (1988) state "The sub-conscious is in the spinal cord and even lower" and "the sub-conscious extends to one's T-cells [and] one's monocytes, and, ... back to one's brain cells." The origin of Pert's inference was at the dorsal horn of the spinal cord.

Burstein and Potrebic (1993), Harvard Medical School, provide evidence for direct projection of spinal cord neurons to the amygdala and orbital cortex. Their laminar distribution in the spinal cord and the involvement of the amygdala and orbital cortex in limbic functions suggest these pathways play a role in neuronal circuits that enable somatosensory information, including pain, to effect autonomic, endocrine, and behavioral functions. Giesler, *et al.* (1994), University of Minnesota, found the spinal pathways to the limbic system for nocioceptive information; they describe the pathway to include the hypothalamus bilaterally. Prior to Giesler, *et al.* nocioceptive information was thought to reach the hypothalamic neurons through indirect, multisynaptic pathways.

Raffa *et al.* (1993), Robert Wood Johnson Pharmaceutical Research Institute, report evidence linking the immune and opioid systems. Kyles *et al.* (1993), University of Bristol, found that when dopaminergic and opioid systems process nocioceptive information it is mediated spinally." (30)

The model for the role of Subluxation in RDS sees the affects of spinal subluxation via the development of AMCT, in producing tonal piezoelectric changes and resulting changes in neuropeptide release and reception, starting at the level of the dorsal horn and cascading through to global "state of wellbeing" negative changes.

CLINICAL IMPLICATIONS:

Much of the focus of Chiropractic research has been towards the nerve compression hypothesis. This author wishes to suggest that expansion of the research agenda by including investigation into this concept of mechanical spinal cord tension may be more productive in explaining some of the observed clinical benefits from chiropractic care.

Below are some abstracts of research previously conducted which would seem to suggest that the physiological changes initiated by the chiropractic adjustment/s may be better understood in the light of a tonal model. These studies were included on the basis that they expressly aimed to reduce AMCT or involved techniques which are expressed in tonal terms:

1) "OBJECTIVE: To describe the chiropractic management of a patient with paresthesia on the entire left side of her body and magnetic resonance imaging (MRI)-documented cervical spinal cord deformation secondary to cervical spinal stenosis. CLINICAL FEATURES: A 70-year-old special education teacher had neck pain, headaches, and burning paresthesia on the entire left side of her body. These symptoms developed within hours of being injured in a side-impact motor vehicle accident. Prior to her visit, she had been misdiagnosed with a cerebrovascular accident. INTERVENTION AND OUTCOMES: Additional diagnostic studies revealed that the patient was suffering from cervical spinal stenosis with spinal cord deformation. Two manipulative technique systems (Advanced Biostructural Therapy and Atlas Coccygeal Technique) unique to the chiropractic profession and based on the theory of relief of adverse mechanical neural tension were administered to the patient. This intervention provided complete relief of the patient's complaints. The patient remained symptom-free at long-term follow-up, 1 year post-accident. CONCLUSION: There is a paucity of published reports describing the treatment of cervical spinal stenosis through manipulative methods. Existing reports of the manipulative management of cervical spondylosis suggest that traditional manual therapy is ineffective or even contraindicated. This case reports the excellent short-term and long-term response of a 70-year-old patient with MRI-documented cervical spinal stenosis and spinal cord deformation to less traditional, uniquely chiropractic manipulative techniques. This appears to be the first case (reported in the indexed literature) that describes the successful amelioration of the symptoms of cervical spinal stenosis through chiropractic manipulation." (31)

2) "OBJECTIVE: To discuss the case of a patient who was diagnosed with attention-deficit /hyperactivity disorder (ADHD) by a general practitioner and was treated with chiropractic care. CLINICAL FEATURES: A 5-year-old patient was diagnosed with ADHD and treated by a pediatrician unsuccessfully with methylphenidate (Ritalin), Adderall, and Haldol for 3 years. The patient received 35 chiropractic treatments during the course of 8 weeks. A change from a 12 degrees C2-7 kyphosis to a 32 degrees C2-7 lordosis was observed after treatment. During chiropractic care, the child's facial tics resolved and his behavior vastly improved. After 27 chiropractic visits, the child's pediatrician stated that the child no longer exhibited symptoms of ADHD. The changes in structure and function may be related to the correction of cervical kyphosis. CONCLUSION: The patient experienced significant reduction in symptoms. Additionally, the medical doctor concluded that the reduction in symptoms was significant enough to discontinue the medication. There may be a possible connection that correction of cervical kyphosis in patients with ADHD may produce a desirable clinical outcome." (32)

3) "OBJECTIVE: To review the effectiveness of chiropractic care using an upper cervical technique in the case of a nine-year old male who presented with Tourette Syndrome (TS), Attention Deficit Hyperactivity Disorder (ADHD), depression, asthma, insomnia, and headaches. CLINICAL FEATURES: This nine-year-old boy suffered from asthma and upper respiratory infections since infancy; headaches since age 6; TS, ADHD, depression and insomnia since age 7; and neck pain since age 8. His mother reported the use of forceps during his delivery. His medications included Albuterol, Depakote, Wellbutrin, and Adderall. Intervention: During the patient's initial examination, evidence of a subluxation stemming from the upper cervical spine was found through thermographic and radiographic diagnostics. Chiropractic care using an upper cervical technique was administered to correct and stabilize the patient's upper neck injury. Diagnostics and care were performed in accordance with the guidelines of the International Upper Cervical Chiropractic Association. OUTCOME: Evaluation of the patient's condition occurred through doctor's observation, patient's and parents' subjective description of symptoms, and thermographic scans. After six weeks of care, all six conditions were no longer present and all medications were discontinued with the exception of a half-dose of Wellbutrin. At the conclusion of his case at five months, all symptoms remained absent. CONCLUSION: The onset of symptoms soon after the boy's delivery; the immediate reduction in symptoms correlating with the initiation of care; and the complete absence of symptoms within six weeks of care; suggest a link between the patient's traumatic birth, the upper cervical subluxation, and his neurological conditions. Further investigation into upper cervical trauma as a contributing factor to Tourette Syndrome, ADHD, depression, insomnia, headaches, and asthma should be pursued." (33)

4) “The spinal cords were examined in eighteen cases of multiple sclerosis, with special attention to the cervical enlargement. It was found that lesions in the cervical cord are about twice as common as at lower levels, in this region there is a striking preponderance of fan-shaped lesions in the lateral columns. It is argued that both these findings are explicable on the theory that mechanical stresses play a part in determining the site of lesions; that such stresses are commonly transmitted to the cord via the denticulate ligaments during flexion of the spine; and that many of the lesions are attributable to vascular leakages due to tension in the denticulate ligaments. It is concluded that in patients with multiple sclerosis neck flexion is dangerous – especially in cases where Lhermitte's sign has occurred.” (34)

5) “OBJECTIVE: The objective of this article is threefold: to examine the role of head and neck trauma as a contributing factor to the onset of Multiple Sclerosis (MS) and Parkinson’s disease (PD); to explore the diagnosis and treatment of trauma-induced injury to the upper cervical spine through the use of protocol developed by the International Upper Cervical Chiropractic Association (IUCCA); and to investigate the potential for improving and arresting MS and PD through the correction of trauma induced upper cervical injury. Data from 81 MS and PD patients who recalled prior trauma, presented with upper cervical injuries, and received care according to the above protocol are reviewed. CLINICAL FEATURES: Each patient was examined and cared for in the author’s private practice in an uncontrolled, non-randomized environment over a five-year period. Of the 81 MS and PD patients, 78 recalled that they had experienced at least one head or neck trauma prior to the onset of the disease. In order of frequency, patients reported that they were involved in auto accidents (39 patients); sporting accidents, such as skiing, horseback riding, cycling, and football (29 patients); or falls on icy sidewalks or down stairs (16 patients). The duration between the traumatic event and disease onset varied from two months to 30 years. INTERVENTION AND OUTCOME: Two diagnostic tests, paraspinal digital infrared imaging and laser-aligned radiography, were performed according to IUCCA protocol. These tests objectively identify trauma-induced upper cervical subluxations (misalignment of the upper cervical spine from the neural canal) and resulting neuropathophysiology. Upper cervical subluxations were found in all 81 cases. After administering treatment to correct their upper cervical injuries, 40 of 44 (91%) MS cases and 34 of 37 (92%) PD cases showed symptomatic improvement and no further disease progression during the care period. CONCLUSION: A causal link between trauma-induced upper cervical injury and disease onset for both MS and PD appears to exist. Correcting the injury to the upper cervical spine through the use of IUCCA protocol may arrest and reverse the progression of both MS and PD. Further study in a controlled, experimental environment with a larger sample size is recommended.” (35)

6) “OBJECTIVE: This case report reviews the application of chiropractic care for the purpose of subluxation correction in a 19 year old female diagnosed with a mental health disorder, General Anxiety Disorder (GAD). CLINICAL FEATURES: In November 1999 the patient first experienced symptoms of dizziness, trembling, sweating, heart palpitations, sleep deprivation, poor concentration, depersonalization, and headaches. Symptoms continued and escalated intermittently, resulting in multiple Emergency Room visits, referrals to medical specialists, medical procedures, and expenses. In December 2000 a neurologist rendered the diagnosis of General Anxiety Disorder and prescribed Paroxetine (Paxil). This medication produced side effects and minor relief, resulting in decreased Quality of Life and stressing familial relationships. CHIROPRACTIC CARE AND OUTCOME: In December 2001 the patient presented for a chiropractic evaluation. Her history revealed physical, emotional, and chemical stresses including multiple motor vehicle accidents, childhood emotional abuse from an alcoholic father, and smoking daily since age 17. Exams and EMG scans revealed evidence of chronic vertebral subluxations in multiple locations, and altered spinal curves in cervical and thoracic areas. The patient was educated on chiropractic principles and consented to care. Diversified Technique was utilized, with adjustments applied to specific vertebra to promote restoration of proper nerve function. Improvement was noted after the first adjustment, 50% reduction in anxiety, 30% reduction in headache symptoms, and increased mobility in neck. CONCLUSION: Results were documented over a four month course of care. Medication was discontinued successfully, symptoms of anxiety and headache reduced 80% and 90% respectively, function and Quality of Life increased. These improvements suggest positive changes in mental health function may be associated with subluxation correction from the application of chiropractic care. As anxiety conditions burden the U.S. with $42 billion annually in health care expenses and lost productivity, clearly this is a serious problem calling for full attention and broad resources. Research funding is called for to examine the benefits, safety, and cost effectiveness on the impact of chiropractic subluxation correction in mental health. (36)

7) …a randomized, placebo controlled, single blind study utilizing subluxation-based chiropractic care (Torque Release Technique) was implemented in the same residential setting. Three groups were randomized: active treatment comprising daily adjustments to correct vertebral subluxations using the Integrator adjusting instrument to deliver a set amount of force and direction with an audible click; a placebo treatment utilizing the same instrument but set to deliver zero force with no direction while maintaining the audible click; and a usual care group who followed the general policies of the residential program. The chiropractic and usual care groups each had 33 subjects while the placebo group had 32 subjects. All of the Active group completed the 28-day program, while only 24 (75%) of the Placebo group and 19 (56%) of the Usual Care group completed 28 days. These completion rates are significantly different than that for the Active group ($p<0.05$). A Kaplan-Meier survival analysis showed that the probability of retention in the Placebo and Usual Care groups was less than that for the Active treatment group (Log Rank Test, $p<0.001$). At four weeks the Spielberger State Anxiety scores were 32.0 + 1.6 for the Active group, 42.5 + 3.0 for Placebo group, and 33.1 + 3.7 for the Usual Care group. The Active and Placebo groups were significantly different at four weeks ($p<0.05$), with the Active group showing a significant decrease in anxiety (19.0 + 2.2, $p<0.001$) while the Placebo group showed no decrease in anxiety (2.3 + 2.9, ns). Among the Active treatment group only 9% made one or more visits to the Nurse, while 56% of the Placebo groups ($p<0.001$ compared to Active) and 48% ($p<0.002$ compared to Active) made such visits. In summary, these modalities show significant promise for increasing retention of RDS patients in the residential setting and warrants further study. (37)

8) The present study represents a retrospective characterization of Network Care, a health discipline within the subluxation-based chiropractic model. Data were obtained from 156 Network offices (49% practitioner participation rate) in the United States, Canada, Australia, and Puerto Rico. Sociodemographic characterization of 2,818 respondents, representing a 67-71% response rate, revealed a population predominately white, female, well-educated, professional, or while collar workers. A second objective of the study included the development and initial validation of a new health survey instrument. The instrument was specifically designed to assess wellness though patients' self-rating different health domains and overall quality of life at two "time" points: "presently" and retrospectively, recalling their status before initiating care ("before Network"). Statistical evaluation employing Chronbach's alpha and theta coefficients derived from principle components factor analyses, indicated a high level of internal reliability in regard to the survey instrument, as well as stable reliability of the retrospective recall method of self-rated perceptions of change ($p<0.000$) in all four domains of health, as well as overall quality of life. Effect sizes for these different scores were all large (>0.9). Wellness was assessed by summing the scores for the four health domains into a combined wellness scale, and comparing this combined scale "presently" and "before Network." The difference, or "wellness coefficient," suggests that Network Care is associated with significant benefits. These benefits are evident from as early as 1-3 months under care, and appear to show continuing clinical improvements in the duration of care intervals studied, with no indication of a maximum clinical benefit. These findings are being further evaluated through longitudinal studies of current populations under care in combination with investigation of the neurophysiological mechanisms underlying its effects. (38)

9) A preliminary study was conducted to evaluate changes in digital skin temperature (DST), surface electromyography (sEMG), and electrodermal activity (EDA) in a group of twenty subjects receiving Network Spinal Analysis (NSA) care. Data, simultaneously derived from all three parameters, were considered to be indirect correlates of sympathetic nervous system activity. Subjects, including a group of five controls, were assessed for a period of 17 minutes. The continuous assessment period included a baseline interval of 4.5 minutes, followed by a 12.5 minute period which was divided into 2.5 minute intervals. Care was administered to the NSA recipient group immediately after the baseline period, whereas controls received no intervention following baseline. Results revealed no significant differences in DST either within or between the groups. Surface EMG readings were relatively constant over the five intervals following baseline in the NSA group while the controls showed significant ($p<0.05$) increases in sEMG at the second through fifth intervals relative to the first interval following baseline activity. Electrodermal activity was significantly decreased ($p<0.01$) in the NSA group at the third through fifth intervals. It was concluded that the increasing EMG activity in the control groups may have reflected an increasing level of anxiety due to the duration of the recording period. Since the NSA group expressed constancy in sEMG activity during the same period, coupled to significant decreases in EDA, a "sympathetic quieting effect" was postulated to occur in subjects receiving NSA care. This conclusion is consistent with hypothesized neurological pathways linked to responses observed during NSA care, as well as other reports of self-reported improvements in mental/emotional state and stress reduction in patients receiving Network Chiropractic Care. (39)

TECHNICAL CONSIDERATIONS:

In this paper we have summarised the evidence base for dural attachments between the spinal column and spinal dura mater, and from the dura to the pia mater and hence nerve tissue. We have also summarised evidence for the mechanics, pathophysiology and clinical implications of adverse mechanical cord tension. We have also described a model for the role of the Subluxation in the perpetuation or at the very least, exacerbation of adverse mechanical cord tension.

Does all this information have technical implications for the practice of chiropractic? This author would like to suggest that the answer is affirmative.

A Subluxation model based on tension is not a new concept: DD Palmer proposed a tonal model for Chiropractic. “Life is an expression of tone. Tone is the normal degree of nerve tension. Tone is expressed in function by normal elasticity, strength, excitability… the cause of disease is any variation in tone.” (36) Might it be time to review this concept in the light of AMCT as opposed to the predominant Chiropractic hypothesis of nerve compression?

Many techniques have proposed a “tonal approach” and have attempted to reduce spinal cord tension by means of a biomechanical intervention in the hope of producing a neurological response.

From pioneering work by BJ Palmer with Upper Cervical Specific technique, to Logan Basic, to SOT, through to more modern developments through Network Spinal Analysis and Torque Release Technique. Even more mechanistic models such as CBP and ABC have embraced the concept of restoring normal spinal curves to reduce the flexion tension in the spinal column.

This author would like to make some general observations based on the evidence provided:

As proposed earlier there appears to be three levels of dural attachment:

1) Permanent predictable and significant attachments;

2) Variable and slightly less significant attachments;

3) Irregular and much less significant attachments.

Could it be that this prioritisation of dural attachments would be mirrored by the clinical importance of some Subluxations over others? That not all Subluxations are created equal?

Upper Cervical Techniques see the upper cervical spine as being the most clinically important region, and based on the number and strength of dural attachments this may be justifiable. SOT takes this one step further by including the pelvic region and interestingly includes the next most significant area of dural attachments. NSA and TRT have taken this concept even further by prioritising and ranking the spinal levels most likely and significantly involved in AMCT. The agreement between the two methodologies in terms of this ranking, and also the similarities to the significance and degree of dural attachments is striking:

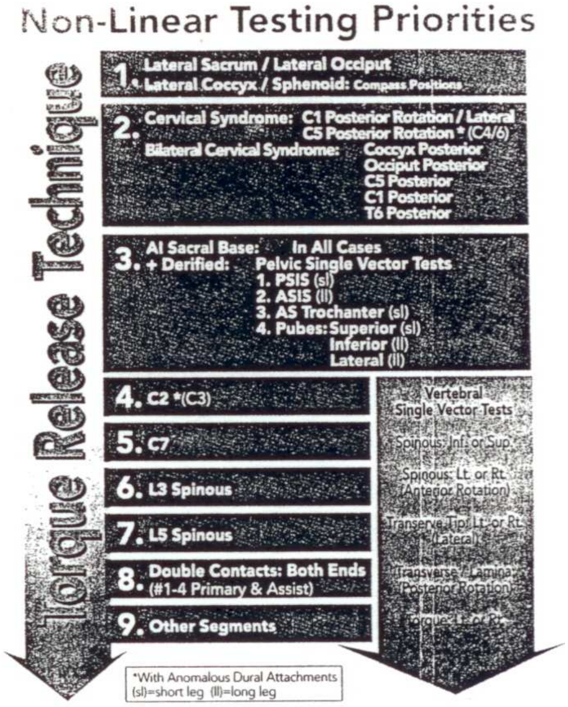

Fig 5. Torque Release Technique Subluxation Priorities Rankings. (41)

The technical lesson from this would appear to be that for a Chiropractor to attempt to intervene in the case of AMCT he/she requires methodologies to 1) assess for the presence of AMCT, 2) locate the level of Subluxation which may be contributing most significantly to the AMCT, 3) Have system to assess for the reduction of that Subluxation, and 4) Employ outcome tools that support the notion that AMCT has been reduced.

There may also be some cautionary knowledge provided by this information. Methodologies which require the implementation of significant spinal flexion and/or extension particularly if combined with the application of mechanical forces may be successful in the production cavitation of spinal joints, and may attempt to counteract the observed misalignment patterns of the client’s spinal column. But, could it be argued that these forces applied in good intent may also be contributing to the introduction of further spinal cord tensioning vectors?

REFERENCES:

1) Chiropractic Textbook. Stephenson, R.W. 1927.

2) The Art of Chiropractic. Stephenson R.W. 1927. Art 64.

3) Clinically Oriented Anatomy, 3rd edition, Moore, K.L. 1992, Pg. 366. Williams and Wilkins.

4) Gray's Anatomy, 35th edition, 1973, Warwick, R., Williams, P.L. (Editors). Pg 989 & 992. Longman.

5) Anatomic relation between the nuchal ligament (ligamentum nuchae) and the spinal dura mater in the craniocervical region. Dean NA, Mitchell BS. Clin Anat. 2002 May; 15(3):182-5.

6) Investigation of connective tissue attachments to the cervical spinal dura mater. Humphreys BK, Kenin S, Hubbard BB, Cramer GD. Clin Anat. 2003 Mar; 16(2): 152-9.

7) Anatomic Relation Between the Rectus Capitis Posterior Minor Muscle and the Dura Mater. Hack, GD, etal. Spine. 1995 Vol 20, No. 23: 2484-2486.

8) Meningeal-Neural Relations in the Intervertebral Foramen. Sunderland, S. J. Neurosurg. 40: 756-761, 1974.

9) Anatomical background of low back pain: Variability and degeneration of the lumbar spinal canal and intervertebral disc. Van Roy P, Barbaix E, Clarijs JP, Mense S. Schmerz. 2001 Dec; 15(6): 418-24.

10) Meningovertebral ligaments and their putative significance in low back pain. Meningovertebral ligaments and their putative significance in low back pain. Bashline SD, Bilott JR, Ellis JP. J. Manipulative Physiol Ther. 1996 Nov-Dec; 19(9): 592-6.

11) Anterior sacrodural attachments-Trolard's ligaments revisited. Barbaix E, Girardin MD, Hoppner JP, Van Roy P, Clarijs JP. Man Ther. 2000 Mar; 1(2): 88-91.

12) The anatomic relation among the nerve roots, intervertebral foramina, and intervertebral discs of the cervical spine. Tanaka N, Fujimoto Y, An HS, Ikuta Y, Yasuda M. Spine. 2000 Feb 1; 25 (3): 286-91.

13) The anterior dural (Hofmann) ligaments. Wadhwani S, Loughenbury P, Soames R. Spine. 2004 Mar 15; 29 (6): 623-7.

14) Anatomical and radiologic studies on the lumbosacral meningo-vertebral ligaments of humans. Scapinelli R. J Spinal Disord. 1990 Mar; 3 (1): 6-15.

15) Non-linear switching dynamics in Surface Electromyography of the Spine. Lohsoonthorn P, Jonckheere EA. Dept. Electrical Engineering Systems University of Southern California. http://eudoxus.usc.edu/CHAOS/switching.ppt

16) Adverse Mechanical Tension in the Central Nervous System. Breig, A. 1978. John Wiley and Sons.

17) The denticulate ligament: anatomy and functional significance. Tubbs RS, Salter G, Grabb PA, Oakes WJ. J Neurosurg. 2001 Apr; 94 (2 Suppl): 271-5.

18) A review of biomechanics of the central nervous system--part II: spinal cord strains from postural loads. Harrison DE, Cailliet R, Harrison DD, Troyanovich SJ, Harrison SO. J Manipulative Physiol Ther. 1999 Jun; 22 (5): 322-32.

19) Dynamic studies of cervical spinal canal and spinal cord by magnetic resonance imaging. Koschorek F, Jensen HP, Terwey B. Acta Radiol Suppl. 1986; 369: 727-9.

20) Stretch-associated injury in cervical spondylotic myelopathy: new concept and review. Henderson FC, Geddes JF, Vaccaro AR, Woodard E, Berry KJ, Benzel EC. Neurosurgery. 2005 May;56 (5): 1101-13; discussion 1101-13.

21) Pathophysiology of tethered cord syndrome: correlation with symptomatology. Yamada S, Won DJ, Yamada SM. Neurosurg Focus. 2004 Feb 15; 16(2): E6.

22) Mechanical and physiological effects of dentatotomy. Cusick JF, Ackmann JJ, Larson SJ. J Neurosurg. 1977 Jun; 46 (6): 767-75.

23) Cervical laminectomy and dentate ligament section for cervical spondylitic myelopathy. Benzel EC, Lancon J, Kesterson L, Hadden T. J Spinal Disord. 1991 Sep; 4 (3): 286-95.

24) In vivo human cervical spinal cord deformation and displacement in flexion. Yuan Q, Dougherty L, Margulies SS. Spine. 1998 Aug 1; 23 (15): 1677-83.

25) Pathogenesis of cervical spondylotic myelopathy. Levine DN. J Neurol Neurosurg Psychiatry. 1997 Apr; 62(4): 334-40.

26) A review of the pathophysiology of cervical spondylotic myelopathy with insights for potential novel mechanisms drawn from traumatic spinal cord injury. Fehlings MG, Skaf G. Spine. 1998 Dec 15; 23 (24): 2730-7.

27) Spinal cord distraction: an in vitro study of length, tension, and tissue pressure. Jarzem PF, Kostuik JP, Filiaggi M, Doyle DJ, Ethier R, Tator CH. J Spinal Disord. 1991 Jun; 4 (2): 177-82.

28) The Nicolas Andry Award. The pathomechanics and pathophysiology of cervical spinal cord injury. Torg JS, Thibault L, Sennett B, Pavlov H. Clin Orthop Relat Res. 1995 Dec; (321): 259-69.

29) Intrathecal ligaments and nerve root tension: possible sources of lumbar pain during spaceflight. Kershner D, Binhammer R. Aviat Space Environ Med. 2004 Apr; 75 (4): 354-8.

30) Breakthrough Brain Research Links Chiropractic Treatment to Addictive Behaviors. Blum K, Cull JG, Holder J. Letter.

31) The amelioration of symptoms in cervical spinal stenosis with spinal cord deformation through specific chiropractic manipulation: a case report with long-term follow-up. Kukurin GW. J Manipulative Physiol Ther. 2004 Jun; 27(5): e7.

32) Cervical kyphosis is a possible link to attention-deficit/hyperactivity disorder. Bastecki AV, Harrison DE,

Haas JW. J Manipulative Physiol Ther. 2004 Oct; 27 (8): e14.

33) Upper Cervical Chiropractic Care For A Nine-Year-Old Male With Tourette Syndrome, Attention Deficit Hyperactivity Disorder, Depression, Asthma, Insomnia, and Headaches: A Case Report. Elster E. JVSR: July 12, 2003, pp. 1-11.

34) The cervical cord in multiple sclerosis. Oppenheimer DR. Neuropathol Appl Neurobiol. 1978 Mar-Apr; 4 (2): 151-62.

35) Eighty-One Patients with Multiple Sclerosis and Parkinson's Disease Undergoing Upper Cervical Chiropractic Care to Correct Vertebral Subluxation: A Retrospective Analysis. Elster EL. JVSR: August 2, 2004, pp 1-9.

36) The Impact Of Subluxation Correction On Mental Health: Reduction Of Anxiety In A Female Patient Under Chiropractic Care. Behrendt M, Olsen N. JVSR: September 20, 2004, pp 1-10.

37) Increasing retention rates among the chemically dependent in residential treatment: auriculotherapy and subluxation-based chiropractic care. Jay M. Holder, Robert C. Duncan , Matthew Gissen, Michael Miller , and Kenneth Blum. Molecular Pysch. Vol 6, Suppl 1, Part2, 2001, Feb; S8.

38) Retrospective Assessment of Network Care Using a Survey of Self-Rated Health, Wellness and Quality of Life. Blanks RH, Schuster TL, Dobson M. Journal for Vertebral Subluxation Research Volume 1, Number 4 , 1997, 15-31.

39) Changes in Digital Skin Temperature, Surface Electromyography, and Electrodermal Activity in Subjects Receiving Network Spinal Analysis Care. Miller E, Redmond PD. Journal for Vertebral Subluxation Research Volume 2, Number 2, June, 1998, 87-95.

40) Textbook of the Art, Science and Philosophy of Chiropractic. The Chiropractor's Adjuster. Palmer DD, Portland, OR. Portland Publishing House. 1910.

41) Hyman R. Torque Release Technique Seminar Notes. Holder Research Institute, Miami Beach, Florida. 1997.

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