Sustained improvement of heart rate variability in patients undergoing a program of chiropractic care: A retrospective case series

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SUSTAINED IMPROVEMENT OF HEART RATE VARIABILITY IN PATIENTS UNDERGOING A PROGRAM OF CHIROPRACTIC CARE: A RETROSPECTIVE CASE SERIES

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ABSTRACT

Objective: The purpose of this study was to report the sustained changes in heart rate variability (HRV) observed in 6 patients undergoing continuous chiropractic care for the correction of vertebral subluxations.

Clinical Features: Six patients between 25 to 55 years of age all presented with primarily musculoskeletal complaints for chiropractic care in a private practice setting. All patients were nonsmokers with no reported cardiac pathology. All patients were initially assessed for indicators of vertebral subluxation before being accepted for chiropractic care, and were monitored for changes in HRV scores over time.

Intervention and Outcomes: Chiropractic care, using Diversified and Thompson techniques to correct vertebral subluxations, was provided for an initial period of 10 to 52 weeks at a frequency of 2 to 3 visits per week. HRV, measured by SSDN, increased over the early part of their course of chiropractic care, and these increases were sustained whilst the patient remained under long term continuous care in all 6 patients. Improvements in SDNN ranged from 50% to greater than 300% as compared to pre-care values.

Conclusion: Patients receiving continuous chiropractic care to correct vertebral subluxation demonstrated a sustained improvement in HRV. This novel finding objectively demonstrates long-term change consistent with improved neurophysiological regulation, adaptability and resilience in patients undergoing chiropractic care, and suggests the utility of chiropractic care for outcomes greater than only musculoskeletal improvements. (*Chiropr J Australia 2017;45:338-358*)

Key Indexing Terms: Chiropractic; Heart Rate Variability

INTRODUCTION

The primary objective of chiropractic care is to optimize health and wellbeing through the enhancement of nervous system function by reducing nerve interference caused by vertebral subluxations. (1-3) The Australian Spinal Research Foundation defines vertebral subluxation as “a diminished state of being, comprising of a state of reduced coherence, altered biomechanical function, altered neurological function and altered adaptability.” (4) A vertebral subluxation has been recognised as a complex of functional and/or structural changes in the articulations of the spine and pelvis that compromise neural integrity and may influence organ system function and general health. (5) The correction of vertebral subluxations is achieved through chiropractic adjustments that are a typically manually performed. (1,2,6) Research over the past 2 decades has shown that the chiropractic adjustment (also referred to as chiropractic spinal manipulation in the chiropractic research literature) results in changes in spinal biomechanics and structure (7-11), central nervous system function (12-16), motor output (17-20), and autonomic output. (21,22)

Using objective measures of spinal and neurological function provides the means to quantitatively observe the effects of the chiropractic adjustment. Objective measures used in chiropractic clinical practice to identify the site of intervention and/or to measure outcomes often include both musculoskeletal assessments such as pre- and post-adjustment x-ray, leg length inequality, posture or gait changes, sEMG, algometry, range of motion, motion and static palpation (23), and non-musculoskeletal metrics such as paraspinal thermal balance, heart rate, blood pressure, respiration, reaction time, head repositioning sense, and balance testing. (23,24) While each measure represents a unique and targeted view on structural and/or physiological changes associated with the chiropractic adjustment, employing alternative outcomes assessment technology allows for the opportunity to expand our understanding of the effects of the adjustment in a way that reflects global changes in autonomic nervous system function and adaptability, and also interfaces with multiple healthcare disciplines. (25)

Measurement of heart rate variability (HRV) has been documented as an effective method to objectively measure improvement in nervous system function. Originally conceived as an assessment tool for cardiac physiology (26), HRV reflects the influence of the Vagus nerve and the sympathetic nervous system on intrinsic heart rhythm (25-27) and therefore HRV monitoring represents a unique window into autonomic nervous system function.

Studies of HRV in the past 2 decades have established that decreased HRV, or "vagal tone", correlates and/or predicts pathological conditions such as cardiovascular disease (26-28), inflammation (29-31), diabetic neuropathy (32), emotional dysregulation and post-traumatic stress disorder (33-37), sleep disorders (38), and cancer. (38-41) Conversely, high HRV has been associated with healthy longevity (42-44), and is used by elite athletes to predict their ability to function optimally in an upcoming workout. (45) According to McCraty et al (25), an optimal level of HRV within an organism reflects healthy function and an inherent self-regulatory capacity, adaptability or resilience. Too little variation indicates age-related system depletion, chronic stress, pathology or inadequate functioning in various levels of self-regulatory control systems. McCraty's assessment echoes the ideas of Hans Selye, the Nobel laureate who described the General Adaptation Syndrome (46), the body's mal-adaptation to sustained emotional, physical or chemical stressors. HRV is increasingly emerging as a way to assess and predict multiple health outcomes, from disease to thriving health. (25) Accordingly, interventions that increase HRV "vagal tone" would be expected to improve health outcomes and promote vitality and wellness.

The chiropractic profession, as well as the professions of acupuncture and osteopathy, have increasingly used HRV for research purposes (47-58); however, none of these studies have approached the effect of long-term chiropractic care on HRV. The current study chronicles the improvements in HRV in 6 patients undergoing long-term continuous chiropractic care (of 3 months to 3 years' duration) for the correction of vertebral subluxation.

CASE SERIES

This retrospective case series compares recorded baseline and ongoing progress HRV measurements of 6 patients following a program of chiropractic care for the correction of vertebral subluxation. The patients (3 female and 3 male) were 25 to 55 years of age, nonsmokers with no cardiac, hypertensive, or frank pathological conditions reported. As per criteria recommended by Nunan et al (59), patients whose data were included for the study reported no use of of statins, beta blockers, drugs that affect baroreceptor activity, neuroactive drugs, or SSRIs. Patient data were excluded if the patient reported unusual physical, chemical, or emotional stress in the day preceding testing.

Assessment for Vertebral Subluxation Complex

All patients were assessed for eligibility for chiropractic care using multiple objective methods to identify the locations and components of vertebral subluxation (23,25), including posture or movement asymmetry, supine or prone leg length inequality, tissue texture/tonal/temperature changes or tenderness, pain or sensation changes, static and motion palpation findings, sEMG and paraspinal thermography, x-ray analysis of weightbearing spinal integrity and structure (7-11), biotensegrity-based posture and movement assessment (60), cerebellar testing including Rhomberg's and/or Mittelmeyer's test, proprioceptive/balance deficit and reaction time via the BESS (Balance Error Scoring System) based mobile SWAY® app (61,62) (SWAY Medical, LLC, Tulsa, OK).

Outcome Measure: HRV

HRV data were collected using Pulse Wave Profiler™ (PWP) instrument. Patients were assessed for baseline HRV at their initial appointment, prior to the start of care, and reassessed every 12 visits for 3-months, at 6-months, and every 6-months thereafter throughout their program of chiropractic care. HRV test-test reliability was confirmed by recording a set of 3 consecutive HRV measurements on non-adjusted control patients. For each HRV assessment during the course of a patient's care program, the following protocol was followed. Patients were seated comfortably in a closed room. No breathing instructions were given, and patients were instructed to refrain from movement, conversation, or using digital devices. The left hand was used for data collection, which consisted of 1 minute of resting measurement followed by 5 minutes of data collection. After data collection, the resultant heart rate graph was visually inspected and SDNN data were accepted unless anomalies such as random spikes or missed data capture were noted (less than 10% of samples). Results for each case were compared to normal HRV scores for 5’ SDNN measurements per age and gender as per Voss et al (63), though conflicting reports suggest that normative 5’ SDNN values may be higher (44, 59) or lower. (55)

Chiropractic Management

Initial chiropractic care programs ranged from 2 to 3 visits weekly for 10 to 52 weeks based on patient presentation. (64,65) Visit frequency transitioned to weekly after improvement or normalization of objective testing as well as posture and movement patterns. Exercises to facilitate neuromuscular re-education were selected per patient and included Pettibon Cervical Traction™, use of a Pettibon Therapeutic Wobble Chair™, home use of Pettibon Headweights™ or a Chiropractic BioPhysics® Denneroll, “pointer” spinal stabilizing exercise, and isometric head retraction exercises against a wall or car headrest.

All patients were managed using Diversified and Thompson Terminal Point techniques. Chiropractic adjustments were primarily manual full-spine or drop-assisted, with some instrument-assisted adjusting using an Activator™ instrument. Diversified is the most widely used chiropractic technique and system of adjusting that uses primarily motion and static palpation to locate levels of vertebral subluxation, and focuses on the restoration of proper biomechanics within the spine (66) and improved nervous system function. The Thompson Terminal Point Technique is a full-spine analysis and adjusting technique that utilizes a drop table to assist in the delivery of high-velocity, low amplitude chiropractic adjustments. (67) Pre- and post-adjustment assessments of each level of vertebral subluxation were noted, as well as subjective statements made by the patient. The force administered during a chiropractic adjustment was modified individually to a patient’s size, frame and spinal integrity.

Patient Responses to Chiropractic Care

Case 1

A 52-year-old female presented with a chief complaint of pain in her right lower back and a concern with lack of progress in recovering from multiple pneumonias. Her baseline HRV recording indicated an SDNN of 21.6 msec, below the normal SDNN of 36.9 ± 13.8 msec reported for her gender and age. (63)

An initial program of chiropractic care consisted of 3 visits a week for 10-weeks, and progressed to 2 scheduled visits per week when muscle activity and balance improved as measured by sEMG. Subjective outcomes included improvement of lung and low back pain, improved immune system function as reflected by reported reduced frequency of respiratory infections, and improvement of athletic endurance. Objective radiographic improvements, (64,65) after 4-months of care, included reduction of forward head posture from 2.1 cm to 0.7 cm, a 66.7% improvement, as well as improvement of C2-C7 sagittal curve (from 30° to 38.7° as measured by X-ray, representing a 22.5% improvement) and atlas plane to horizontal (from 22.8° to 29.9°, representing a 31.1% improvement). Her baseline SDNN of 21.6 msec improved to 125.2 msec after 6-weeks of care (a 479.6% increase from initial testing) and to 143.2 msec after 9-months of care (a 563% increase from her initial testing). After 21-months of care, her SDNN settled to 87.5 msec, an increase of 305.1%, and after another 13-months of weekly visits, her SDNN measured 88.9 msec (an increase of 311.6%) while also dealing with increased work and family stressors.

Case 2

A 43-year-old, athletic female presented with a chief complaint of right arm/elbow pain that inhibited her from lifting heavy weights in the gym, and goals of being active and fit. Her baseline HRV recording indicated an SDNN of 86.2 msec, above the normal of 45.4 ± 20.5 msec for her gender and age (63) but consistent with an SDNN for an aerobically-trained athlete. (69-71)

An initial program of chiropractic care consisted of 2 visits per week for 52-weeks. Outcomes of care included elimination of arm and elbow pain with the first 12 visits, improved muscle balance and activity as measured by sEMG after 8-months of care, reported improved weight lifting and athletic performance through the course of her care, and improved measured sagittal cervical spine structure (atlas plane to horizontal improved from 24° to 32.8°) after 18-months of care. (64,65) HRV improved after 2-months of care to an SDNN of 152.4 msec, and after 15-months her SDNN was 143.6 msec. The patient continued ongoing care at a frequency of weekly visits. Her HRV recordings showed an SDNN of 142.5 after 28 continuous months of care, a 72.5% improvement from her initial pre-care HRV measurement.

Case 3

A 31-year-old, athletic male presented with a chief complaint of left upper back and shoulder pain, and goals of increased fitness, strength, and endurance. His baseline HRV recording indicated an SDNN of 69.6 msec, within the reported normal SDNN of 50.0 ± 20.9 msec for his gender and age. (63)

An initial program of chiropractic care consisted of 28 visits over 3-months, and progressed to 2 scheduled visits per week when muscle activity and balance improved as measured by sEMG, and once per week when the patient's symptoms fully abated, at which time he terminated care. His baseline SDNN of 69.6 msec improved over 8-months to a sustained measurement of greater than 116 msec, a 69.4% improvement over his initial HRV measurement.

Case 4

A 48-year-old male presented with occasional headaches, poor sleep patterns, fatigue, and right shoulder pain, with goals of increased cardiovascular fitness. His baseline HRV recording indicated an SDNN of 24.3 msec, at the low end of the normal SDNN of 36.8 ± 14.6 msec reported for his gender and age. (63)

An initial program of chiropractic care consisted of 3 visits a week for 12-weeks, and was ongoing at the time of manuscript preparation. Subjective outcomes include improvement of sleep and decreased fatigue, and elimination of shoulder pain. Objective outcomes include increased cervical range of motion and improved overall posture as assessed by visual observation, as well as an improvement of reaction time as measured by SWAY® testing from a baseline of 427 ms before care to 309 ms after 3-months of continuous care. Normal reaction time for a patient of this age is 280 ± 40 msec. (61) His baseline SDNN of 24.3 msec improved to 30.9 msec within the first month of care, with a further improvement to 90.2 msec after 3-months of care, an improvement sustained at 4.5 months of care with an SDNN of 88.0 representing a 262.1% increase in HRV as compared to his pre-care score.

Case 5

A 25-year-old female referred by her gastroenterologist presented for chiropractic care seeking improvement of lower back pain, gastrointestinal dysfunction, and anxiety. Her baseline HRV recording indicated an SDNN of 50.6 msec, within the reported normal range of 48.7 ± 19.0 msec for her gender and age. (63)

An initial program of chiropractic care consisted of 3 visits a week for 12-weeks, and was ongoing at the time of manuscript preparation. Subjective outcomes after 3-months of care include resolution of anxiety, improvement of elimination function from 4 times per week to twice daily, and reduction of low back pain. Objective outcomes include improvement of muscle activity and balance as measured by sEMG, and improvement in single leg raise balance as measured by SWAY® (baseline proprietary SWAY score 78.2/100 before care to 92.7/100 after 3-months of care. (62) Her pre-care HRV baseline SDNN of 50.6 msec improved to 62 msec after one month of care, and to 110.6 after 2-months of care, and slightly diminished to 75.9 msec after 3-months of care (a sustained 50% increase over her pre-care score), possibly due to reported life stressors.

Case 6

A 42-year-old male presented with right neck and shoulder pain, with goals of maintaining strength and increasing flexibility. His baseline HRV recording indicated an SDNN of 59.3 msec, within the reported normal range of 44.6 ± 16.8 msec for his age and gender. (63)

An initial program of chiropractic care consisted of 3 visits per week for 12-weeks, and was ongoing at the time of manuscript preparation. Subjective outcomes include reduced neck and shoulder pain, improved athletic performance, and improvement of gait and flexibility. Objective improvements include an improvement of proprietary SWAY balance score from 60.1/100 before care to 95.2/100 after 3-months of care. (65) His baseline SDNN of 59.3 msec increased to 93.6 msec after 1-month of care, and was maintained at 95.6 msec after 3-months of care, a 61.2% increase from his pre-care score.

This work was approved by the IRB of the Foundation for Vertebral Subluxation.

RESULTS

Data from unadjusted patients were collected to confirm protocol test-test reliability. While the individual baseline SDNN differed between individuals as predicted by Pinna's HRV reliability analysis (68), the HRV trials for each unadjusted individual in Figure 1 demonstrate good test-test reliability, with standard deviations of less than 10%. The test-test reliability observed indicates that changes observed in Figures 2 and 3 are due to physiological change rather than random chance. Previous studies have demonstrated that HRV is not affected in non-adjusted controls and is not affected by the placebo effect. (55)

Figure 2 shows 6 retrospective case studies of patients whose baseline SDNN measured lower at their initial intake, prior to administration of care, and progressively increased over the course of their care, with a sustained improvement. HRV assessment for these data points was performed prior to any adjustment performed during that day's visit. Trend lines on each graph represent the progressive increase of baseline HRV in these patients over time, which is indicated on the X-axis in number of months.

Figure 3 contains comparative PWP representations of autonomic activity and balance for the 6 case studies, prior to initiation of chiropractic care and at their most recent assessment

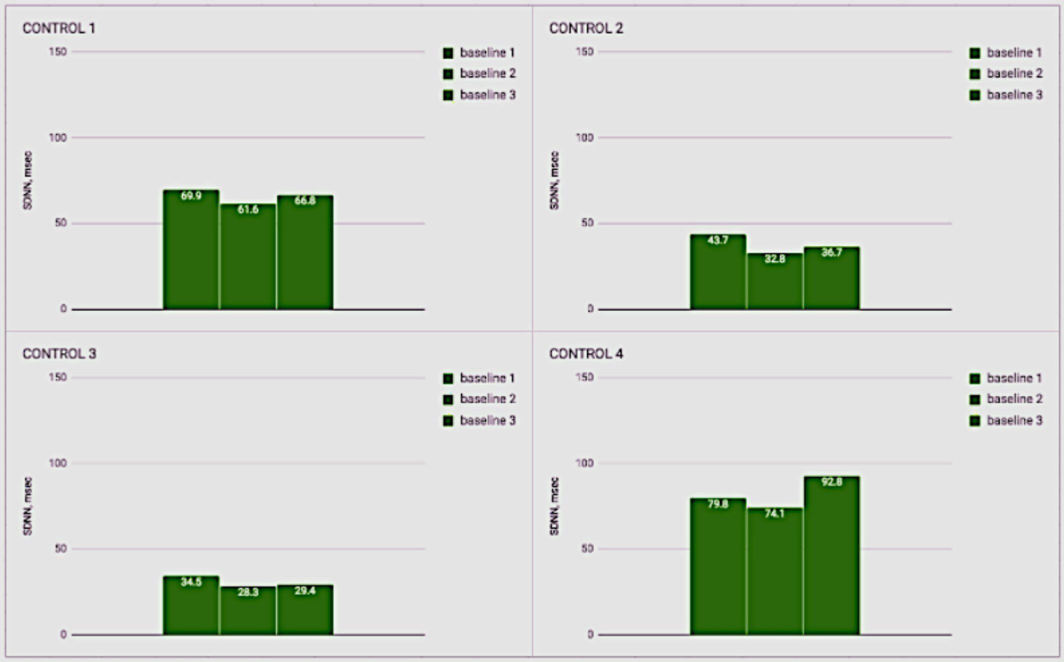

Figure 1. Test-retest reliability of SDNN obtained from control patients without adjustment. Patients were assessed pre-adjustment for heart rate variability three times in sequence on the same day. Standard deviations from SDNN data in panels A through D are as follows: (A) 4.2%; (B) 5.5%; (C) 3.3%, (D) 9.6%

Figure 1. Test-retest reliability of SDNN obtained from control patients without adjustment using PWP HRV analysis.

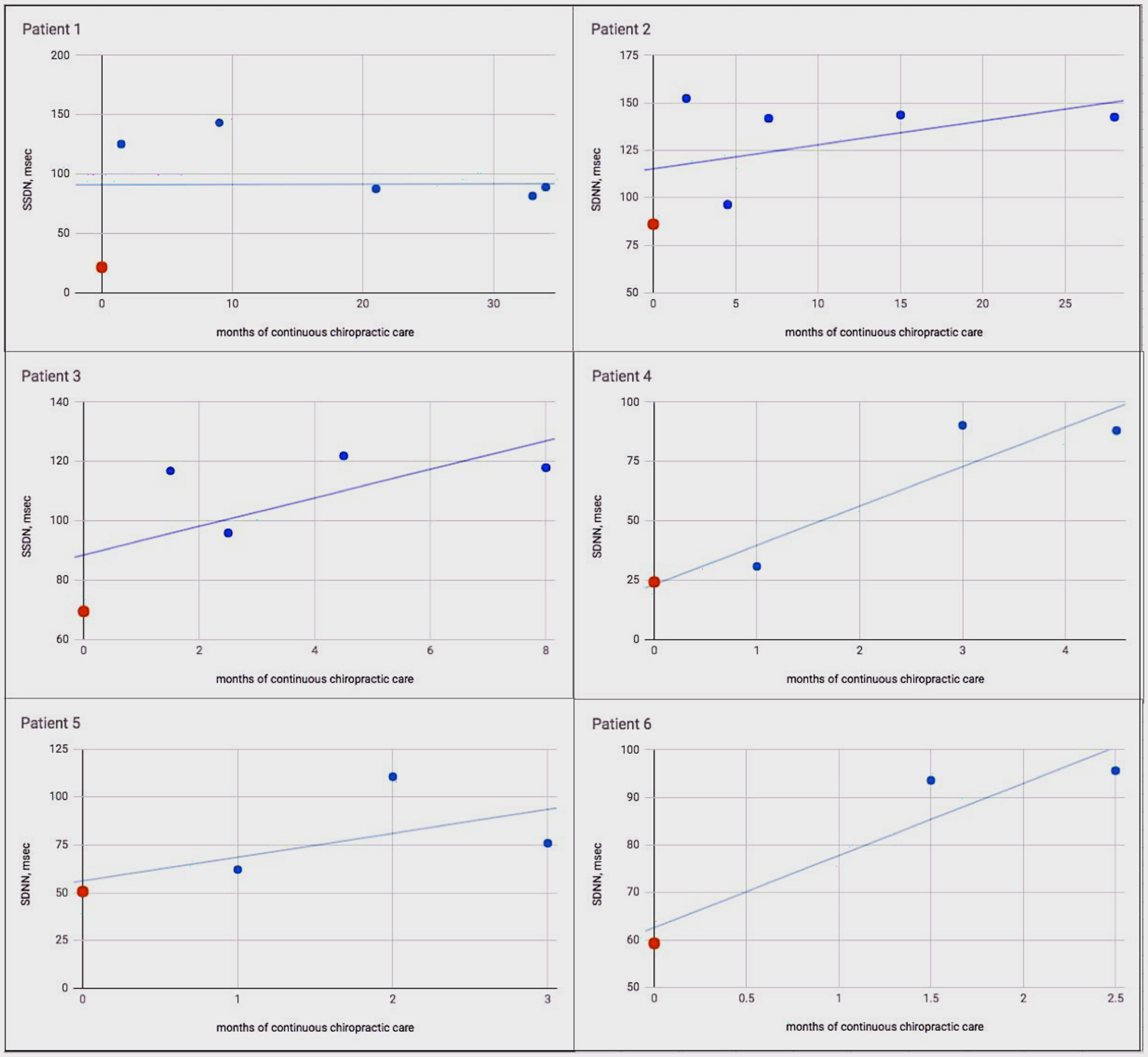

Figure 2. Changes in HRV as measured by SDNN of 6 patients over a course of chiropractic care. Baseline SSDN measurements acquired before the initiation of chiropractic care are labeled in red. Subsequent baseline SSDN measurements are labeled in blue, per months of continuous chiropractic care as indicated on the X axis..

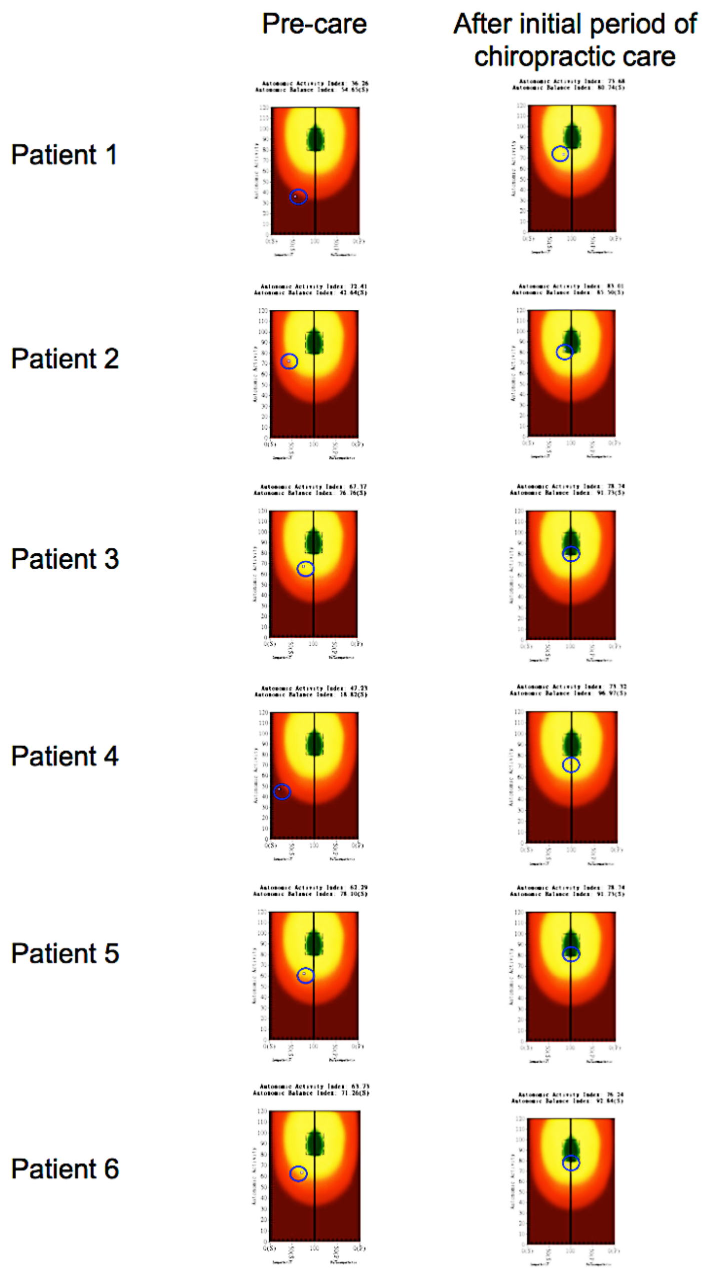

Figure 3. CLA PWP® representation of improvements of HRV pre- versus with chiropractic care for cases 1 through 6. HRV is represented graphically by 2 factors: a data point (circled in blue) centered on the X axis signifies sympathetic / parasympathetic balance, and deviation to either side indicates sympathetic (left) or parasympathetic (right) shift; placement of the data point at 100 on Y axis, representing normal autonomic activity for the individual's age and gender as compared a control group of healthy subjects, whereas lower than 100 on the Y axis indicates decreased autonomic activity.

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DISCUSSION

This case series chronicles HRV changes of 6 adult patients receiving chiropractic care using Diversified and Thompson adjusting techniques for the correction of vertebral subluxation. The data described here are consistent with immediate and long-lasting neurophysiological changes effected by chiropractic case management. While the absolute values of baseline and post-care HRV differed between individuals, each individual's outcome improved to values more consistent with younger or athletic individuals (69-71), and the improvements in HRV of 2 of these individuals are consistent with a transition from predicted worse health outcomes to greatly improved health outcomes (27).

One concern central to the use of HRV in clinical outcomes data is that HRV data is reported using many different units of measure as time domain versus frequency domain, power spectrum, high-frequency, low-frequency, very-low-frequency, and ratios of these various units, which are intended to represent balance and coherence within the autonomic nervous system. Of the data analysis methods available, SDNN is thought to reflect both parasympathetic and sympathetic activity and to provide an index of total HRV (27). Multiple studies have shown that of the data set derived from HRV measurement, SDNN has stronger reliability (68) and decreases linearly with age (44,55), and therefore is simplest and most useful for cross-study comparison. Further, age normalized standards for SDNN obtained using 5-minute sampling times are readily available from multiple sources (59,63) making SDNN data readily comparable across healthcare disciplines. Therefore, while all HRV metrics are reported in appendix 1, this study focuses on changes in SDNN in particular.

Pinna's review of reliability of HRV measurements states that "short-term HRV measures are subject to large day-to-day variations…[and that] differences between individuals mostly reflect differences in the subject's error-free values rather than random error". (68) Intra-subject variability is also due to an intrinsic lability of HRV parameters, probably because they are under the influence of such factors as mood, alertness and mental activity, which are very difficult to control for in any study, as well as changes associated with frequency and depth of respiration. (68) Intrinsic intra-individual HRV variation complicates cross-group comparison and may indeed underlie the variation and wide standard deviation in SDNN ranges reported. (43,45,56,60,63) Since individual physiology can vary according to the effect of various stressors on dynamic physiology (37,45), the magnitude of response to various interventions, including chiropractic adjustment, may vary per individual per day. Therefore, we hypothesized that while any individual data point may not hold conclusive data, a collection of data points over time may show a trend indicative of HRV change. Furthermore, since changes in HRV 5 minute readings after interventions such as exercise are known to be transient (45), changes observed pre- versus post-adjustment cannot be interpreted to signify that the individual adjustments performed confer permanent physiological change. The sustained nature of the HRV improvements reported in these 6 cases may therefore reflect neuroplastic changes associated with long-term chiropractic care.

Sustained improvement of HRV over a course of chiropractic care may have implications for prediction of multiple health outcomes. For cardiac cases, data from 24-hour sampling times demonstrate a 5.3 times higher (34%) mortality for individuals with abnormally low SDNN. (29) Strikingly, in 1 report, patients with moderate 24-hour sampling time SDNN values (50-100 msec) have a 400% lower risk of mortality than those with low values (0-50 msec). (25) For the purposes of comparison of SDNN obtained under the conditions used in the current study, Bilchick et al (27) suggest a "cutoff" of 30 msec for 5-minute sampling-time SDNN for separation of better or worse health outcomes in cardiac cases. It is of interest that cases 3 and 4 in the current case series show a pre-adjustment SDNN value close to 30 msec and a post-adjustment SDNN value greatly increased past this "cutoff." Abnormally low SDNN has implications for non-cardiac health outcomes as well: low HRV has been shown to be predictive of worsened prognosis in cancer cases (39,40), and conversely, higher HRV may increase resilience to cancer. (40) The case studies presented here are consistent with immediate and lasting improvement in health outcomes, and these data suggest the possibility that sustained improvement of HRV after a course of chiropractic care may have positive implications for the body's ability to overcome pathologies such as cancer and cardiovascular disease.

Several of the post-care SDNN values in these case studies described herein are above the normative values established in the literature. (59,63) Though clear lower limits have been established for 5' HRV measurements, no clear upper limits have been identified as yet, therefore the significance of these findings is unclear. One possible explanation may be extrapolated from Stein *et al's* study on 24-hour Holter monitoring of older adults, which suggested that some values of HRV may be mildly exaggerated by erratic rhythms found more prevalently in this age group. However, SDNN in particular was less affected than the other HRV metrics reported. (72) Without the ability or expertise to evaluate the individual PQRST waveforms used to generate the data in these case studies, the authors cannot exclude the possibility of an undetected erratic rhythm in cases 1 and 3 in this study generating an artificially elevated SDNN. Alternatively, because SDNN values used as comparable normative data per age and gender for the 6 case studies were generated from a "normal" population (59,63), it is possible that a higher reference range would be identifiable for highly functional and healthy individuals, and that the SDNN values observed for cases 1 and 3 may simply be reflective of physiology improved above what is expected from a "normal" population. Indeed, several studies have shown that trained aerobic athletes have a higher baseline SDNN than their untrained counterparts. Aubert et al (69) reported elevated 10' SDNN values of 97.9 ± 15.7 msec for aerobic trained athletes as compared to 65.4 ± 38.9 for sedentary individuals; similarly, Martinelli et al reported elevated 5'

SDNN values of 89.9 ± 24.8 msec for endurance-trained cyclists as compared to 59.1 ± 36.5 for their untrained counterparts (70), and for young (ages 18-25) individuals, Corrales et al report elevated 5' SDNN values for male athletes of 101.2 ± 37.4 msec, and for female athletes of 106.6 ± 38.1 msec, significantly higher than for their untrained male (83.1 ± 31.7) or female (71.8 ± 24.5) counterparts. (71) The observation of significantly higher reference ranges for aerobically trained athletes suggests the possibility that the unexplained higher SDNN values reported for cases 1 and 3 could be consistent with improved cardiovascular physiology, as is found in trained athletes. Further study will be necessary to explore this possibility.

Improvement of HRV may reflect a means by which the chiropractic adjustment affects human physiology and is not exclusive of other potential physiological effects of the chiropractic adjustment as theorized by Kent (73) and Pickar (74), or Ingber (75). Rather, improvement of HRV may represent readout of the physical and physiological effects that is related to and interconnected with these theories and others.

While the neurophysiological basis for the effect of the chiropractic adjustment on HRV remains to be further elucidated, recent research suggests several plausible mechanisms by which incoming sensory information from joints in the spine, especially of the head and neck, may affect cardiac regulation. (76) The fastigial nucleus (FN), an evolutionarily-conserved structure, receives input from spinocerebellar tracts, in particular somatosensory information from the spinal joints of the head and upper body. (77) Projections have been identified reaching from the FN of the cerebellum to several different structures that may affect cardiac regulation, including the amygdala, the hypothalamus, and medullary nuclei including the cardiovascular centre. (78) Further, the FN sends projections to the nucleus tractus solitarius (NTS), which contains the intermedius nucleus of the medulla (InM). The InM contains neurochemically diverse neurons and sends both excitatory and inhibitory projections to the NTS. (79,80). These data provide a novel pathway that may underlie possible reflex changes in autonomic variables after neck muscle spindle afferent activation. Incoming information from either the spinocerebellar tracts or directly from cervical spine afferents may therefore relay somatosensory input through the FN, the NTS, and the InM, both of which may in turn affect sympathetic as well as cardiac control centers.

Alternatively, input created via a chiropractic adjustment relayed through the FN to the amygdala could influence the integration of signals from inside and outside the body, thus affecting the body's adaptive capacity. Thayer's neurovisceral integration model (81) holds that a core set of neural structures provides an organism with the ability to integrate signals from inside and out the body and adaptively regulate cognition, perception, action, and physiology. Thayer's recent meta-analysis of fMRI and PET data has demonstrated association of activation of the the amygdala and the prefrontal cortex with changes in HRV. (81) Consistent with this hypothesis, Lelic et al. (82) have demonstrated that manipulation of dysfunctional spinal joints affects sensorimotor integration in the prefrontal cortex. Therefore, reduced or abnormal vertebral motion or position, intersegmentally or globally, could result in alteration of somatosensory input through the spinocerebellar tracts to structures that influence neurovisceral integration, as measured by HRV. Much research will be needed to test this hypothesis; however, the existence of neural pathways leading from the spine through the brain to the modulators of cardiac activity is a promising start.

Thayer's neurovisceral integration model is reminiscent of modulation of physiology via a central pattern generator (CPG), a cooperative set of neurons that generate rhythmic patterns such as gait, breathing, and swallowing. (83) A particular property of a CPG-modulated system is that sensory input to CPGs leads to adaptive changes (84), such a pebble in a shoe will lead to a limping gait pattern. A third possible underlying neurophysiological mechanism by which chiropractic care may affect HRV is that changes in sensory input as generated by a chiropractic adjustment, when perceived by any of the neural apparati discussed above, may affect a CPG that modulates heart rate. If this is the case, changes in HRV with chiropractic care could be viewed as evidence of adaptive changes executed by a CPG in response to sensory input. Consistent with this possibility, Senzon et al have demonstrated that sensory input generated by Network Spinal Analysis care results in generation of rhythmic muscle contraction that when measured by sEMG shows mathematical properties of CPG-modulated activity. (85) Indeed, if vertebral subluxation was to create afferent sensory changes delivered to neural structures that either comprise or influence a CPG, reduction or resolution of vertebral subluxation by the chiropractic adjustment may represent a means by which adaptive capacity may be modulated. Much further study will be necessary to explore this intriguing possibility.

The 6 case studies presented here contradict multiple studies that have clearly established a linear decline in SDNN with age. (44,55,63) The observed improvement in SDNN in the 6 cases presented suggests the possibility that the cumulative effect of regular chiropractic care may reverse a diminished HRV, and indeed, may be protective against the predicted age-related decline in HRV. Further longitudinal study will be necessary to confirm this observation and to explore the physiology that may underpin these improvements.

Limitations

As with any case series there are a number of inherent limitations. Although all patients demonstrated objective improvements in HRV, the inability to define whether these improvements were due to natural progression, pain reduction, unreported home care and self-medication, adjunct therapies administered during the program of care, or vertebral subluxation based chiropractic care makes these factors limitations to the study and causal effect cannot be determined. It's clear that further clinical research is required to evaluate the relationship between chiropractic care for the correction of vertebral subluxation and improvement in HRV in adult patients.

CONCLUSION

The data presented demonstrate a sustained improvement in HRV over a course of chiropractic care that is consistent with improved health outcomes. While no definitive conclusion can be made from this study, these data show objective, non-musculoskeletal outcomes that are consistent with neurophysiological effects associated with reduction or resolution of vertebral subluxation including improvements in coherence, spinal biomechanical function, neurological function, resilience, and adaptability. Future directions for HRV research in the chiropractic research arena should include expanding upon the current research using a sample size large enough for statistical analysis and longitudinal study, exploration of potential effects of the chiropractic adjustment on EEG activity of cardiac and cardiac-related nuclei, and exploration of whether sensory input generated by the chiropractic adjustment may affect nuclei in the medulla in a way that directs HRV changes.

REFERENCES

1. World Health Organization. WHO guidelines on basic safety and training in chiropractic. Geneva: World Health Organization; 2005.
2. Association of Chiropractic Colleges. The Association of Chiropractic Colleges Position Paper # 1. July 1996. ICA Rev. 1996; November/December.
3. Haavik H, Holt K, Murphy B. Exploring the neuromodulatory effects of vertebral subluxation and chiropractic care. Chiropr J Australia, 2010; 40(1):37-44.
4. THE VERTEBRAL SUBLUXATION: CONCEPTUAL DEFINITION FOR RESEARCH AND PRACTICE [Press Release]. Available at: https://spinalresearch.com.au/wp-content/uploads/2017/06/The-Vertebral-Subluxation.pdf The Australian Spinal Research Foundation, June 2017.
5. Association of Chiropractic Colleges. Update - The Association of Chiropractic Colleges Position Paper # 1. July 1996
6. World Federation of Chiropractic. Definitions of Chiropractic 2015 [Available from: https://www.wfc.org/website/index.php?option=com_content&view=article&id=90&Itemid=110
7. Harrison DD, Troyanovich SJ, Harrison DE, Janik TJ, Murphy DJ. A normal sagittal spinal configuration: a desirable clinical outcome. J Manipulative Physiol Ther, 1996;19(6):398-405.
8. Harrison DE, Cailliet R, Harrison DD, Troyanovich SJ, Harrison SO. A review of biomechanics of the central nervous system. PART I: spinal canal deformations due to changes in posture. J Manipulative Physiol Ther, 1999; 22(4):227-234.

9. Harrison DE, Cailliet R, Harrison DD, Troyanovich SJ, Harrison SO. A review of biomechanics of the central nervous system. PART II: strains in the spinal cord from postural loads. J Manipulative Physiol Ther, 1999; 22(5):322-332.
10. Harrison DE, Cailliet R, Harrison DD, Troyanovich SJ, Harrison SO. A review of biomechanics of the central nervous system. PART III: spinal cord stresses from postural loads and their neurologic effects. J Manipulative Physiol Ther, 1999; 22(6):399-410.
11. Harrison, D. E., Harrison, D. D., Troyanovich, S. J., & Harmon, S. (2000). A normal spinal position: It's time to accept the evidence. J Manipulative Physiol Ther 23(9), 623–644.
12. Haavik-Taylor H, Murphy B. Cervical spine manipulation alters sensorimotor integration: a somatosensory evoked potential study. Clin Neurophysiol, 2007; 118(2):391-402.
13. Taylor HH, Murphy B. Altered sensorimotor integration with cervical spine manipulation. J Manipulative Physiol Ther, 2008; 31(2):115-126.
14. Taylor HH, Murphy B. Altered central integration of dual somatosensory input after cervical spine manipulation. J Manipulative Physiol Ther, 2010; 33(3):178-188.
15. Daligadu J, Haavik H, Yielder PC, Baarbe J, Murphy B. Alterations in cortical and cerebellar motor processing in subclinical neck pain patients following spinal manipulation. J Manipulative Physiol Ther, 2013; 36(8):527-537.
16. Niazi IK, Turker KS, Flavel S, Kinget M, Duehr J, Haavik H. Changes in H-reflex and V-waves following spinal manipulation. Exp Brain Res, 2015; 233(4):1165-1173.
17. Holt KR, Haavik H, Lee A, Murphy B. Effectiveness of chiropractic care to improve sensorimotor function associated with falls risk in older people: a randomized controlled trial. J Manipulative Physiol Ther, 2016; 39(4):267-278.
18. Botelho MB, Andrade BB. Effect of cervical spine manipulative therapy on judo athletes' grip strength. J Manipulative Physiol Ther, 2012; 35(1):38-44.
19. Smith DL, Dainoff MJ, Smith JP. The effect of chiropractic adjustments on movement time: a pilot study using Fitts Law. J Manipulative Physiol Ther, 2006; 29(4):257-266.
20. Morningstar MW. Improvement of lower extremity electrodiagnostic findings following a trial of spinal manipulation and motion-based therapy. Chiropr Osteopat, 2006; 14(1):20-26.
21. Bakris G, Dickholtz M, Meyer PM, Kravitz G, Avery E, Miller M, Brown J, Woodfield C, Bell, B. Atlas vertebra realignment and achievement of arterial pressure goal in hypertensive patients: a pilot study. J Human Hypertens, 2007; 42:1206-1206.
22. Welch A, Boone R. Sympathetic and parasympathetic responses to specific diversified adjustments to chiropractic vertebral subluxations of the cervical and thoracic spine. J Chiropr Med, 2008; 7(3):86-93.
23. Triano JJ, Budgell J, Bagnulo A. Review of methods used by chiropractors to determine the site for applying manipulation. Chiropr Man Therap, 2013; 21(1):36.

24. Holt K, Russell D, Cooperstein R, Young M, Sherson M, Haavik H. Inter-examiner reliability of the detection of vertebral subluxations using continuous measures and confidence levels. J Chiropr Educ, 2016; 30:59.
25. McCraty R, Shaffer F. Heart rate variability: new perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. Glob Adv Health Med, 2015; 4(1):46-61
26. Tsuji H, Larson MG, Venditti FJ, Manders ES, Evans JC, Feldman CL, Levy D. Impact of reduced heart rate variability on risk for cardiac events: The Framingham Heart Study. Circulation, 1996; 94(11):2850-2855.
27. Bilchick KC, Berger RD. Heart rate variability. J Cardiovasc Electrophysiol, 2006; 17(6):691-694.
28. Hillebrand S, Gast KB, de Mutsert R, Swenne CA, Jukema JW, Middeldorp S, Rosendaal FR, Dekkers OM. Heart rate variability and first cardiovascular event in populations without known cardiovascular disease: meta-analysis and dose-response meta-regression. Europace, 2013; 15(5):742-749.
29. Lampert R, Bremner JD, Su S, et al. Decreased heart rate variability is associated with higher levels of inflammation in middle-aged men. Am Heart J, 2008; 156(4):759.e1-7.
30. Cooper TM, McKinley PS, Seeman TE, Choo T-H, Lee S, Sloan RP. Heart rate variability predicts levels of inflammatory markers: Evidence for the vagal anti-inflammatory pathway. Brain Behav Immun, 2015; 49:94-100.
31. Pavlov VA, Tracey KJ. The vagus nerve and the inflammatory reflex—linking immunity and metabolism. Nat Rev Endocrinol, 2012; 8(12):743-754.
32. Wulsin LR, Horn PS, Perry JL, Massaro JM, D'Agostino RB. Autonomic imbalance as a predictor of metabolic risks, cardiovascular disease, diabetes, and mortality. J Clin Endocrinol Metab, 2015; 100(6):2443-2448.
33. Williams DP, Cash C, Cash C, et al. Resting heart rate variability predicts self-reported difficulties in emotion regulation: a focus on different facets of emotion regulation. Front Psychol, 2015; 6:122-128.
34. Gorman JM, Sloan RP. Heart rate variability in depressive and anxiety disorders. Am Heart J, 2000; 140(4):S77-S83.
35. Chalmers, JA, Quintana, DS, Abbott, MJ, Kemp, AH. Anxiety disorders are associated with reduced heart rate variability: a meta-analysis. Front Psychiatry, 2014; 5:80.
36. Minassian A, Maihofer AX, Baker DG, Nievergelt CM, Geyer MA, Risbrough VB. Association of predeployment heart rate variability with risk of postdeployment posttraumatic stress disorder in active-duty Marines. JAMA Psychiatry, 2015; 72(10):979–8.
37. Delaney JP, Brodie DA. Effects of short-term psychological stress on the time and frequency domains of heart-rate variability. Percept Mot Skills, 2000; 91(2):515-524.
38. Aeschbacher S, Bossard M, Schoen T. Heart rate variability and sleep-related breathing disorders in the general population. Am J Cardiol, 2016, 118(6):912-917.
39. Guo Y, Koshy S, Hui D, Palmer JL, Shin K. Prognostic value of heart rate variability in patients with cancer. J Clin Neurophysiol, 2015; 32(6):516-520.

40. De Couck M, Gidron Y. Norms of vagal nerve activity, indexed by Heart Rate Variability, in cancer patients. Cancer Epidemiol, 2013; 37(5):737-741.
41. Gidron Y, De Couck M, De Greve J. If you have an active vagus nerve, cancer stage may no longer be important. J Biol Regul Homeost Agents, 2014; 28(2):195-201.
42. Zulfiqar U, Jurivich DA, Gao W, Singer DH. Relation of high heart rate variability to healthy longevity. Am J Cardiol, 2010; 105(8):1181-1185.
43. Nicolini P, Ciulla MM, Asmundis CD, Magrini F, Brugada P. The prognostic value of heart rate variability in the elderly, changing the perspective: from sympathovagal balance to chaos theory. Pacing Clin Electrophysiol, 2012; 35(5):622-638.
44. Umetani K, Singer DH, McCraty R. Twenty-four hour time domain heart rate variability and heart rate: relations to age and gender over nine decades. J Am Coll Cardiol, 1998; 31(3):593-601.
45. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. Sports Med, 2013; 43:773.
46. Selye, H. Stress and the General Adaptation Syndrome. Br Med J, 1950 Jun 17; 1(4667):1383–1392.
47. Ruffini N, D'Alessandro G, Mariani N, Pollastrelli A, Cardinali L, Cerritelli F. Variations of high frequency parameter of heart rate variability following osteopathic manipulative treatment in healthy subjects compared to control group and sham therapy: randomized controlled trial. Front Neurosci, 2015; 9:1043–12.
48. Budgell B, Polus B. The effects of thoracic manipulation on heart rate variability: a controlled crossover trial. J Manipulative Physiol Ther, 2006; 29(8):603-610.
49. Castro-Sánchez AM. A randomized controlled trial investigating the effects of craniosacral therapy on pain and heart rate variability in fibromyalgia patients. Clin Rehabil, 2011; 25(1):25-35.
50. Giles PD, Hensel KL, Pacchia CF, Smith ML. Suboccipital decompression enhances heart rate variability indices of cardiac control in healthy subjects. The J Altern Complement Med, 2013; 19(2):92-96.
51. Budgell B, Hirano F. Innocuous mechanical stimulation of the neck and alterations in heart-rate variability in healthy young adults. Auton Neurosci, 2001; 91(1):96-99.
52. Shafiq H, McGregor C, Murphy B. The Impact of Cervical Manipulation on Heart Rate Variability. Conf Proc IEEE Eng Med Bio Sci, 2014: 3406-3409.
53. Roy RA, Boucher JP, Comtois AS. Heart rate variability modulation after manipulation in pain-free patients vs patients in pain. J Manipulative Physiol Ther, 2009; 32(4):277-286.
54. Zhang J. Effect of age and sex on heart rate variability in healthy subjects. J Manipulative Physiol Ther, 2007; 30(5):374-379.
55. Zhang J, Dean D, Nosco D, Strathopulos D. Effect of chiropractic care on heart rate variability and pain in a multisite clinical study. J Manipulative Physiol Ther, 2006; 29(4):267-274.

56. Win NN, Jorgensen AMS, Chen YS, Haneline MT. Effects of Upper and Lower Cervical Spinal Manipulative Therapy on Blood Pressure and Heart Rate Variability in Volunteers and Patients With Neck Pain: A Randomized Controlled, Cross-Over, Preliminary Study. J Chiropr Med, 2015;14(1):1-9.
57. Welch A, Boone R. Sympathetic and parasympathetic responses to specific diversified adjustments to chiropractic vertebral subluxations of the cervical and thoracic spine. J Chiropr Med, 2008; 7(3);86-93.
58. Ruffini N, D'alessandro G, Mariani N. Variations of high frequency parameter of heart rate variability following osteopathic manipulative treatment in healthy subjects compared to control group and sham therapy. Front Neurosci, 2015; 9(272).
59. Nunan D, Sandercock GRH, Brodie DA. A quantitative systematic review of normal values for short-term heart rate variability in healthy adults. Pacing Clin Electrophysiol, 2010; 33(11):1407-1417.
60. Myers T. (2014) Anatomy Trains. Churchill Livingstone Elsevier.
61. Dykiert D, Der G, Starr, JM, Deary IJ. Age differences in intra-individual reliability in simple and choice reaction time: systematic review and meta-ananlysis. PLoS One, 2012; 7(10), e45759.
62. Patterson JA, Amick RZ, Thummar T, Rogers ME. Validations of measures from the smartphone SWAY balance application. Int J Sports Phys Ther, 2014; 9(2):135-9.
63. Voss A, Schroeder R, Heitmann A, Peters A, Perz S. Short-term heart rate variability: influence of gender and age in healthy subjects. PLoS One, 2015; 10(3):e0118308-e0118333.
64. Troyanovich, S, Harrison, D, Harrison, D. Structural rehabilitation of the spine and posture: rationale for treatment beyond the resolution of symptoms. J Manipulative Physiol Ther, 1998 Jan; 21(1): 37-50.
65. Oakley P, Harrison D, Harrison D, Haas J. Evidence-based protocol for structural rehabilitation of the spine and posture: review of clinical biomechanics of posture (CBP) publications. J Can Chiropr Assoc, 2005 Dec; 49(4): 270-296.
66. Cooperstein R, Gleberzon B. (2004) Technique systems in chiropractic. Elsevier Health Sciences.
67. Cooperstein R. Technique system overview: Thompson Technique. Chiropractic Technique. 1995; Vol. 7, No. 2: 60-63.
68. Pinna GD, Maestri R, Torunski A, Danilowicz-Szymanowicz L, Szwoch M, La Rovere MT, Raczac G. Heart rate variability measures: a fresh look at reliability. Clin Sci, 2007; 113(3):131-140.
69. Aubert A, Beckers F, Ramaekers D. Short-term heart rate variability in young athletes. J Cardiol, 2001; 37(Suppl 1); 85-88.
70. Martinelli FS, Chacon-Mikahil MPT, Martins LEB, Lima-Filho EC, Golfetti MA, Paschoal MA, Gallo-Junior L. Heart rate variability in athletes and nonathletes at rest and during head-up tilt. Braz J Med Biol Res, 2005; 38(4):639-647.
71. Corrales M, Torres, B, Esquivel A, Salazar M, Naranjo Orellana, J. Normal values of heart rate variability at rest in a young, healthy and active Mexican population. Health, 2012; 4,377-385.

72. Stein P, Domitrovich P, Hui P, Rautaharju P, Gottdiener D. Sometimes higher heart rate variability is not better heart rate variability: results of graphical and nonlinear analyses. J Cardiovasc Electrophysiol, 2005;16(9):954-959.
73. Kent C. Models of vertebral subluxation: a review. J Vert Sublux Res, 1996; 1(1):1-7.
74. Pickar JG. Neurophysiological effects of spinal manipulation. Spine J, 2002; 2(5):357-371.
75. Ingber D. Mechanobiology and diseases of mechanotransduction. Ann Med, 2003; 35(8):564-577.
76. Edwards IJ, Lall VK, Paton JF, et al. Neck muscle afferents influence oromotor and cardiorespiratory brainstem neural circuits. Brain Struct Funct, 2014; 220(3):1421-1436.
77. Zhang X-Y, Wang J-J, Zhu J-N. Cerebellar fastigial nucleus: from anatomic construction to physiological functions. Cerebellum Ataxias, 2016; 3(1):272.
78. Cao BB, Huang Y, Jiang YY, Qiu YH. Cerebellar fastigial nuclear glutamatergic neurons regulate immune function via hypothalamic and sympathetic pathways. J Neuroimmune Pharmacol, 2015; 10(1):162-178.
79. Edwards IJ, Dallas ML, Poole SL. The neurochemically diverse intermedius nucleus of the medulla as a source of excitatory and inhibitory synaptic input to the nucleus tractus solitarii. J Neurosci, 2007; 27(31):8324-8333.
80. Edwards IJ, Deuchars SA, Deuchars J. The intermedius nucleus of the medulla: a potential site for the integration of cervical information and the generation of autonomic responses. J Chem Neuroanat, 2009; 38(3):166-175.
81. Thayer JF, Ahs F, Fredrikson M, Sollers JJ, Wagner. A meta-analysis of heart rate variability and imaging studies: Implications for heart rate variability as a marker of stress and health. Neurosci Biobehav Rev, 2012; 36:747-756.
82. Lelic D, Niazi IK, Holt K, Jochumsen M, Dremstrup K, Yielder P, Murphy B, Drewes A and Haavik H. Manipulation of dysfunctional spinal joints affects sensorimotor integration in the pre-frontal cortex: a brain source localization study. Neural Plasticity, volume 2016 (2016).
83. Guertin PA. Central pattern generator for locomotion: anatomical, physiological, and pathophysiological considerations. Front Neurol, 2012; 3:183.
84. Stein W. Sensory input to central pattern generators. Encyclopedia of Computational Neuroscience, 2015. pp1-11.
85. Senzon SA, Epstein DM, Lemberger D. The Network Spinal Wave as a Central Pattern Generator. J Altern Complement Med, 2016;22(7):544-566.