Regarding High-Velocity/Low-Amplitude (HVLA) adjusting techniques in chiropractic: Controlled pre-loaded impulse of low amplitude; Part 5 of a Series.

Peter Rome and John Waterhouse

Abstract: A discussion is presented which questions the relevance and interpretation of the term *High Velocity Low Amplitude* (HVLA) is used as a descriptive for seemingly most spinal manipulative techniques. It is suggested that among the range of manual manipulative techniques a distinct majority may be regarded as being of varying degrees of both velocity and amplitude although relatively few may be considered as strictly HVLA. It seems that the HVLA term has been loosely adopted and presumed as a descriptive of manipulation without due research or serious consideration as to its accuracy and has often been misunderstood and adopted inappropriately.

Contrary to earlier assumptions, it is suggested that the chiropractic vertebral adjustment does not take an articulation beyond its normal range of movement. There are occasions when an HVLA technique could be employed as the technique of choice. These still do not necessarily take a joint beyond its physiological limit.

Classification of manipulative techniques is submitted in order to more accurately identify the physical characteristics involved in the different forms of manipulation, including chiropractic adjustments. However, due to the capricious nature in identifying the subtleties of the technique, any classification remains quite subjective and renders limited definitive value to the HVLA term. In essence, the accuracy and appropriateness of the so-called *High Velocity Low Amplitude* or *HVLA* technique in manual spinal manipulation is questioned.

Indexing terms: Manipulation, Vertebral adjustment, Technique, Chiropractic.

Introduction

There are about 15 commonly applied chiropractic adjustive techniques, while Hayden nominates five common techniques. Overall, there are claims of 200 named chiropractic adjustive technique. This would include those named technique systems with integrated analytical procedures. Another estimate notes that there are 150 techniques referenced in chiropractic literature. (1, 2, 3)

... in essence, the accuracy and appropriateness of the so-called High Velocity Low Amplitude or HVLA technique in manual spinal manipulation is questioned.'

The so-called term high velocity low amplitude (HVLA) seems to have been broadly applied to many manipulative procedures. (4) While some forms of spinal manipulation may be regarded as HVLA, it seems a broad generalisation to classify all or even most thrust techniques as such.

Cattrysse and colleagues defined spinal manipulation as '*... a high-velocity, low amplitude thrust applied to a bony prominence of a vertebral motor segment.*' (5) We find such a definition inappropriate as it so loosely generalises and fails to recognise nuances, the uniqueness of techniques, specificity, intensities, especially as there can be distinct differences. The range of control of amplitudes and the ability to alter velocity demonstrate the dissimilarities. These particularly exemplify the variations and subtleties of long-established vertebral adjustments. While generic manipulative techniques may be broadly applied with less specificity, refinement, and subtlety, not all could be regarded as HVLA. (6)

Generally however, one could not draw comparisons by classifying virtually all thrust, pull or rotatory manipulations or adjustments under the single term HVLA. That would incorrectly assume that similar techniques and forces would be employed for each segment in each spinal region when that is clearly not the case as each case has its own determinate and each patient must be considered individually. (7)

It is suggested here that to nominate audible cavitation of a metacarpophalangeal joint (MCP) as HVLA is also misleading as cavitation of MCPs or phalangeal joints can occur at very different velocities of distraction. In addition, there are other factors incorporated in the strategic art of adjusting vertebrae. (8)

The term 'high velocity' may tend to sound somewhat intense even harsh and is deserving of appropriate interpretation with no indication as to the extent of velocity. It is a similar case with the amplitude element where the thrust is generally no more that 3-4 mm in controlled manual adjustive techniques. This may appear contrary to some forms of general manipulation.

While elements of HVLA techniques have been reviewed by Downie et al, there appears to be little evidence to suggest that neither the velocity nor the amplitude have or can be consistently quantified in the clinical setting - with the exception of instrument assisting techniques. The variables with practitioners employing different techniques and adaptations would tend to mitigate consistently defining these considerations. (4)

Superficial impressions of the HVLA term suggest a highly physical procedure. On the contrary, an analysis would indicate refined action which is conducted with controlled, segment-specific, spinal adjustments are modelled for safety, comfort, and efficacy. The notion that refined and calculated manipulation of a high velocity low amplitude impetus might sprain articular ligaments and the capsule is not sustainable. The absence of such signs and symptoms associated with tissue damage of that nature would be apparent if it occurred. Extreme techniques that may occasionally take a joint to its end range or even slightly beyond are not chiropractic techniques. Chiropractic techniques are conducted within a joint's physiological range of movement (RoM). (9-12)

This ambiguity concerning an HVLA technique may be eased when it is recognised that a heartbeat or even blinking may be regarded as HVLA.

Ianuzzi and Khalsa found that in the process of lumbar spinal manipulation the magnitude of forces were within the physiological range indicating that spinal manipulation is biomechanically safe. (9)

It is suggested here that in chiropractic, relatively few techniques fall within a range which may be regarded as HVLA. The selection of the appropriate technique for a particular patient is important as it depends on a number of subjective and objective clinical findings and considerations. As such, a range of considerations concerning velocity and amplitude factors need

to be considered. These include the patient's general condition, severity and location of signs and symptoms, as well as their comfort and preferences. (13)

Review

In 2016, Nougarou and colleagues used T6-T8 transverse processes and spinous processes as contact points. They noted distinct differences in the effects of manipulation when comparing the rate of the peak force application in relation to neuromuscular effects. Its modulation effected changes in vertebral displacement. This would be consistent with an observation made by Downie et al in their extensive review that the smaller the contact interface permits lower impetus to complete the adjustment. (4, 14)

Vertebral motions during spinal adjustments of the lumbar spine are relatively small with translations (0.25 – 1.62 mm) (Nathan and Keller). This is less than in normal physiological flexion-extension where Byrne and colleagues found that the range for L5/S1 showed less translation (3.5 mm), compared to L2/3 (5.9 mm), L3/4 (6.3 mm), L4/5 (6.6 mm). (16, 17)

Cattrysse and colleagues found that end range '*HVLA*' manipulation produced a C1/C2 and at Co/C1 motion of 1° '*in all cardinal directions*', whereas the maximum rotation noted did not exceed 3.5°. It is emphasised however that chiropractic adjusting techniques take place within vertebrae's normal range of motion – within the facet centrode where the fixation has taken place. (5)

In a 2003 study, '*manually assisted*' movement demonstrated using impulse forces ranging from 30 N to 150 N, displacement of lumbar vertebra (L1, L3, L4) ranged from 0.07 to 0.81 mm. (18, 19)

Four orthopaedic surgeons and two physiotherapists in Pittsburgh measured the kinematics of cervical manipulation, '*which was performed by a licensed chiropractor*'. They found that the average rate of facet gapping was 6.2 ± 3.9 mm/s while global head movement increased by 8° in later al bending, 10° in axial rotation and 13° in flexion-extension. Peak force was 65 ± 4 N at a rate of 440 ± 58 N/s. (20)

In relation to the velocity factor in HVLA technique, Cramer et al cite Eisenberg stating that the faster the pressure changes the greater possibility of causing cavitation. It is suggested that this audible cavitation is an indication of a successful release of the target articulation. (21)

Although a number of variables must be taken into account, in relation to forces in applying a spinal adjustment. Todd, Carroll and Mitchell extensively reviewed the forces involved in spinal adjustments, they identified and averaged the four levels of input (Grades I – IV) for children up to age 18. March and estimated the safe level of force involved with manipulation of the cervical spine in paediatric patients in particular age groups. (22-24)

		Todd et al	Marchand
Neonates	2 months	11.2.N	20 N
Infants and Toddlers	3 – 23 months	33.6 N	50 N
Young children	2 - 8 years	56 N	85 N
Older children	8 – 18	89.6 N	135 N

It is submitted here that an infant would notice a subcutaneous or intramuscular injection far more than a routine chiropractic manual or instrument adjustment – and considerably more

discomfort from a tonsillectomy or circumcision. One infant with a history of colic slept right through a mild rotatory cervical adjustment. (Rome - 'as PLR')

If the positioning of the patient and the contact preparation are well set-up, the thrust impulse would usually release the designated fixation with relatively little effort. Patient positioning and segmental locking, non-targeted segments can assist in localising the specificity of an adjustment and isolating the hinge axis point. (6) Consideration of facet orientation is a further critical factor for an optimal adjustment. Patient positioning can however be varied depending on the duration and/or the acuteness of the condition, the body type of the patient presenting, and the tone of the musculature at the time to complement the subtlety of the technique.

Instrument assisted

Development of highly refined adjusting instruments with variable, controlled, amplitude and velocity also challenge the notion of HVLA generalisations. The finesse of such instruments can hardly be regarded as harsh considering of governed impact of its impulse. (25)

Instrument assisted adjustment such as an Activator®, employ particularly high velocity with very low amplitude. Both these factors would be governed by various considerations including the region of the spine and the patient's body type and their age. In the appropriate setting, such mechanical impulse adjusting instruments demonstrate that release of a fixation does not have to necessarily impart great amplitude to resolve a subluxation – or be associated with an audible cavitation. The minimal contact interface plus the physics of Force =Mass x Acceleration results in an adjustment that is barely noticeable to the patient. The impulse of the Activator adjusting instrument can be calibrated for specific situations depending on the patient's age, segmental level, and patient condition. Its impulse can be varied to range from 20 N to 137.8 N in manual models, and up to 190 N on an electronic model. Depending on the setting, the depth of penetration of the cushioned stylus is 1-6 mm, and the duration of the thrust is 5-6 ms. The depth of the impulse must also be considered depending on the depth of the soft tissue overlying the contact point. (22 [p 36],26, 27, 28)

A medical paper by Koch et al, estimated that an upper cervical manipulation using an impulse instrument on infants aged 1 – 12 months, was 50 N to 70 N. (29)

A physiotherapy study of posterior-anterior mobilisation both centrally and unilaterally of the cervical spine determined that the thrust peak forces ranged from 21.8 N to 61.0 N. A physiotherapy comparative study of cervical mobilisation compared to HVLA thrust manipulation of the cervical spine has been estimated to impart a force of 20 N. Dunning et al note non-thrust manipulations as being markedly less effective that thrust manipulation. (30, 31)

Other mechanically assisted units which can assist in patient comfort can include spring-loaded segments and drop pieces on the adjusting table, flexions distraction tables as well as depth of cushioning on the adjusting table surface. These options help to facilitate some techniques permitting even lower force adjustments and impulse absorption.

In contrast to HVLA, adjusting techniques may include Sacro-Occipital Technique (SOT), some Applied Kinesiology (AK), and Logan Basic technique. One relatively passive SOT technique involves a category analysis and uses wedge shaped blocks strategically placed under the pelvis to allow the body's weight in the supine or prone position to coerce the sacroiliac joints into certain corrections with further adaptations in spinal segments superiorly through the spine. SOT practitioners may also employ a mobilising stair-step technique for the cervical spine. (32)

Discussion

The HVLA term may sound deceptively harsh to the uninitiated. It is suggested that an appropriate alternative term could described as a specific pre-loaded controlled variable impulse of low amplitude.

Despite addressing the topic to techniques rather extensively, it is noted that the HVLA term was not mentioned in the entire report on chiropractic in the New Zealand Commission of Inquiry in 1979. In fact the Inquiry found that '*What they (chiropractors) have done has been to develop the art of spinal functional analysis and "adjustment" to a degree with which the medical profession as a whole cannot compete. They have developed a range of techniques and skills which few in New Zealand outside the chiropractic profession have been able to master.*' (13 p29)

The high-velocity, low-amplitude or HVLA technique is among the oldest and most frequently misunderstood chiropractic techniques. Considerable chiropractic clinical research and experience has focused on evaluating the efficacy of all forms of spinal manipulation has been previously published. (33, 34, 35)

Depending on a variety of clinical factors and particularly the type of clinically diagnosed subluxation, a practitioner may select from an array of techniques. Not all chiropractic adjustments can be considered HVLA, on occasion a practitioner may select a technique that includes general manipulative procedures such as light or deep massage, trigger point therapy, or general mobilisation. In addition, both the velocity and the amplitude may vary depending on the practitioner's assessment, training, psychomotor skills, and uptake of ongoing seminars on evolving techniques. HVLA is just one option in considering the appropriate technique for a particular patient and their clinical presentation.

On hearing the term High Velocity Low Impact techniques, a patient may find the term somewhat portentous. Their preference may also influence the choice of a particular practitioner for an HVLA technique. That preference may also lead the practitioner to modify or adopt an alternative technique. Misinterpretation of these considerations may add further reason to dismiss the term HVLA and avoid misinterpretation.

On the other hand, at times in noting a rapid positive response, the positive outcome would validate and justify a particular technique. Indeed HVLA can be seen as safe, popular and successful techniques for over 120 years indicating no necessity to dismiss certain adjusting techniques only modify the terminology referring to them.

In controlled, developed and honed procedures, where training considers all factors including a patient's likely bone density, possible pathologies and other potential red or orange flags, such considerations can provide an optimal setting for an HVLA-type procedure. If that technique is selected, both the velocity and the amplitude would be modified for the individual circumstances.

To call a manipulative thrust high velocity overlooks the fact that it is more of a short impulse which is employed with the low, controlled, amplitude. Co-called HVLA techniques usually utilise a specific focal contact that acts as a fulcrum using lever principles, the adjustment can often be minimal in amplitude. Despite the variables, true HVLA techniques have not been marginalised when employed and adapted appropriately and professionally for specifically selected situations.

Spinal adjustments may be modified depending on a number of factors. Before any spinal adjustment is conducted, a range of considerations are taken into account. These include the patient's age, height, weight, presenting symptoms, their health status, the segmental level involved, palpation and other relevant clinical findings upon testing, assessing, and diagnosis.

Chiropractic management may also consider non-manipulative health care such as exercises, occupation, sport, hobbies, dietary advice, and life style modifications. If a patient is not considered a candidate for chiropractic care, the patient would be so advised and referred directly to an appropriate practitioner or for further diagnostic evaluation and management.

To state that a patient was manipulated with an HVLA technique is essentially the same as saying they were just manipulated – a vague statement. Without greater detail the statement does not convey any definitive detail. The interpretation of the term HVLA will differ amongst individuals.

Controlled pre-loaded impulse with low amplitude

When one considers manipulative techniques, it is apparent that relatively few could be categorised under the wide interpretation of HVLA, or what constitutes HVLA techniques. Such variables do not convey an idea as to the actual technique to be used.

It is considered here, that rather than HVLA, some spinal adjustment techniques are more aptly described as controlled pre-loaded impulse with low amplitude, or as Evans designates a gradual pre-loaded pressure followed by an impulse release of a fixation. These manual practices would be localised with the smallest appropriate contact point and a predetermined directional impulse-type end-thrust with the line of drive being critical in considering the plane of the involved articulation surface. (4, 36, 37, 38)

The amplitude of such a technique is also critical, both for the success of achieving the release of the subluxation, and for the safety and comfort of the patient. If the patient is relaxed, they should not experience greater discomfort – except if the patient is in an acute pain presentation.

The relevance of the term designated as the adjustment as being pre-loaded refers to that part of the adjusting technique which compresses the overlying soft tissue and to recoup regional spinal laxity or 'give' in the section being addressed. This is not a part of the segmental adjustment impulse thrust or amplitude. It is required in order to optimise the potency of input with minimal impact on the smallest contact point on the vertebral objective or osseous structure to attain the adjustment's objective.

Depending of the technique being employed, without the pre-loading component the thrust of the technique would initially be through a soft tissue and spinal laxity of up to an estimated 7 cm (2-3"). This would naturally be governed by the region to be addressed, the patient's posture and their body type. Without the pre-loading the articular release may not be as effective and the patient may even experience some pressure or discomfort. Pre-loading helps to potentiate the benefit and ease of the adjustment. Evans and Breen encapsulate this by requiring '… *a pre-thrust position, in which the target joint is ideally positioned into its own neutral zone motion region, thus maximizing the efficiency of the manipulation.*' (39)

Following the initial pre-loading, the next step involves the controlled adjustive thrust. The velocity of the procedure is determined by the technique and the practitioner's training.

The velocity of a thrusting impulse and its force varies considerably amongst the so-called HVLA techniques as well as the delivery from individual practitioners. This renders the term both meaningless and illusory. (4)

Amplitude has been defined as '… *the maximum extent of a vibration or oscillation, measured from the position of equilibrium*.' The degree of displacement of a fixated vertebra in response to the impulse - thrust manipulation is essentially dependent on the amplitude, direction and conduction velocity. (40)

Emphasis on the term displacement must be tempered by considering it as primarily a release of a joint fixation, but in a corrective direction if repositioning is indicated. It would be a natural

inclination for a vertebra to be directed towards its neutral, resting centrode position and more difficult and illogical to thrust it away from this natural neutral site. (41,42)

The term HVLA would also suggest that there must also imply Low Velocity High Amplitude (LVHA) , Low Velocity Low Amplitude (LVLA), and High Velocity High Amplitude (HVHA) techniques. Then there are the intermediate versions in various combinations such as medium velocity with moderate amplitude (MVMA). It is a clinical decision for each individual clinical presentation.

The following classifications are offered to delineate the thrust and amplitude variables. However these appraisals are still open to individual interpretation and overlap.

HVHA	Some generic manipulations, Cyriax (43), cervical rotation-traction manipulation (CRTM) (44).
HVLA	Some Diversified techniques, Some generic manipulation, Toggle recoil, Instrument assisted (Activator) (26)
MVMA	Some Diversified techniques, Gonstead, Cox flexion/distraction, Thompson, Pierce Stillwagon, Prone thoracic. (1, 34)
MVLA**	Anterior thoracic, Lumbar roll – spinous hook, Lumbar roll mammillary contact thrust. (1, 34)
LVHA (45)	Logan Basic (46), pressure point, Nimmo/Receptor tonus
LVLA	SOT (32), massage, mobilisation, SNAG (47), Lateral Glide (48), Apophyseal glide (49), 'non-thrust' manipulation (31).
LVMA	General manipulation, mobilisation (50-53)

[L = Low, V = Velocity, H = High, A = Amplitude, M = Medium.]

** It can be noted that chiropractic techniques are modified at the time of application depending on a range of factors, as such, a classification here would tend to overlap. In recognising this, a conclusion can be drawn that this form of classification is redundant.*

*** In addition, some techniques are conducted on specifically designed tables with pneumatic mechanisms or spring loading to cushion the impulse.*

It is suggested that clinically however, without appropriate quantifying instrumentation it is not possible to monitor the degree of velocity or amplitude in order to classify a technique. Such observations again render the classification essentially meaningless. Mechanical or electrical adjusting instruments would be an exception to this statement.

It is noted the existence of the Maitland grades comprising levels of small to large amplitudes without mention of velocity nor the term HVLA. However grades for HVLA are quite subjective. (54,55)

Grade	small amplitude movement at the beginning of the available range of movement
Grade II	large amplitude movement at within the available range of movement
Grade III	large amplitude movement that moves into stiffness or muscle spasm
Grade IV	small amplitude movement stretching into stiffness or muscle spasm
Grade V	(Thrust Manipulation) - Small amplitude, quick thrust at end of available range of movement

Within these categories, the practitioner's discretion of velocity and amplitude may be modified to facilitate variable considerations as noted by Dulhunty. The adjustment inherently include factors of '*load, resistance, displacement and time*' (56)

These variables are subject to practitioner individuality in assessing their own technique. Graham, Clausen and Bolton noted that in toggle recoil, the displacement and forces could vary considerable. Owens recorded such variables with Gonstead lumbar technique on simulated models. (57, 58, 59)

Displacement of vertebrae during an adjustment

While the application of manual procedures may vary, some may experience HVLA adjustments with audible cavitation during the release a vertebral fixation with a thrust that is little more than a shallow flinching impulse, while others are subject to more assertive general manipulation. (43)

In assessing studies on the manual sciences, studies should state whether the conducting practitioner is a student in the research, an established chiropractor, the manipulator's profession and years of experience. Although attempts have been made and given to these clinical variables, it is difficult to translate the topic of displacement of a vertebra under a velocity and amplitude factors into consistent magnitudes in clinical practice. (4) This exemplifies the advantage of named mechanically assisted techniques such as Activator. In view of these manual elements, the term HVLA or similar, is somewhat ill-defined and inadequate. (60)

Conclusion

Nominated HVLA techniques cannot be clearly categorised under definitive terms in the clinical setting due to so many variables. High velocity has been used in relation to a wide range of techniques and applications, yet what constitutes high has never been determined. Similarly, low amplitude is a subjective term and open to wide interpretation.

A vertebral adjustment comprises the release of a fixated or dysfunctional segment from within its normal range of movement. The displacement element of a fixated vertebra by a segmental adjustment is a part of the fixation release. Its adjustment would take place in a corrective direction usually towards its neutral axis zone not towards the anatomical articular limit. The chiropractic adjustment occurs with relatively little thrust but with adroit, focussed, considered, preparation, and leverage.

We would concede that HVLA is not seen as a practical term as its use is too broad and vague to be incorporated over the many variations and interpretation. If the HVLA term is adopted, then it requires greater descriptive clarity in relation to the degrees of velocity, amplitude, and loading. These factors are associated with various manual techniques while generic manipulations are more mechanical and overlook both the subtleties and the significant individual features of a manipulative technique.

Peter Rome
DC (ret), FICC
cadaps@bigpond.net.au

John D Waterhouse
DC, FACC
Private practice, Melbourne

Cite: Rome P. Waterhouse JD. Regarding High-Velocity/Low-Amplitude (HVLA) adjusting techniques in chiropractic: Controlled pre-loaded impulse of low amplitude: Part 5 of a series Asia-Pacific Chiropr J. 2021;1.4. URL www/apcj.net/rome-and-waterhouse-regarding-hvla-techniques/

References

1. Painter FM. https://chiro.org/LINKS/ABSTRACTS/Chiropractic_Techniques.shtml.

2. Chapter 10. Modes of care and management. In: Clinical guidelines for chiropractic practice in Canada. Chiropractic in Canada. https://chiro.org/LINKS/FULL/CANADA/Modes_Of_Care.html.

3. Hayden R. 5 Common chiropractic adjustment techniques. Angie's List, https://www.angieslist.com/articles/5-common-chiropractic-ajustment-techniques.htm.

4. Downie AS, Vemulpad S, Bull P. Quantifying the high-velocity, low-amplitude spinal manipulative thrust a systematic review. J Manipulative Physiol Ther 2010;33(7):542-53.

5. Cattrysse E, Gianola S, Provyn S, van Roy P. Intended and non-intended kinematic effects of atlanto-axial rotational high-velocity, low-amplitude techniques. Clin Biomech. 2015;30(2):149-152.

6. Harwich AS. Joint manipulation: toward a general theory of high-velocity, low amplitude thrust technique. J Manipulative Physiol Ther. 2017;24(1):15-23.

7. Yeomans SG. Spinal manipulation: high-velocity low amplitude (HVLA). 2013; July 19. https://www.spine-health.com/treatment/chiropractic/spinal-manipulation-high-velocity-low-amplitude-hvla.

8. Kawchuk GN, Fryer J, Jaremko JL, Zeng, Rowe L, Thompson R. Real-time visualisation of joint cavitation. PLoS One. 2015;10(4):e0119470.

9. Ianuzzi A, Khalsa PS, Comparison of human lumbar facet joint capsule strains during simulated high-velocity, low-amplitude spinal manipulation verses physiological motions. Spine J. 2005;5(3):277-290.

10. Rome PL, Waterhouse JD. The specific chiropractic adjustment is conducted within an articulation's physiological range of motion. Asia Pacific Chiropr J. 2021 *(In Press)*.

11. Rome PL, Waterhouse JD. Differentiating chiropractic articular adjustments from manipulation.Asia Pacific Chiropr J. 2021 *(In Press)*.

12. Ebrall PS. The paraphysiological space of manipulation: A pragmatist's appraisal. J Philos Principles Practice Chiropr. 2020;May 4:8-17.

13. Inglis BD. Chiropractic in New Zealand: Report of the Commission of Inquiry. Wellington, NZ: PD Hasselberg, Government Printer. 1979.

14. Nougarou, F., Pagé, I. Loranger, M. et al. Neuromechanical response to spinal manipulation therapy: effects of a constant rate of force application. BMC Complement Altern Med. 2016; 16, 161.

15. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4890324/pdf/12906_2016_Article_1153.pdf.

16. Nathan M, Keller TS. Measurement and analysis of the in vivo posteroanterior impulse response of the human thoracolumbar spine: a feasibility study. J Manipulative Physiol Ther. 1994;17:431–41.

17. Byrne J, Zhou Y, Zheng L, Chowdhury S. Segmental variations in facet joint translations during in vivo lumbar extension. J Biomech 2018 70:88-95.

18. Keller TS, Colloca CJ, Gunsburg R. Neuromechancial characterization of in vivo lumbar spinal manipulation, Part I, vertebral motion. J Manipulative Physiol Ther. 2003;26(9):567-78.

19. Keller TS, Colloca CJ, Moore RJ, Gunzburg R, Harrison DE. Increased multiaxial lumbar motion responses during multiple-impulse mechanical force manually assisted spinal manipulation. Chiropr Osteopat. 2006;14:6. Published 2006 Apr 6. doi:10.1186/1746-1340-14-6.

20. Anderst WJ, Gale T, LeVasseur C, Raj S, Gongaware K, Schneider M. Intervertebral kinematics of the cervical spine before, during, and after high-velocity low-amplitude manipulation. Spine J. 2018;18(12):2333-2342. doi: 10.1016/j.

21. Cramer GD, Ross K, Raju PK, et al. Quantification of cavitation and gapping of lumbar zygapophyseal joints during spinal manipulative therapy. J Manipulative Physiol Ther. 2012 Oct; 35(8): 614–621. Citing: Eisenberg P. Mechanics of cavitation. Streeter VL, editor. Handbook of fluid mechanics. New York: McGraw-Hill Book Co.; 1961. p. 12.2-12.24.

22. Ebrall P. Spinal Adjustment. Tokyo: Tokyo College of Chiropractic 2019 ISBN 978-1-6854-358-8.

23. Todd AJ, Carroll MT, Mitchell EKL. Forces of commonly used chiropractic techniques for children: a review of the literature. J Manipulative Physiol Ther 2016;38(6):401-10.

24. Marchand AM. A proposed model with possible implications for safety and technique adaptations for chiropractic spinal manipulative therapy for infants and children. J Manipulative Physiol Ther. 2015;38(9):9713-9726.

25. Fuhr AW. Activator methods chiropractic technique. 2nd edn. Phoenix. Motion Palpation Institute. 1990.

26. https://www.activator.com/adjustment-instrument-details/.

27. https://epdf.pub/the-activator-method.html.

28. http://www.freepatentsonline.com/9345633.html (Extracted 13 April 2020.).

29. Koch LE, Koch H, Graumann-Brunt S, Stolle D, Ramirez JM, Saternus KS. Heart rate changes in response to mild mechanical irritation of the high cervical spinal cord region in infants. Forensic Sci Int. 2002;128(3):168-76.

30. Snodgrass SJ, Rivett DA, Robertson VJ. Manual forces applied during cervical mobilization. J Manipulative Physiol Ther. 2007;30(1):17-25.

31. Dunning JR, Cleland JA, Waldrop MA, et al. Upper cervical and upper thoracic thrust manipulation verses nonthrust mobilisation in patients with mechanical neck pain: a multicentre randomized clinical trial. JOSPT. 2012'42(1):5-18.

32. SOTO Australasia. http://www.soto.net.au/A-patients-guide-to-the-practice-of-SOT.

33. Janse J, Houser RH, Wells BF. Chiropractic principles and technic. Chicago. National College of Chiropractic. 1947.

34. Bergmann TF, Peterson DH. Chiropractic technique: principles and procedures. 3rd edn. St Louis: Mosby Elsevier. 2011.

35. Gleberzon BJ, Cooperstein R. Chiropractic name techniques. London: Butterworth-Heinemann;2002.

36. Evans DW. Mechanisms and effects of spinal high-velocity, low amplitude thrust manipulation: previous theories. J Manipulative Physiol Ther 2002;25(4):251-62.

37. Nougarou F, Dugas C, Loranger M, Pagé I, Descarreaux M. The role of preload forces in spinal manipulation: experimental investigation of kinematic and electromyographic responses in healthy adults. J Manipulative Physiol Ther. 2014;37:287-93.

38. Pagé I, Nougarou F, Dugas C, Descarreaux M. The effect of spinal manipulation impulse duration on spine neuromechancial responses. J Canad Chiropr Assoc. 2014;58(2):141-8.

39. Evans DW, Breen AC. A biomechanical model for mechanically efficient cavitation production during spinal manipulation: prethrust position and the neutral zone. J Manipulative Physiol Ther. 2006;29(1):72-82.

40. Cooper I. Visual physics online. Waves. Simple. Harmonic Motion. School of Physics, University of Sydney..http://www.physics.usyd.edu.au/teach_res/hsp/sp/mod31/m31_wavesA.htm.

41. The Motion Palpation Institute. https://www.motionpalpation.org/about.

42. Schafer RC. Motion palpation and chiropractic technique. https://chiro.org/ACAPress/Motion_Palpation.html.

43. Cyriax J. Textbook of orthopaedic medicine. Vol 11. Treatment by manipulation and massage. London. Cassell. 1965. Plates 8,14,55a,57,60,65,69,73.

44. Liguo Z, Minshan F, Xunlu Y, et al. Kinematics analysis of cervical rotation-traction manipulation measured by a motion capture system. Evid Based Complement Altern Med. 2017;2017:5293916.

45. Henderson CNR. Animal models in the study of subluxation and manipulation: 1964-2004. In: Gatterman MI. Foundations of chiropractic subluxations. 2nd edn. St Louis: Elsevier Mosby;2005:51.

46. Logan HB, Textbook of Logan basic methods. St Louis: Self Published; 1950.

47. Hall T,Chan HT, Christensen L, et al Efficacy of a C1-C2 self-sustained natural apophyseal glide (SNAG) in the management of cervicogenic headaches. JOSPT. 2007;37(3):100-9.

48. Coppieterss MW, Stappaerts KH, Wouters LL, Janssen K. The immediate effects of cervical lateral glide treatment technique in patients with neurogenic cervicobrachial pain. JOSPT. 2003;33(7):369-78.

49. Kim S-Y, Kim N-S, Kim LJ. Effects of cervical sustained natural apophyseal glide on forward head posture and respiratory function. J Phys Ther Sci. 2015;27(6):1851-64.

50. Araujo FX, Ferreira GE, Angellos RF, et al. Autonomic effects of spinal manipulative therapy: systematic review of randomized controlled trials. J Manipulative Physiol Ther 2019; pii: S0161-4754(18)30184-2. doi: 10.1016/j.jmpt.2018.12.005

51. Bergman TF. Chiropractic technique. In: Gatterman MI. Foundations of chiropractic subluxations. 2nd edn. St Louis: Elsevier Mosby;2005:133-167.

52. Lee R, Evans J. An in vivo study of the intervertebral movements produced by posteroanterior mobilization. Clin Biomech (Bristol, Avon) 1997;12:400–8.

53. Dunning JR, Cleland JA, Waldrop MA, et al. Upper cervical and upper thoracic thrust manipulation verses nonthrust mobilization in patients with mechanical neck pain: a multicenter randomized clinical trial. JOSPT. 2012;42(1):5-18.

54. Maitland Mobilisation. https://www.physio-pedia.com/Maitland%27s_Mobilisations.

55. Manual therapy. Physiopedia. https://www.physio-pedia.com/Manual_Therapy.

56. Dulhunty JA. A mathematical basis for defining vertebral subluxations and their correction. Chiropr J Aust. 1996;26(4):130-138. [Also ;Dynamic Chiropr 1997;15(20). https://www.dynamicchiropractic.com/mpacms/dc/article.php?id=38527].

57. Graham BA, Clausen P, Bolton PS. A descriptive study of the force and displacement profiles of the toggle-recoil spinal manipulative procedure (adjustment) as performed by chiropractors. Man Ther. 2010;15(1):74-9.

58. Owens EF, Hosek RS, Mullin L, et al. Thrust magnitude, rates, and 3-dimensional directions delivered in simulated lumbar spine high-velocity, low-amplitude manipulation. J Manipulative Physiol Ther. 2017;40(6):411-9.

59. Owens EF, Hosek RS, Sullivcan S, et al. Establishing force and speed training for lumbar spine high-velocity, low-amplitude chiropractic adjustments. J Chiropr Educ. 2016;30(1):7-13.

60. Keller TS, Colloca CJ, Beliveau JG. Force-deformation response of the lumbar spine: a sagittal plane model of posteroanterior manipulation and mobilization. Clin Biomech (Bristol, Avon) 2002;17:185–96.