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Review Article

Restoring cervical lordosis by cervical extension traction methods in the treatment of cervical spine disorders: a systematic review of controlled trials

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Abstract. [Purpose] To systematically review the literature on the use of cervical extension traction methods for increasing cervical lordosis in those with hypolordosis and cervical spine disorders. [Methods] Literature searches for controlled clinical trials were performed in Pubmed, PEDro, Cochrane, and ICL databases. Search terms included iterations related to the cervical spine, neck pain and disorders, and extension traction rehabilitation. [Results] Of 1,001 initially located articles, 9 met the inclusion/exclusion criteria. The trials demonstrated increases in radiographically measured lordosis of 12–18°, over 5–15 weeks, after 15–60 treatment sessions. Untreated controls/ comparison groups not receiving extension traction showed no increase in cervical lordosis. Several trials demonstrated that both traction and comparison treatment groups experienced immediate pain relief. Traction treatment groups maintained their pain and disability improvements up to 1.5 years later. Comparative groups not receiving lordosis improvement experienced regression of symptoms towards pre-treatment values by 1 years' follow-up. [Conclusion] There are several high-quality controlled clinical trials substantiating that increasing cervical lordosis by extension traction as part of a spinal rehabilitation program reduces pain and disability and improves functional measures, and that these improvements are maintained long-term. Comparative groups who receive multimodal rehabilitation but not extension traction experience temporary relief that regresses after treatment cessation.
Key words: Spine traction, Cervical lordosis, Systematic review

INTRODUCTION

Neck pain is among the greatest contributors to disability[1)]. It is typically episodic or recurrent throughout its disease course with great variation in symptomatology[2)]. There are also wide variations in assessment methods and treatment approaches for patients presenting with cervical spine disorders[3)]. Most treatments for neck disorders have limited efficacy and this is particularly evident after long-term, post-therapeutic follow-up[4)].

As compared to other parts of the spine, the cervical spine has its own unique anatomical and physiological characteristics[5)]. Functionally, the cervical spine must paradoxically, maintain a dynamic ability as it is the most mobile area of the spine[6)], while balance this need with the requirement for stability[7)] in the critical role of preserving horizontal gaze[8)]. Cervical

spine alignment has been shown to be significantly related to patient outcomes; this has been particularly substantiated within the surgical literature[6, 9, 10], but also in some manual therapy literature[11, 12]. Cervical kyphosis, for example, is considered a spinal deformity and is associated with pain and disability[13–15]. Altered cervical spine alignment is associated with various specific craniocervical symptoms including headache[16–19], migraine[19, 20], as well as radiculopathy and myelopathy[21, 22]. Anterior head translation (AHT), which has variable cervical subluxation patterns[23], is highly associated with neck pain[24] and is also associated with altered cervical sensorimotor control and autonomic nervous system function[25].

The study of cervical spine biomechanics involves routine radiographic assessment[23, 26, 27]. The traditional measures used to assess cervical spine alignment parameters includes AHT, termed the cervical sagittal vertical axis (cSVA), and cervical lordosis (CL)[28]. Newer developments in the understanding of cervical spine biomechanics recognizes the association of the tilt of C7 (C7 slope) or T1 (T1 slope), as those with increased thoracic curve (hyperkyphosis) tend to have a larger CL and those with less thoracic curve (hypokyphosis) tend to have a smaller CL[29, 30]. The ratio of T1-CL (or C7-CL) is thus an important biomechanical parameter for modern cervical spine analysis[31, 32]. Other important parameters include the thoracic inlet angle (TIA)[33], the chin-brow vertical axis (CBVA), and others[7]. Although understanding of the craniocervical biomechanics is less developed than other areas of the spine, the research is evolving.

Despite continued efforts to discover more precisely, the biomechanical interrelationships between the various cervical parameters, there has long been efforts to improve a patient's head and neck posture. Historically, efforts have been directed at attempts to improve the cervical lordosis by non-surgical manual therapy methods, particularly by chiropractors. Traditional spinal manipulative therapy, however, has largely proven unsuccessful for increasing CL[34–37]. With the advent of a unique spinal traction method developed by Don Harrison in the 1980s, cervical extension traction (CET) was shown to be effective for increasing CL as demonstrated in the first published clinical trial of this new approach in 1994[35]. In that paper it was discussed that the success for changing the spine structure was likely due to both the 'more efficient direction of the applied tractioning force' and the 'use of a sustained force'. Regardless of actual mechanism, the ability to restore the anatomic cervical spine curve may be an under-utilized therapeutic approach to a myriad of craniocervical disorders[38–42].

The purpose of the present study was to systematically review and summarize the existing literature on clinical controlled trials investigating the efficacy of cervical extension traction (CET) methods employed to rehabilitate the cervical lordosis in patients with hypolordosis and cervical spine disorders. Specifically, for located studies, we aimed to investigate magnitude of lordosis improvement, the frequency and duration of treatment and the clinical effect on pain and disability outcome measures.

METHODS

This study assessed clinical controlled trials utilizing extension traction methods to increase cervical lordosis for the treatment of patients with cervical spine disorders.

Inclusion criteria included: (a) both randomized controlled trials (RCTs) and non-randomized controlled trials (nRCTs); (b) only trials that radiographically assessed CL; (c) only trials that applied the intervention of 'extension traction' to increase CL; (d) only trials that treated patients with any type of craniocervical disorder. Exclusion criteria included reviews, conference papers, non-trials such as case reports, surgical or animal studies, or trials not treating the cervical spine. We adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline[43].

All RCTs were assessed for methodological quality using the 10-point PEDro scale[44–46]. All studies were assessed for risk of bias using the Scottish Intercollegiate Guidelines Network (SIGN 50) checklist for RCTs[47]. All scoring of study quality and bias were performed by the first two authors with discrepancies resolved by consensus of all authors.

The literature was reviewed using the following databases: PubMed, PEDro (Physiotherapy Evidence Database), Cochrane, and ICL (Index to Chiropractic Literature). Key words used in literature searches included varied combinations of terms associated with the anatomical region, anatomically related pathology, traction rehabilitation methods as well as achieving lordosis restoration. Search terms included 'cervical spine', 'cervical lordosis', 'neck', 'pain', 'disc herniation', 'headache', 'migraine', 'radiculopathy', 'traction', 'extension traction', 'restoration', 'correction', 'increase', and 'rehabilitation'. The references of located articles were also screened for citations. The date range for searches included each databases inception to April, 2020. Only articles of English language were included, and only adult cohorts (>17 years) were considered.

Any located articles were independently assessed by the first two authors. Studies were reviewed to extract data related to age, traction set-up, concurrent rehabilitation procedures, with the principal summary measures of interest consisting of magnitude of lordosis improvement, treatment duration, treatment number and treatment frequency and clinical outcomes of pain, disability or functional ability scale scores. All pertinent data were extracted for baseline, post-treatment and follow-up assessments.

RESULTS

Initial searches identified 1,001 articles from the four databases (Fig. 1). One hundred-thirty-nine citations were removed for duplication (n=862). The titles and abstracts were then screened for irrelevant topics where a further 736 were removed due to: Non-cervical area=26, review=9, case report=7, conference paper=3, surgical=419, other=272. Note that 'other'
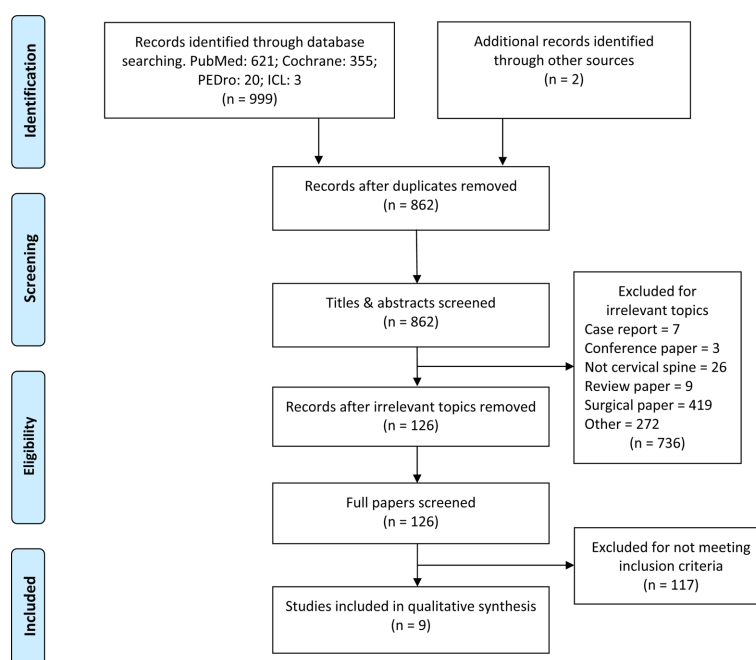
Fig. 1. Flow diagram of searched, screened, and included studies.

indicates articles also deemed irrelevant as topics included medication trials, children cohorts, genetic diseases, bone density loss, range of motion studies, dental, trial registry, biomechanical modeling, cancer cohorts, not a clinical trial or trials on irrelevant treatments including massage therapy, acupuncture, Chinese medicine, music therapy, spiritual healing, kinesiotaping, shockwave therapy, cutaneous nerve stimulation, and other holistic therapies. The remaining 126 articles were screened for inclusion criteria, leaving 9 controlled trials, 6 RCTs[48–53] and 3 nRCTs[35, 54, 55] (Table 1).

According to the PEDro quality assessment scale the quality of the RCTs was generally moderate to high, only one having a poor score (4/10)[51], all others scored 7–9/10[48–50, 52, 53] (Table 2). The risk of bias according to the SIGN 50 criteria was high quality for 5 trials and acceptable for the remaining 4 trials[35, 51, 54, 55]; in other words, all studies were adequately designed to minimise the risk of bias (Table 3).

The 9 included trials involved a total of 299 CET intervention patients suffering from the primary conditions of chronic neck pain (n=63[54, 55]), cervical disc disease (n=20[48]), spondylotic radiculopathy (n=15[51]), discogenic radiculopathy (n=30[52]), myofascial pain syndrome (n=60[49]), cervicogenic dizziness (n=36[50]), fibromyalgia (40[53]), or simply cervical hypolordosis (n=35[35]). Trials included a total of 315 controls including patients who received comparative treatments less CET (comparative treatment groups, n=231[35,48–53]) or patients who served as traditional controls (no treatment, n=84[35, 54, 55]). The extracted data from the trials is shown in Table 1.

Results demonstrate CET patients achieved a 12–18° increase in cervical lordosis after 15–60 treatment sessions over 5–15 weeks. This corresponded to a 6–25 mm reduction of AHT. The trials that had follow-up, ranging from 3 months to 15.5 months (7/9 trials[49–55]), demonstrated that lordosis correction was relatively stable, with no or slight loss of initial improvement (up to 3.5° (19% of original correction) at 15.5 months[55]).

CET patients showed a 2–4 point reduction on 11-point pain intensity scales, and a 10–27% reduction on various other disability scales. The average age of patient groups across the trials ranged from 32–54 years. Notably, all comparison groups (n=231) receiving various treatments but not CET, as well as all traditional controls (n=84) receiving no treatment, had no improvement in cervical lordosis.

DISCUSSION

This systematic review identified 9 controlled trials (6 RCTs; 3 nRCTs) which utilized extension traction to increase the cervical lordosis in patient cohorts with hypolordosis having various cervical spine disorders (Fig. 1; Table 1). All trials reported positive outcomes detailing increases in cervical lordosis concomitant with improvements in pain intensity, disability scores, functional measures including increased range of motion, as well as other physiological measures including increased spinal canal diameter, improved kinesthetic sense and increased central somatosensory conduction time.

The quality of the randomized trials overall, were of high-quality, five of six RCTs scoring 7–9/10 on the PEDro assessment scale (Table 2). All 9 trials were also adequately designed to minimize the risk of bias of the results (Table 3). Despite

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Table 1. Summary of 6 randomized and 3 non-randomized controlled trials incorporating cervical extension traction methods used to treat cervical spine disorders in patients presenting with cervical spine hypolordosis

Author	Year	Condition	Exp/Control	n	Age (SD)	No. of Txts	Duration of txt	Pre-post Lordosis	Lordosis Increase	f/u Lordosis	Pre-post AHT	AHT Reduction	f/u AHT	Pre-post Nk Pain	Pain Reduction	f/u Pain	Pre-post Disability	Disability Reduction	f/u Disability	Other outcome measures	f/u Time
Lee (RCT)	2019	Cervical disc disease	E	20	48.8 (13.3)	15	1.25 m	4.8°/16.9°	12.1°	n/r	n/r	n/r	n/r	6.8/3.3	3.5	n/r	29.9/20.2	9.7	n/r		none
			C	20	43.2 (16.2)	15	1.25 m	5.2°/4.9°	−0.03°	n/r	n/r	n/r	n/r	7.0/4.3	2.7	n/r	28.5/26.9	1.6	n/r	Increased central canal area	none
									p<0.001						p>0.05		(ODI)	p<0.05			
Moustafa (RCT)	2018	Cervical myofascial pain syndrome	E	60 (20f)	33.1 (8)	30	2.5 m	<25°/n/r	n/r	n/r	n/r	n/r	n/r	5.3/1.4	3.9	0.4	35.7/23.3	12.4	17.4	Improved range of motion, pain-pressure thresholds, cervical posture	12 m
			C	60 (24f)	31.9 (7)	30	2.5 m	<25°/n/r	n/r	n/r	n/r	n/r	n/r	5.1/1.6	3.5	4.2	35.1/24	11.1	28.5		12 m
														−	p=0.36	p<0.001	(NDI)	p=0.09	p<0.001		
Moustafa (RCT)	2017	Cervicogenic dizziness	E	36 (14f)	49.3 (4.7)	30	2.5 m	7.5°/21.2°	13.7°	20.9°	35 mm/0.9 mm	25 mm	14 mm	5.7/3.7	2.0	1.2	47.5/23.2	24.3	6.9	Improved dizziness severity, frequency, DHI, head repositioning accuracy	12 m
		Neck pain	C	36 (11f)	50.4 (4.9)	30	2.5 m	7.2°/6.7°	−0.5°	6.2°	32 mm/33 mm	−1 mm	35 mm	5.9/3.6	2.3	6	49.8/24.2	25.6	39.2		12 m
								−	p<0.0005	p<0.0005	−	p<0.0005	p<0.0005	−	p=0.3	p<0.0005	(DHI)	p=0.5	p<0.0005		
Moustafa (RCT)	2017	Cervical spondylotic radiculopathy	E	15 (?f)	n/r	30	2.5 m	n/r	n/r	n/r	n/r	n/r	n/r	n/r	n/a	n/a	n/r	n/a	n/r	Improved lordosis, pain, DSSEPs, flexion-extension kinematics	3 m
			C	15 (?f)	n/r	30	2.5 m	n/r	n/r	n/r	n/r	n/r	n/r	n/r	n/a	n/a	n/r	n/a	n/a		3 m
Moustafa (RCT)	2016	Cervical discogenic radiculopathy	E	30 (11f)	41.5 (3.7)	30	2.5 m	6.5°/19.7°	13.1°	19.2°	25.4 mm/13.0 mm	13.3 mm	15.1 mm	5.1/1.3	3.8	0.5	20.2/7.7	12.5	4	Improved arm pain, DS-SEPs, central somatosensory conduction time	12 m
			C	30 (12f)	43.9 (6.2)	30	2.5 m	6.5°/6.7°	0.2°	6.8°	24.4 mm/23.5 mm	0.9 mm	24.1 mm	4.7/1.2	3.5	3.9	20.6/12.9	7.7	20		12 m
								−	p<0.0005	p<0.0005	−	p<0.0005	p<0.0005	−	p=0.6	p<0.0005	(NDI)	p<0.0005	p<0.0005		
Moustafa (RCT)	2013	Fibromyalgia	E	40 (10f)	54.3 (7)	36	3 m	6.6°/19.4°	12.8°	18.3°	27.9 mm/14.5 mm	13.4 mm	14.9 mm	5.2/3.2	2.0	2.9	70.9/44.1	26.8	9.3	Improved 3D posture, algometry, QOL, fatigue, depression, anxiety, sleep, fibromyalgia	12 m
			C	40 (12f)	52.2 (6)	36	3 m	7.5°/7.2°	−0.4°	5.5°	27 mm/19.1 mm	7.9 mm	21.2 mm	4.6/3.1	1.5	4.7	71.3/43.6	27.7	47.9		12 m
								−	p<0.0001	p<0.001	−	p<0.0001	p<0.0001	−	p=0.3	p<0.0005	(FIQ)	p=0.4	p<0.0005		
Harrison (nRCT)	2003	Chronic neck pain	E	33 (14)	36.0 (14.2)	38	3.75 m	4.2°/22.1°	17.9°	22.0°	24.9 mm/15.4 mm	9.5 mm	15.0 mm	4.1/1.1	3.0	n/r	n/r	n/r	n/r		14 m
			C	30 (14)	37.0 (11.1)	0	n/a	10.2°/11.1°	0.9°	n/r	23.1 mm/22.4 mm	0.8 mm	n/r	3.5/3.4	0.1	n/r	n/r	n/r	n/r		8.5 m
															p<0.0001						
Harrison (nRCT)	2002	Chronic neck pain	E	30 (25F)	33.1 (14.3)	35	2.25 m	12.4°/26.6°	14.2°	22.9°	22.1 mm/15.9 mm	6.2 mm	15.3 mm	4.3/1.6	2.7	n/r	n/r	n/r	n/r		15.5 m
			C	24 (13F)	35.1 (13.9)	0	n/a	9.9°/10.8°	0.9°	n/r	n/r	n/r	n/r	3.6/3.8	−0.2	n/r	n/r	n/r	n/r		8 m
Harrison (nRCT)	1994	n/s (hypolordosis)	E1	35 (11)	34.5 (10.9)	60	3 m	14.5°/27.7°	13.2°	n/r	19.5 mm/12.7 mm	6.8 mm	n/r	n/r	n/r	n/r	n/r	n/r	n/r		none
			E2	30 (20f)	35.8 (12.5)	60	3 m	18.7°/19.9°	1.2°	n/r	21.3 mm/19.3 mm	2.0 mm	n/r	n/r	n/r	n/r	n/r	n/r	n/r	Reliability assessment of X-ray markings by 3 examiners	none
			C	30 (17f)	34.8	0	n/a	18.2°/21.2°	2.9°	n/r	20.9 mm/20.4 mm	0.5 mm	n/r	n/r	n/r	n/r	n/r	n/r	n/r		none

Harrison C: control group with no treatment; Harrison E2: manipulation but no CET; Moustafa C: comparison groups receiving 'conventional rehab' but no CET; AHT: anterior head translation; DHI: dizziness handicap inventory; DSSEPs: dermatomal somatosensory evoked potentials; f/u: follow-up; FIQ: fibromyalgia index questionnaire; Nk: neck; NDI: neck disability index; QOL: quality of life. All trials measured lordosis by posterior tangents C2-C7 except Lee, who used C2-C7 Cobb, to convert to tangents add 9°.

Table 2. Study quality assessment using the PEDro scale

First author	Date	Items of PEDro scale											Total score
		1	2	3	4	5	6	7	8	9	10	11	
Lee	2019	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	9/10
Moustafa	2018	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Moustafa	2017	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Moustafa	2017	N	Y	N	Y	N	N	N	N	N	Y	Y	4/10
Moustafa	2016	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Moustafa	2013	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	7/10

1. Eligibility criteria, 2. Random allocation, 3. Concealed allocation, 4. Similar groups, 5. Blinding of participants, 6. Blinding of therapists, 7. Blinding of assessors, 8. Adequate follow-up, 9. Intention-to-treat analysis, 10. Between group comparison statistics, 11. Point measures and variability. Scale item No. 1 not included in PEDro score. Only randomized controlled clinical trials can be assessed by PEDro scale.

Table 3. Risk of bias using the SIGN 50 checklist

First author	Date	Items of SIGN 50 checklist										Overall assessment
		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	
Lee	2019	++	++	++	++	++	++	++	++	++	n/a	++
Moustafa	2018	++	++	++	+	++	++	++	++	++	n/a	++
Moustafa	2017	++	++	++	+	++	++	++	++	++	n/a	++
Moustafa	2017	++	+	?	?	?	++	++	?	++	n/a	+
Moustafa	2016	++	++	++	+	+	++	++	++	++	n/a	++
Moustafa	2013	++	++	++	?	++	++	++	+	++	n/a	++
Harrison	2003	++	n/a	n/a	n/a	++	++	++	+	++	n/a	+
Harrison	2002	++	n/a	n/a	n/a	++	++	++	++	++	n/a	+
Harrison	1994	++	n/a	n/a	n/a	−	++	+	++	++	n/a	+

1.1, clear study question; 1.2, randomization; 1.3, adequate concealment; 1.4, blinding of participants/investigator; 1.5, baseline group similarities; 1.6, only difference being intervention; 1.7, outcome validity/reliability; 1.8, drop out percentage less than 20%; 1.9, intention-to-treat analysis; 1.10, multi-site similarities. n/a: not applicable, ?: cannot answer question from manuscript. ++ high quality, + acceptable, − low quality. Questions 1.2–1.4 do not apply for non-randomized controlled trials.

the overall high-quality and low risk of bias, the generalizability of the data is limited due to population cohorts being exclusively mid-aged adults (average age of cohorts 32–54 years), as well as many of the trials were conducted in Egypt (5 trials[49–53])), which has a different socio-cultural atmosphere to other populations including the US.

Notably, seven of nine trials (5/6 RCTs; 2/3 nRCTs) included a follow-up of CET treated patients which allowed for assessment of the stability of the initial lordosis improvement. In three RCTs including follow-up, each showed a loss of 1.4%,[50] 2.5%[52] and 5.6%[53]) of the original lordosis improvement achieved (13–14° over a 2.5 to 3-month CET treatment program) over a 12-month follow-up period. In two nRCTs, the 2002 trial[55]) showed a loss of 3.7°, or 14% of the original improvement achieved (14.2°) at a 15.5-month follow-up, while the 2003 trial[54]) showed no loss of lordosis of an original 17.9° improvement at a 14-month follow-up. The latter trial however, did have patients attend 'maintenance' treatments which averaged 6.1 treatments (SD 5.6) over 14 months, or about once every two months, and it was suggested by the authors that the maintenance treatments undoubtedly preserved the correction and prevented any loss of original lordosis correction[54]). Thus, it seems lordosis improvements occurring over short 2.5 to 3.75-month durations remain relatively stable. The slight loss of lordosis over time also supports the rationale for intermittent maintenance treatments after the completion of CET protocols to purposefully preserve the improved lordosis and to prevent the loss of lordosis over time.

It is noted that although all trials demonstrated improvements in lordosis in CET treated patients, treatments were typically limited to 2.5 to 3-months and limited to 30–38 treatments (with two exceptions[35, 48])). The ending curvature improvements in CET treated groups were not considered physiologically ideal as an end of goal result[11, 12, 56, 57]). For example, using the posterior tangent method (C2-C7), Harrison et al. determined that patients having a lordosis less than 29° (~17° Cobb) were likely to have acute neck pains, and those having a lordosis less than 22° (~13° Cobb) were likely to have chronic neck pains[11]). McAviney et al. determined that patients having a cervical lordosis less than 20° were significantly more likely to have neck pain, and that data from 277 patients suggested a 'clinically normal' range of lordosis of between 31–40° (C2-C7 posterior tangents)[12]). In 1996, Harrison suggested a clinically normal cervical curve of 34° (C2-C7 posterior tangents)[56, 57]). Considering most post-treatment lordosis measurements from the trials ranged from 19–28° (C2-C7 posterior tangent), in

all practicality, the patients should have received further treatment to attain an average lordosis of at least 30° as determined from the studies discussed. It becomes apparent further studies are warranted to assess CET treatment that is continued until an end-of-care cervical curve threshold is reached as the goal of care which would be more similar to actual clinical practice for providers of these techniques[4, 58].

There were 5 different extension traction approaches described in the 9 located trials. The original 1994 nRCT[35] featured an extension-compression type traction where the patient lay supine on an angled bench and extended their head off the end of the bench where a strap pulled the head into a hyper-extended position. The second nRCT (2002[55]), featured 'Pope's 2-way' traction which introduced a posterior-to-anterior transverse pull at the mid-neck while the patient was seated in a chair having their head distracted while in a retracted and extended position. The third nRCT (2003[54]), utilized an extension-compression with a posterior-to-anterior transverse mid-neck pull while the patient was in a seated position. Many of the RCTs[49, 50, 52, 53] featured the cervical Denneroll traction orthotic (Denneroll Spinal Orthotics, Wheeler Heights, NSW, Australia), and one trial[48] used a modified traditional axial-distraction cervical traction table (Kinetrac KNX-9900 Hanmed Co., Gimhae, Republic of Korea) with a cervical support that placed a posterior-to-anterior push onto the mid neck while the patient lay supine. While it is unknown which traction approach is most effective, as taught through CBP© seminars (www.idealspine.com), different traction approaches are better suited for different cervical spine subluxation patterns[59].

Comparing lordosis improvements between traction devices must include consideration of both treatment number and traction duration. For instance, in the 1994 trial,[35] traction was only performed for 10-minute durations and for 60 treatment sessions resulting in a 13.2° lordosis improvement. In 3 trials using the cervical Denneroll[50, 52, 53], 20-minute traction durations resulted in 13–14° improvements after 30–36 treatments. It is likely that 10-minute durations are less than ideal, and that with 20-minute traction sessions, larger lordosis increases may be accomplished in less treatments, however, this needs to be tested in future trials. Also, when considering the percentage of lordosis increase by treatment number, the trials are comparable at about 0.4–0.45° improvement per treatment. The 1994 trial[35] shows half this (0.22°/treatment) and a 2019 trial[48] on the adapted axial traction table shows 2.4°/treatment. The latter trial was conducted on patients with cervical disc disease, and it is not known if these patients may respond differently than patients suffering from other cervical spine disorders; there are also more critical concerns about this trial that we will discuss.

Another issue to consider when re-assessing a patient's cervical lordosis is when a post-treatment X-ray is taken. It is known that taking an X-ray immediately after a patient performs CET is likely to produce better results than has actually occurred as the soft tissues require about 8 hours duration to fully recover from a sustained loading[60]. As discussed previously[54], this is why in all 3 nRCTs, a 1 day wait period was included prior to the taking of the post-treatment radiographs. Of the 4 other RCTs that reported post-treatment X-ray results[49, 50, 52, 53], none of them detailed the timing of the post-treatment cervical X-ray in the manuscripts, however since at least one of the current authors had co-authored these trials, it was confirmed that at least a days' time period was allowed prior to the post-treatment X-ray (Patient's received post X-rays 1–7 days after the last treatment session). Regarding the Lee RCT however, this is of major concern, and is a critical flaw in the design of the Lee trial as they specifically state that the lateral cervical X-ray was taken "two days before the first treatment session and after the last treatment session". Thus, the larger degree of lordosis change per treatment (2.4°/treatment) may be an artifact of the methodology that would overestimate the lordosis correction. This may explain the inconsistency with the change reported in the Lee trial as compared to the other trials (0.4–0.45°/treatment). Regardless, explanation of the timing of post-treatment radiographs is an important detail that needs to be reported in future CET trials.

Another important consideration in post-treatment radiography is the repeatability and reliability of posture. It is well demonstrated that measuring cervical spine subluxation on radiographs is repeatable and reliable[61–66]. Dating from the 1970s, Beck and Killus[67] stated "several X-rays of the same individual furnished reproducible results, even when they were taken years apart". It is surprising that this criticism is still being perpetuated[68]. Based on the control and comparative groups however, this criticism has no merit, as all the trials reporting post-treatment radiographs for patients not getting CET show no change, and therefore confirm the reliability and repeatability cervical spine X-ray measurement[35, 48, 50, 52–55].

Another possible criticism with cervical re-alignment is that it could be argued that a patient/doctor may be excited to show improved lordosis which may influence the patient to slightly extend their head. In two different studies assessing slight head nodding, it was shown that for each degree of head extension, half as much occurs in the cervical spine. Harrison et al.[69] determined a 14° head extension caused a 6.9° cervical extension, and Hellsing[70] found a 20° head extension caused a 10° cervical extension. A 20° head extension is large and a radiographer should notice such efforts, thus, it is important to specify to the patient the precise instructions prior to taking the X-ray. As performed in the nRCTs, all patients were instructed to close their eyes, flex and extend the head twice, and assume a comfortable resting position. Due to the pre-post cervical lordosis changes in the trials being relatively large (12–18°) it is deemed the structural improvements as reported are beyond what a slight head nod may produce, validating lordosis improvements due to treatment effect.

Yet another criticism regarding changes in cervical spine structure, and as discussed previously[54], is the notion of cervical muscle spasm causing loss of lordosis[71–73]. It has been argued that if this were the case, then SMT alone would relieve the spasm, as has been shown to occur[74, 75], and lead to an increased lordosis, however, this is not the case[34–37]. Further, most of the trials involved chronic neck disorder patients, which nullifies any argument about acute muscle spasms causing cervical hypolordosis. In fact, the Moustafa trials[49–53] were so designed to include physiotherapeutic methods that would relieve any muscle spasms, but comparison treated patients, not receiving CET, still did not achieve any improvements in lordosis. Also,

Fedorchuk et al. recently showed that cervical muscle engagement simulating muscle spasm most likely induces an increase in curvature, not a straightening of the cervical spine[76].

Why does CET restore cervical lordosis? As discussed as early as the 1994 trial[35] showing for the first time the efficacy of CET in improving cervical lordosis versus no lordosis improvements in a comparison group receiving SMT, the difference in structural outcome was stated as being either due to: 1) the 'more efficient direction of the applied traction force vs. those used in chiropractic manipulation' or 2) use of sustained force. We suggest it is due to both of these reasons. It has been verified that the most direct approach to correcting a cervical kyphosis is by applying a transverse load at the apex of the kyphosis[77]. This is consistent with using CBPs 'mirror image' approach, or the application of load vectors that are directly opposite to the spine misalignments[4, 58]. The use of a 'sustained force' is key for traction application, specifically for 'extension traction' as has been discussed recently[4, 78]. It is suggested that extension traction creates a sustained visco-elastic deformation and creep-relaxation effect in the soft tissues including specifically, the anterior longitudinal ligament and anterior portions of the intervertebral discs[4, 78]. Traction must be performed in a continuous and sustained manner to have these two processes occur[79–83]. This is likely the reason SMT does not routinely correct spine alignment. Thus, the biomechanical elongation of the anterior spinal structures leads to a permanent structural tissue resting length change and when performed in a repeated manner (e.g. daily or three times per week), a steady and consistent change to the spine and postural alignment is possible, as has been demonstrated by the clinical trials included in this review (12–18° cervical lordosis increase after ~30–40 CET treatments).

How does CET traction differ from traditional cervical traction? As stated by Harrison et al., "All cervical traction concepts have accepted the premise that traction in flexion, with consequent decrease in lordosis, is the goal. This concept implies that lordosis is nonphysiologic and is the cause of the pathology"[55]. Although some reports have shown large proportions of asymptomatic populations having decreased cervical lordosis[84], these reports often have methodological flaws, for example, Hey et al.[84] used full-spine X-rays to measure the cervical curve which projects it to appear straighter[85, 86]. The results from this review[35, 48–55] as well as surgical outcomes[87–92] show that restoring lordosis leads to better patient outcomes. The surgical literature is profuse with evidence of superior outcomes including better pain, disability and quality of life scores, and less post-surgical complications and re-surgeries and the prevention of adjacent disc disease when the lordosis of the cervical spine is re-established/maintained[87–92]. Also, a recent meta-analysis of 21 studies confirmed that even in asymptomatic patients, the literature shows that a cervical lordosis is the norm[93]. Several trials included in this review also clearly demonstrate positive outcomes and, in many trials, superior long-term outcomes from spinal rehabilitation programs that include CET for the treatment of neck pain[50, 54, 55], cervical discogenic radiculopathy[52], cervical spondylotic radiculopathy[51], cervical myofascial pain syndrome[49], cervicogenic dizziness[50] and fibromyalgia[53] that result in increased cervical lordosis after initial treatment.

The long-term maintenance of symptomatic relief in patient groups receiving CET as a part of their rehabilitation undoubtedly resulted from achieving increased cervical lordosis. This is substantiated by the fact that 6 trials featured the CET as the only difference between the treatment and comparison group treatment arms[48–53]. Traditional views on cervical traction, endorsing flexion and/or axial (longitudinal) angle of pull ignore important biomechanical implications for the spinal cord, nerve roots, their dura, and the blood vessels of the nerve roots[55]. As postulated by the cadaveric studies of Breig, traditional flexion and axial traction has a negative consequence on the pons-cord traction, including the spinal cord, nerve roots, pons and potentially cranial nerves 5–12[94–98]. Axial and flexion traction lengthens the cervical spine and spinal canal which exerts traction forces onto the neural tissues; although temporary separation of the intervertebral discs and opening of the intervertebral foramen may provide temporary relief for a classic bulged disc-pinched nerve root, neurologically this may be more detrimental for those having chronic craniocervical disorders involving more globally, a pathologic traction effect of the pons-cord tract system. Thus, understanding of the biomechanics of the central nervous system provides an intriguing and logical explanation for the beneficial results achieved in groups receiving CET as has been summarized recently[99]. This also questions the implications of the long-term effects of traditional axial and flexion traction procedures[94].

Indeed, it is the relief of biomechanical neurological tension that is presumed to be the mechanism responsible for the improved neurophysiological measures as demonstrated in several of the trials included in this review[48–53]. This has been summarized recently[99], where it was shown that the influence of sagittal plane spine alignment correction of cervical lordosis had direct effects on neurophysiology and sensorimotor control measures; this includes increased motor function. Although the limited trials identified in this review included many measures of human performance, future trials incorporating CET should continue to incorporate more diverse measures of human performance. These trials demonstrate the optimization of function through spinal structural correction.

The limitations to the present review were that we only included publications that were in English, potentially leading to missing evidence from other languages. Since all studies involved cohorts being of a mid-age the results cannot necessarily be generalized to people of all ages. Not all trials used the same cervical lordosis measurement method. Lee[48] used the C2-C7 Cobb angle and Moustafa[49–53] and Harrison[35, 54, 55] used the C2-C7 posterior tangent method. It is noted that to convert the C2-C7 Cobb angle to the equivalent posterior tangent angle, one should add 9°[59].

It is noted that none of the trials included in this review considered sub-cervical spine biomechanics. Current spinal biomechanics accepts that whole-spine alignment has a relationship with the cervical spine, such as the thoracic curve and T1 slope, and that these parameters are important variables to consider in assessing the cervical spine alignment and its

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correction to be more patient-specific[100, 101]. Future trials need to incorporate a global spinal analysis as this will likely play an important role in better determining patient responders to the various CET approaches.

Future trials investigating CET should include more diverse population cohorts, better detail the X-ray instructions as well as describe the timing of the post-treatment X-rays. Future research also needs to confirm which traction approach best suits what cervical spine deformity type, and whether traction time (i.e. 10 vs. 20 minutes) results in quicker structural improvements. More trials need to directly compare CET to SMT.

The implications of these findings for stakeholders (e.g. clinicians, policy makers) are important. The assessment of cervical lordosis is an important clinical parameter that may not be traditionally recognized[102], but may have pathognomonic importance and clinical impact on both a patient's clinical symptoms and long-term response to treatment. Policy makers should account for the screening (i.e. by X-ray) and structural rehabilitation (restoration of lordosis) versus exclusively functional treatments, that are warranted for particular patients presenting with chronic cranio-cervical complaints with concomitant cervical hypolordosis/kyphosis.

Conflict of interest

PAO is a paid consultant to CBP NonProfit Inc.; DEH teaches and sells products to doctors for spinal rehabilitation; There are no other conflicts of interest declared.

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