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RESEARCH

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Cervical intradiscal pressure responses to end-range supine postures: a cadaveric investigation

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Abstract

Background Cadaveric studies suggest neck postures may affect cervical intradiscal pressure (CIDP) and potentially contribute to intervertebral disc (IVD) pathologies. Despite neck flexion and protraction posture prevalence and potential impact on cervical IVD health, no studies have investigated CIDP during end-range protraction and retraction. This study investigated (1) CIDP differences between cervical traction, six sagittal plane cervical end-ranges, and neutral posture; (2) CIDP and segmental cervical range of motion (ROM) correlation; and (3) CIDP measurement reliability.

Methods Seven cadaveric specimens, mean age 80.6±7.2 years, had cervical segmental ROM assessed by lateral radiographs and CIDP responses measured by fiberoptic pressure sensors in C4-5, C5-6, and C6-7 IVDs for supine end-range chin to neck, chin to sternum, protraction-flexion, occiput to neck, occiput to thorax, retraction-extension, and neutral traction.

Results Friedman tests revealed greater CIDP in (1) chin to sternum as compared to traction at C4-5, C5-6 and C6-7 ($p < .02$); (2) chin to sternum as compared to retraction-extension at C5-6 and C6-7 ($p = .027$); and (3) chin to sternum as compared to protraction-flexion at C5-6 ($p = .042$). End-range postures demonstrated moderate effect sizes on CIDP at C4-5 (ES = 0.31), C5-6 (ES = 0.46), and C6-7 (ES = 0.36) using Kendall's W. Strong correlations between cervical segmental ROM and CIDP were identified at C4-5 chin to neck, r_S=0.79, $p = .04$; C5-6 occiput to thorax, r_S=0.79, $p = .04$; and C6-7 protraction-flexion, r_S=0.82, $p = .02$. Reliability was good to excellent for CIDP and segmental ROM measurements (ICC > 0.92, 95%CI 0.86-0.98).

Conclusions Consistent chin to sternum increases and traction decreases in CIDP occurred at all cervical IVD levels. The CIDP tended to increase during flexion end-ranges at all IVD levels, while extension, protraction, and retraction tended to decrease at C5-6, C6-7 and increase at C4-5. Large positive or negative CIDP variations with even larger standard deviations were observed within and between cervical IVD segments during various postures.

Keywords Intervertebral disc, Cervical vertebrae, Pressure, Range of motion

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Background

Discogenic pain represents a common cause of neck pain and accounts for approximately 20% of cervical spine pathology in the United States [1–3]. The lower cervical intervertebral discs (IVDs) are prone to early, multi-level degeneration and result in internal and external IVD disruptions, foraminal and central stenosis, and nerve root compression syndromes [4–8]. Progressive cervical spine degeneration may result in chronic disability for 5–16% of patients with neck pain [1–3, 9].

Cervical intradiscal pressure (CIDP) is a potential factor of discogenic pain and indicator of overall IVD health [3, 4, 7, 10–13]. Increased CIDP correlates with IVD degeneration [3, 4, 7, 10–12], while decreased CIDP can be indicative of annular weaknesses, disc rupture, and potential leakage of nuclear material [8, 14]. Cervical spine postures in the sagittal plane increase CIDP, with flexion demonstrating the largest increases followed by extension. Increased CIDP occurs frequently in adjacent segments of the cervical spine during fusions or arthroplasties and are suggested as an accelerator of IVD degeneration [4, 6, 7, 10, 12, 15–18]. Previous studies have examined CIDP in cadaveric specimen with varying postures and identified increased CIDP in flexion and end range extension [4, 6, 7, 15, 18, 19]; however, these postures were limited in range of motion (ROM) excursion and performed in vitro with mechanical testing simulators [9, 20–22]. The CIDP has been demonstrated to increase in sagittal plane ROM; however, we do not know CIDP responses in the lower cervical IVDs *during* chin to neck flexion, chin to sternum flexion, occiput to neck extension, occiput to upper back extension, protraction, or retraction [4, 7, 9, 10, 12, 15–18, 20–22].

Most studies examined differences between pre- and post-operative CIDP, usually C4-5 and C6-7, following surgical interventions such as arthroplasty and/or fusions of two or more segments [4, 6, 10, 12, 15–17].

Of particular note is the paucity of CIDP assessment in vivo or in situ, where only one study examined CIDP and volume capacity in healthy versus degenerated IVDs in 19 patients under anesthesia prior to surgical intervention [23, 24]. Another weakness in CIDP current knowledge is the lack of pressure response at the C5-6 IVD level, typically the location of surgical fixation in many of the identified studies [4, 6, 12, 15–17]. This gap in CIDP responses at C5-6 represents significant challenges for conservative care as it is the most common level of lower cervical spine IVD pathology [25].

Conservative treatment approaches use sagittal plane postures for manual therapy interventions, as well as exercise prescription to address cervical IVD pathologies. Selected authors addressed effects of cervical traction in cadaveric specimens, revealing decreased CIDP corresponding with distraction forces [19, 26]. A singular in situ study investigated prone manual cervical distraction on nine cadaveric specimens and reported lower CIDP at the C4 to T1 IVD levels during the technique [13]. Of particular interest is cervical retraction, which is a necessary movement to maximally flex the upper cervical spine segments and is a core component of many treatment strategies to address postural dysfunction and discogenic pain [9, 21, 22, 27, 28].

Despite widespread use of cervical retraction to treat cervical IVD pathology, objective information regarding effects of this posture on CIDP are unknown and efficacy is determined by empirical evidence alone [21, 22]. Understanding the effects of sagittal plane end-range postures on CIDP could help inform development of future clinical studies on methods of identification, prevention, and management of cervical IVD conditions.

The purpose of this study was to investigate in human cadaveric specimens the CIDP differences between six sagittal plane end-range cervical postures and traction in neutral, the correlation between CIDP and cervical segmental range of motion (ROM), and the measurement reliability.

Methods

The investigation aimed to establish in human un-embalmed cadaveric specimens (1) CIDP differences between neutral posture with cervical traction and six sagittal plane end-range cervical postures including chin to neck, chin to sternum, protraction with flexion, occiput to neck, occiput to thorax, and retraction with extension (Fig. 1); (2) CIDP differences between each of the lower cervical IVD levels; (3) the correlation between CIDP and cervical segmental ROM, and (4) the CIDP measurements intra-rater reliability during end-range cervical postures in the sagittal plane in supine.

Research design

Experimental test-retest reliability study and pre-test, post-test repeated measures design.

Specimens and sample size

A convenience sampling of ten un-embalmed human cadavers was acquired through the département d'anatomie de l'Université du Québec à Trois-Rivières and the study protocol was approved by the Ethics Subcommittee for use of cadaveric material (SCELERA-21-06). Inclusion criteria consisted of adult, willed body donor, un-embalmed cadavers. Exclusion criteria were any known cervical spine surgery history, cervical spine trauma, cervical ROM limitations greater than 50% [29], cervical spine cancer or significant systemic conditions impairing cervical joint mobility, and radiographic evidence of advanced degenerative cervical spine disease. Criteria were selected to ensure viability

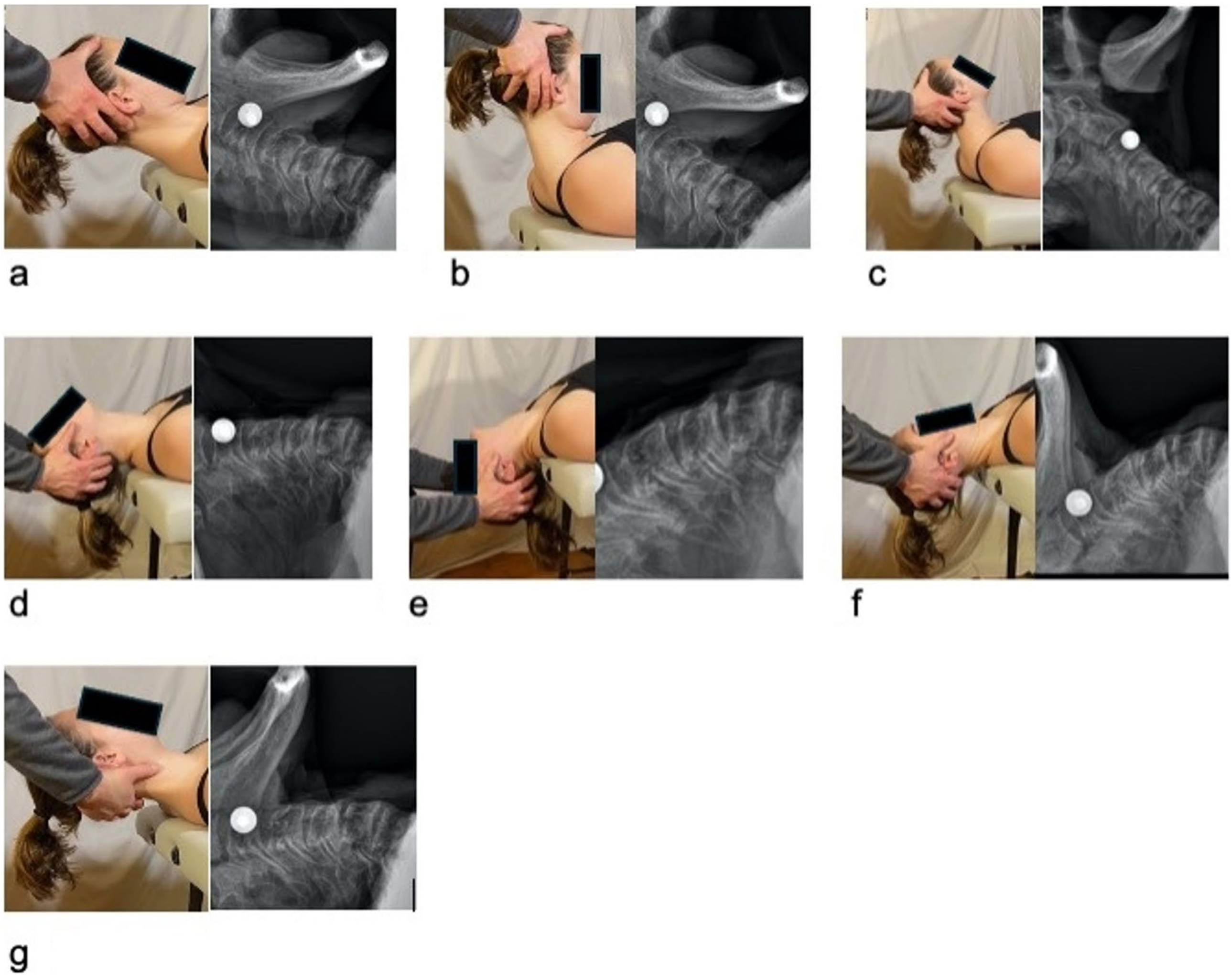

Fig. 1 Supine end-range postures with radiographs. (**a**) Flexion – chin to neck, (**b**) Flexion – chin to sternum, (**c**) Cervical protraction with flexion, (**d**) Extension – occiput to neck, (**e**) Extension – occiput to upper thoracic spine, (**f**) Cervical retraction with extension, (**g**) Neutral with cervical traction

of all lower cervical IVDs and consistency with previous CIDP studies to promote greater applicability of findings. Two cadavers were excluded secondary to radiographic findings including severe degenerative changes and complete fusion of the C4-5 vertebral bodies. A third specimen sustained a C6-7 IVD rupture during end-range posture radiographs and was unable to maintain pressurization for further testing. Four female and three male cadaveric specimens with a mean age of 80.6±7.2 years (range 70–89), mean height of 1.6±0.1 m, mean weight of 57.9±11.8 kg, and mean body mass index of 21.6±2.9 were included in the study.

Lab environment

The cadaveric specimens were wrapped in saline-soaked material, bagged and frozen in storage until needed at −18 degrees Celsius. Each cadaveric specimen was thawed for 24 h at 14–16 degrees Celsius prior to testing. The tissue was frequently irrigated with saline during preparation and testing to preserve tissue moisture.

Specimen preparation

Demographic information including sex, age, height, weight, body mass index, and cause of death was recorded for all specimens during intake of willed body donors by the département d'anatomie de l'Université du Québec à Trois-Rivières. Investigator-1, a physical therapist with 23 years of clinical experience and advanced national certification in musculoskeletal physical therapy, performed and reviewed lateral radiographs to rule out cervical spine exclusion criteria [6, 7, 10–14, 16–19, 26, 30]. After radiographic verification, an anterior midline dissection was performed to expose the anterior surfaces of the cervical spine to allow visualization of the C4 to C7 IVDs [1, 5, 11, 12].

A metal marker of known size was inserted on the lateral aspect of the C3 vertebral body and verified by lateral radiograph (Fig. 2A). This marker assisted with IVD level identification and measurement scaling.

The cadaver was positioned and secured by straps with the T2 spinous process at the edge of the table and the head supported on a portable instrument tray. Investigator-1 positioned cadavers in each sagittal plane end-range posture including neutral without traction, chin to neck (Fig. 2B), chin to sternum, protraction with flexion, occiput to neck, occiput to thorax, and retraction with extension while investigator-2 obtained lateral radiographs using standardized imaging parameters [21, 27, 31]. Radiographic images were saved and later measured segmental ROM for each IVD segment in all seven postures.

Following ROM assessment, 1 and ½ inch 18-gauge needles were inserted into the C4-5, C5-6, and C6-7 IVDs [12–15]. Each segment IVD space was identified counting caudally from the previously marked C3 vertebral body and visually verified for bulging of the IVD during cervical flexion, extension, and lateral flexion movements. Needles were inserted into IVDs and immediately removed and flushed to eliminate annulus material clogging. Careful reinsertion of the needle into initial entrance holes was necessary to prevent IVD pressurization loss and achieved by magnified visualization during withdrawal. Verification of needle placement within IVDs was achieved by filling the Luer lock hub of a needle with water to create a meniscus. The meniscus was observed for movement during cervical ROM, demonstrating bulging during flexion, retraction during extension, or no response with incorrect placement. Needle placement within IVDs was verified by lateral radiographs (Fig. 2C) with repositioning and subsequent re-verification as necessary [1, 4–7, 11, 12, 16]. Sutures were placed within the anterior vertebral ligament to maintain needle position. Cotton patches and tissue glue were placed and cured for five minutes to re-enforce needle placement.

Instrumentation setup and calibration

The CIDP was measured at the C4-5, C5-6, and C6-7 IVD levels simultaneously with three FISO FPI-HR-2 fiberoptic pressure sensors with range ±300 mm Hg and accuracy ±1 mm Hg (FISO Technologies Inc., Québec, QC, Canada) [7, 10, 12, 15, 16, 18]. Pressure chamber systems were constructed from a 4-way stopcock with swivel male Luer lock, an injection adapter with MLL 1 and 7/16 inches, a 17-inch Appx 0.48 mL smallbore ext set with MicroClave clear clamp Luer lock for direct attachment to the IVD needle, and a 10 mL syringe filled with water (Fig. 3). All pressure chamber systems components were pre-loaded with water to eliminate air. Fiberoptic sensors labeled with corresponding IVD levels were introduced by 18-gauge needles into the injection adapter chamber. Needles were retracted once sensors were in the chambers. Pressure system chambers were visually inspected to ensure no air present prior to connecting 17-inch tubing to IVD needles. Preloading IVDs was accomplished introducing up to 0.1 mL water prior to testing and as needed to maintain pressure responses during repeated trials [14, 23].

The OptiTrack 3D motion analysis system (NaturalPoint, Inc., Corvallis, OR, USA) ensured consistency performing repeated sagittal plane end-range postures during Phases 1 and 2. Comparison of OptiTrack to other three-dimensional motion analysis systems demonstrated excellent proficiency with linear measurement accuracy and reliability [32–34]. Data collection occurred in a designated laboratory area with fixed global axes and camera placements for three-dimensional visualization of specimen movements by investigator-1. Static

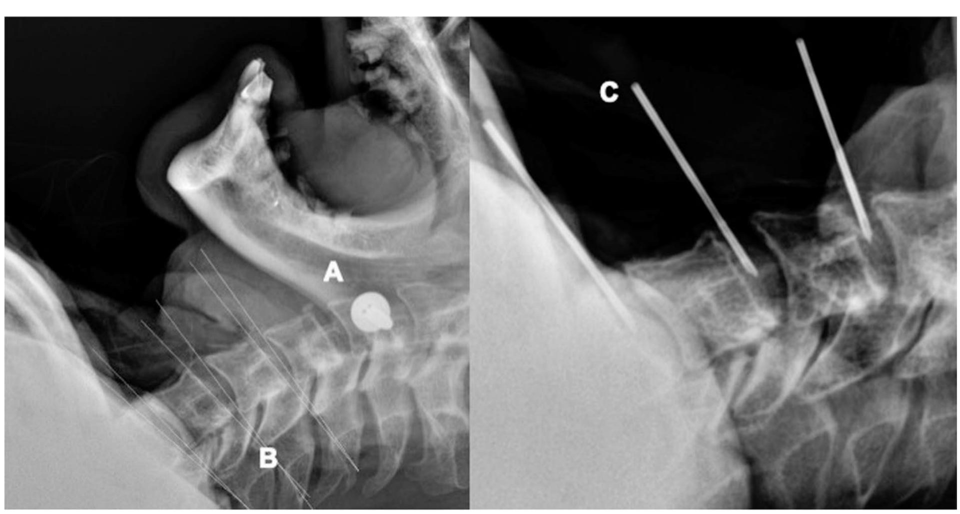

Fig. 2 Lateral radiograph detailing angular ROM measurements and intradiscal needle placement. (A) radiographic marker placed in C3 vertebral body, (B) C5-6 IVD disc space angle during chin to neck posture, (C) C5-6 IVD needle placement verification

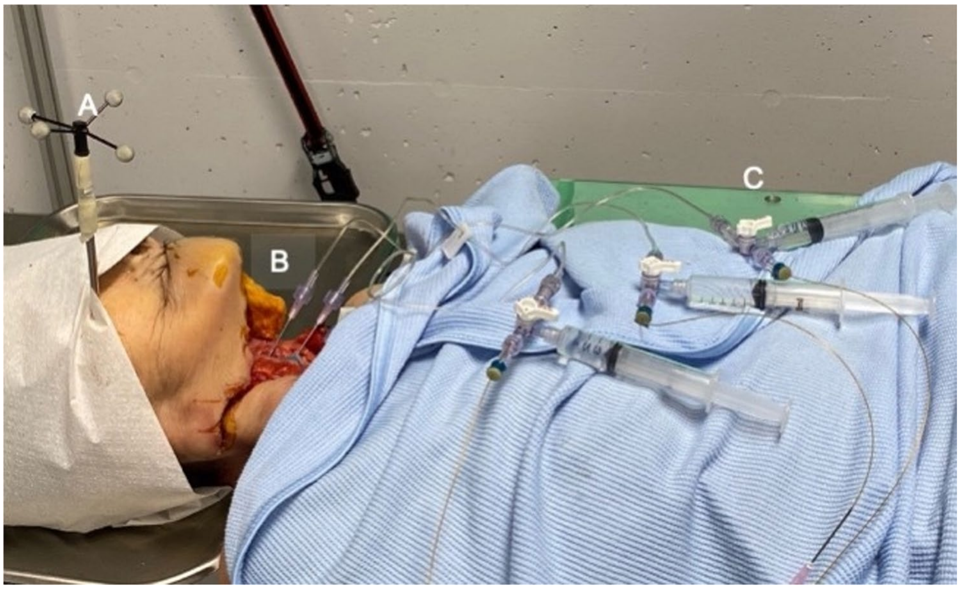

Fig. 3 Cadaveric specimen in supine at completion of preparatory procedures. (A) OptiTrak marker cluster; (B) three 18-gauge needles inserted in C4-5, C5-6, and C6-7 IVDs; (C) three FISO fiberoptic pressure sensors in closed pressure chamber systems

and dynamic system calibration was performed prior to collecting CIDP measurements. A custom-made four cluster marker with 6-inch post was mounted into a pre-drilled location in the zygomatic bone (Fig. 3) [35]. The OptiTrack provided real-time tri-planar motion feedback to investigator-1, ensuring isolated sagittal plane movements. Starting neutral position was defined as mid-range between cervical flexion and extension and specimens were positioned with an adjustable procedure table prior to each trial. Investigator-1 clinical experience determined end-range during the first trial, and the OptiTrak coordinates of this initial end-range position were noted as a reference for investigator-1 during subsequent trials. Each trial consisted of five cycles that began in neutral, proceeded to clinical end-range and held for three seconds, returned to neutral position and held for five seconds.

Data collection

Phase 1: CIDP measurements reliability

Measurement order for each end-range posture was randomly assigned using an analog randomization technique. Each end-range posture trial was started with the specimen head in neutral position determined by the mid-range between cervical flexion and extension [4, 30]. Five trials of each sagittal plane end-range posture were performed for the first two specimens with mean CIDP calculated [4, 6, 7, 10, 15, 16]. This process was repeated three times and reliability calculated for the three measurements. Two investigators performed the data collection. Investigator-1 performed all cervical spine sagittal plane end-range postures using an empirical approach of pressure used in clinical practice (Fig. 4). Investigator-1 was blinded to all CIDP measurements throughout testing. Investigator-2 recorded all CIDP readings for each cervical IVD level (C4-5; C5-6 and C6-7) and monitored results for IVD pressure loss indications requiring system reloading or needle flushing. The same order of measurements was used on all three rounds of reliability testing. Successive testing rounds were repeated 30 min after previous data collection completion.

Phase 2: CIPD measurements

The end-range posture testing order was randomly assigned for each specimen by investigator-2 as previously reported. Neutral head position was obtained as previously discussed prior to each trial of end-range postures. Investigator-1 performed five repetitions of each cervical spine sagittal plane end-range posture with investigator-2 monitoring pressure responses of specimens during testing [4, 6, 7, 10, 15, 16], Investigator-1 remained blinded to CIDP measurements obtained during neutral and end-range postures while Investigator-2 recorded CIDP measurements for each end-range posture during the five trials.

Phase 3: CIDP and segmental cervical ROM correlation

Segmental cervical spine angular ROM was measured at C4-5, C5-6, and C6-7 for all end-range postures for each cadaveric specimen from digital lateral radiograph images. Measurements were performed using open-source software program ImageJ (Wayne Rasband and contributors, National Institutes of Health, Bethesda, Maryland, USA). Segmental ROM for IVD levels were

Fig. 4 Specimen in supine during occiput to neck end-range posture. A. OptiTrack 3D motion reference, B. FISO fiberoptic sensor input device for CIDP recording

measured by anterior disc space angles at neutral and each end-range posture. Tangential lines were drawn at inferior endplates of superior vertebrae and superior endplates of inferior vertebrae. Angles created by tangential lines for each IVD segment were measured for all specimens at each end-range posture and neutral cervical spine using the modified Cobb angle method to determine anterior disc space angle [36, 37]. Intra-rater reliability was determined for investigator-1 by three segmental ROM measurements at C4-5, C5-6, and C6-7 from two specimens completed over three separate days. Segmental ROM and CIDP measurements for each end-range posture were correlated to identify potential associations.

Data analysis

Descriptive statistics including mean, median, standard deviation, minimum and maximum values for specimen demographics including age, gender, height, weight, and body mass index were calculated and reported above.

Inferential statistics were calculated using the IBM SPSS Statistics, Version 27 (IBM Corporation, New Orchard Road, Armonk, NY 10504). Intraclass correlation coefficient [ICC (3,5)] was measured using mean CIDP changes from the five consecutive measurements of each end-range posture at each of the three cervical IVD levels. The CIDP data did not meet assumptions for parametric statistics for normal distribution, therefore multiple Friedman two-way ANOVAs were used to evaluate main effects in CIDP differences during various end-range cervical postures for C4-5, C5-6 and C6-7. Post hoc analyses were performed with Dunn's pairwise comparisons to assess for significant differences in CIDP between each end-range posture for each cervical IVD level. Alpha level was adjusted using Bonferroni correction to <0.002 for multiple comparisons. The effect size of end-range postures on CIDP for each IVD level was calculated by Kendall's W. Intra-rater reliability of segmental cervical spine angular ROM measurements was performed by ICC (3,1). Spearman rank correlation was performed on CIDP and cervical ROM by IVD level for each end-range posture to identify any association between measures.

Results

Descriptive statistics of CIDP for all cervical end-range postures at each IVD level are presented in Table 1. Additional File 1 includes strip plots of CIDP at all IVDs for each specimen across six end-range postures and traction to assist with visualization of variability of pressure responses.

Phase 1 of our study sought to establish the intra-rater reliability of CIDP measurements and resulted in an ICC (3,5) greater than 0.92 (95% confidence interval = 0.86–0.95.86.95).

Table 1 End-range CIDP (mm Hg) means, standard deviations, median, and interquartile range at each IVD level

Posture	Statistics	C4-5	C5-6	C6-7
Chin to Neck	Mean±SD	25.59±44.49	40.62±87.39	9.71±26.58
	Median	3.23	0.26	0.25
	IQR	52.23	95.76	4.81
Chin to Sternum	Mean±SD	104.07±245.61	52.80±69.63	32.55±47.85
	Median	7.77	22.18	15.16
	IQR	26.78	137.08	32.38
Protraction-Flexion	Mean±SD	61.84±249.68	−69.84±130.48	−30.25±71.28
	Median	−7.16	−17.38	−0.61
	IQR	22.80	83.69	34.61
Occiput to Neck	Mean±SD	28.65±37.48	−15.00±100.02	−1.73±8.84
	Median	4.35	−0.50	−0.33
	IQR	78.51	42.10	10.91
Occiput to Thorax	Mean±SD	8.04±75.59	−98.99±132.64	−3.40±32.00
	Median	−0.55	−21.50	−5.99
	IQR	26.14	279.74	36.99
Retraction-Extension	Mean±SD	26.01±73.78	−103.45±129.90	−16.85±36.07
	Median	9.50	−13.65	−4.97
	IQR	109.47	236.07	67.77
Traction	Mean±SD	−51.13±68.41	−101.45±168.12	−45.69±60.61
	Median	−31.40	−9.12	−31.99
	IQR	86.98	238.68	64.05

Positive numbers indicate increased CIDP while negative numbers indicate decreased CIDP

CIDP Cervical intradiscal pressure, *IVD* intervertebral disc, *IQR* interquartile range

Table 2 End-range cervical angular ROM (degrees) means, standard deviations, range, CIDP correlation and significance per IVD

Posture	Statistics	C4-5	C5-6	C6-7
Neutral Posture	Mean±SD	11.44±2.13	10.17±3.23	5.59±3.96
	Range	7.93 to 14.68	4.71 to 13.32	2.32 to 14.04
Mean Differences from Neutral Posture				
Chin to Neck	Mean±SD	−4.37±4.98	−5.48±4.24	0.33±3.38
	Range	−9.37 to 4.77	−9.56 to 2.20	−4.01 to 5.13
	Spearman	**r_s=0.79**, ***p*=.04**	r_s=0.18, *p*=.70	r_s=0.07, *p*=.88
Chin to Sternum	Mean±SD	−6.84±2.92	−5.85±2.57	−1.78±4.80
	Range	−11.56 to −2.49	−9.09 to −2.04	−10.11 to 2.08
	Spearman	r_s=−0.32, *p*=.48	r_s=−0.11, *p*=.82	r_s=−0.36, *p*=.43
Protraction-Flexion	Mean±SD	−6.65±2.96	−6.58±2.36	−1.89±3.43
	Range	−11.58 to −3.86	−9.93 to −4.12	−9.04 to 1.89
	Spearman	r_s=0.18, *p*=.70	r_s=−0.14, *p*=.76	**r_s=0.82**, ***p*=.02**
Occiput to Neck	Mean±SD	−0.05±4.01	0.29±5.91	2.04±3.76
	Range	−7.61 to 3.96	−5.98 to 9.13	−3.51 to 8.94
	Spearman	r_s=−0.21, *p*=.65	r_s=0.29, *p*=.54	r_s=0.50, *p*=.25
Occiput to Thorax	Mean±SD	3.94±4.35	2.03±5.43	3.73±4.54
	Range	−1.86 to 10.92	−2.58 to 11.34	−3.03 to 9.74
	Spearman	r_s=−0.25, *p*=.59	**r_s=0.79**, ***p*=.04**	r_s=0.43, *p*=.34
Retraction-Extension	Mean±SD	2.12±3.82	1.50±6.86	4.16±4.64
	Range	−2.07 to 8.77	−6.71 to 11.35	−4.18 to 9.68
	Spearman	r_s=0.14, *p*=.76	r_s=0.50, *p*=.25	r_s=0.71, *p*=.07

Bold indicates significant values; values represent disc space angle between adjacent vertebral endplates; negative numbers represent decreased angles relative to neutral posture indicating flexion; positive numbers represent increased angles relative to neutral posture indicating extension

CIDP cervical intradiscal pressure, *IVD* intervertebral disc, *ROM* range of motion, r_s Spearman rank correlation

Phase 2 explored the effect of end-range sagittal plane postures on CIDP relevant to the C4-5, C5-6, and C6-7 IVDs using Friedman ANOVAs with results indicating that end-range postures effected changes in CIDP for each IVD level. Pairwise comparisons showed significant CIDP increases from C4-5 traction to chin to sternum (*p* =.011); C5-6 traction to chin to sternum (*p* =.007); C5-6 chin to sternum to retraction-extension (*p* =.027); C5-6 chin to sternum to protraction flexion (*p* =.042); C6-7 chin to sternum to traction (*p* =.018); and C6-7 chin to sternum to retraction-extension (*p* =.027). When considering prevalence of increased CIDP across each end-range posture at all IVD levels, CIDP increased 71% of the time during chin to neck, 100% during chin to sternum, 38% during protraction-flexion, 48% during occiput to neck, 33% during occiput to thorax, 38% during retraction-extension, and 0% during traction. Moderate effect sizes of end-range postures on CIDP at each IVD level were determined by Kendall's Coefficient of Concordance with 0.31 at C4-5, 0.46 at C5-6, and 0.36 at C6-7.

In Phase 3, the intra-rater reliability of radiographic angular measures of segmental cervical spine ROM resulted in an ICC(3,1) greater than 0.96 (95% confidence interval = 0.94–0.98.94.98). Although ROM data did meet assumptions for normality, CIDP did not display a normal distribution, thus the Spearman rank correlation was calculated. Strong correlations between end-range posture and CIDP were identified at C4-5 chin to neck, r_S=0.79, *p* =.04, where cervical flexion and CIDP increased; C5-6 occiput to thorax, r_S=0.79, *p* =.04, where cervical flexion and CIDP decreased; and C6-7 protraction flexion, r_S=0.82, *p* =.02, where cervical flexion increased and CIDP decreased. Expected positive and negative correlations were not found in many of the end-range conditions, including C6-7 protraction flexion. These results may be attributed to outliers created by the wide CIDP variations observed within and between specimens. Segmental cervical spine angular ROM and correlation details are presented in Table 2.

Discussion

Our study was the first to evaluate effects of supine sagittal plane end-range cervical postures including protraction and retraction on CIDP. Results indicated that CIDP was highly variable within and between cadaveric specimens. Variability in CIDP may occur as result of many factors including specimen age, gender, vertebral architecture, gravitational forces, and degenerative changes to the IVD segments all potentially leading to alternations in segmental ROM, disc height, and lordotic angle. Additional studies have explored the impact of IVD degeneration on segmental range of motion and CIDP, suggesting that degeneration ultimately decreases segmental range of motion and CIDP through biomechanical alterations that become progressive in nature and accelerate further degeneration. Considering the contributions of IVD degeneration to decreased motion and pliability of the cervical disc segments leads to the question of whether overall IVD degeneration is the determinant of highly variable CIDP responses. This variability is consistent with previous studies demonstrating wide ranging CIDP values from 700 mm Hg in cervical extension [4] to 7978 mm Hg during cervical flexion and extension movements [12] with greater unpredictability with concomitant cervical IVD degeneration. The CIDP measurements in our study also ranged widely from – 188 to 660 mm Hg at C4-5, –427 to 216 mm Hg at C5-6, and – 189 to 138 mm Hg at C6-7. Several factors may be contributing to overall lower CIDP measurements recorded in our study compared to those reported in previous investigations. First, the mean age of our specimens was 80.6 years, increasing the likelihood of degenerative cervical IVDs. Kambin et al., [23] Menkowitz et al. [14] and Hattori et al. [24] demonstrated decreased CIDP in subjects with IVD degeneration. Hattori et al. [24] detailed the unpredictability of peak CIDP during varied cervical ROM, even citing flexion causing negative CIDP. Instrumentation for measuring CIDP varies widely across the limited studies examining cervical IVDs. Most other studies included some degree of axial compression and vertical postures, which resulted in increased CIDP [4, 6, 7, 11, 16–18], whereas our study was performed in supine without axial loading to simulate clinical conditions.

Our results demonstrated highest CIDP during flexion movements and decreased CIDP during extension and was consistent with the findings of Pospiech et al. [7] and Wu et al. [19] Additionally, Pospiech et al. [7] identified that proximal IVDs, C3-4 in their study, yielded higher CIDP both in flexion and extension ROM, which was reflected in our study with C4-5 tending to display higher CIDP in all end-range sagittal postures than C5-6 and C6-7 [7]. Further support of increased CIDP during flexion, decreased CIDP during extension, and decreasing CIDP in the caudal direction of IVD segments was reported by Liebsch and Wilke [38] in their systematic review and meta-analysis of whole spine intradiscal pressures.

Several cervical postures demonstrated meaningful consistency for CIDP changes. Differences between cervical traction with decreased CIDP and chin to sternum with increased CIDP were statistically significant in all cadaveric specimens at C4-5, C5-6 and C6-7 reflecting the findings of many prior studies. Chin to sternum versus retraction-extension at C5-6 and C6-7 were also statistically significant, while C5-6 also reached significance for chin to sternum compared to protraction-flexion. The findings for Cervical traction CIDP reductions were consistent with Gudavalli et al., [13] Li et al., [26] and Wu et al., [19] while increased CIDP in cervical flexion posture was supported by the findings of Pospiech et al. [7] and Wu et al. [19] Our findings differed from the results of Hattori et al., [28] Eck et al., [4] and Park et al., [6] who reported cervical extension movements increased CIDP greater than cervical flexion. Thus, uncertainty remains about sagittal plane direction impact on CIDP.

Although not statistically significant, a greater percentage of specimens experienced decreased CIDP in protraction (57% at C4-5, 71% at C5-6, and 57% at C6-7), retraction (71% at C5-6 and C6-7), occiput to neck (57% at C5-6 and 57% at C6-7) and occiput to thorax (57% at C4-5, 71% at C5-6 and C6-7), while CIDP increased in a majority of specimens during chin to neck (86% at C4-5, 71% at C5-6, and 57% at C6-7). The exception to the rule was C4-5, which demonstrated increased CIDP during occiput to neck (57%) and retraction (57%). This finding at C4-5 is consistent with higher pressures in proximal IVDs as noted by Pospiech et al. [7] and may represent an important distinction in CIDP responses at the transition between upper and lower cervical spine.

Clinically, our findings showed large CIDP variability in response to sagittal plane end-range postures. Tendencies for CIDP to decrease during extension movements were supported at C5-6 and C6-7, while C4-5 remained less predictable in CIDP responses. Full cervical flexion attained through chin to sternum motion consistently increased CIDP. In contrast, cervical traction decreased CIDP regardless of IVD level. Variable CIDP responses at C4-5 and decreases at C5-6 and C6-7 during extension and retraction postures may present a distinction between the transition of lower to cervical spine and may warrant further investigation. Despite protracted cervical postures requiring end-range flexion of the lower cervical IVD segments, CIDP tended to decrease at all IVD levels during end-range protraction despite similar segmental ROM to chin to sternum postures. This finding was unexpected due to the similar biomechanical properties of the movements and would benefit from further exploration.

Several limitations exist that affect the application of our results to clinical practice. Our convenience sample of cadaveric specimens were of advanced age with cervical IVD degeneration which tends to decrease CIDP. The small sample size is a limitation for the statistical power of the study; however, moderate effect sizes were demonstrated with respect to the significant end-range postures on CIDP. As with all cadaveric studies, direct correlation with live patient care is not possible due to absent contributions of IVD fluid mechanics, active muscle contractions, and neurophysiologic control, which all potentially increase CIDP. Previous studies have demonstrated simulated muscle contractions and axial loading do increase CIDP significantly. Specimens are limited in physiological responses to tissue loading and testing and ignores the contribution of contractile elements on CIDP and ROM.

Our study measured CIDP with all specimens in the supine position and was consistent with procedures in Hattori et al.'s [24] in vivo study of cervical IVDs prior to surgical intervention as well as the two traction studies by Gudavalli et al. [13] and Wu et al. [19] The focus on supine postures was driven by similarity with clinical assessment and treatment as well as feasibility, understanding that loaded postures were the next line of inquiry. Future research directions should evaluate effects of static and dynamic loading end-range postures on CIDP in weight bearing positions to simulate the effects of head weight, muscle forces, and gravitational forces. Axial rotation and lateral bending end-range postures may also be included to cover all components of cervical mobility. Formal IVD degeneration grading by radiograph or magnetic resonance imaging (MRI) should be included in future studies to identify potential correlations on CIDP responses. As addressed in limitations, larger sample sizes comprised of different ages would help reduce the effects of degeneration on IVD segments and provide greater statistical power. Additional areas to study would be the correlation of IVD morphologic measurements such as anterior disc height to CIDP and exploring MRI and diagnostic ultrasound imaging capabilities as a non-invasive assessment of IVD responses to end-range postures in vivo.

Clinical translational directions

This study identified cervical end-range postures that demonstrated increases and decreases in CIDP, with some very consistent and others showing strong tendencies. With the development and validation of non-invasive measures of CIDP or IVD volume, clinical pilot studies assessing efficacy of end-range postures on discogenic pain may be possible. Disc hydration and dehydration management approaches have been suggested for lumbar discogenic pain; although, cervical IVDs are morphologically different, perhaps end-range postures could be used to similar effect. In vivo responses may be compared to in situ for correlation of changes in disc height and lordotic angle during sustained or repeated end-range postures while also considering reported pain responses.

Conclusion

This is the first research study to examine CIDP during supine sagittal plane end-range postures, including retraction and protraction, and improves understanding CIDP variability from a cadaveric context, which may inform future clinical investigations. Our findings demonstrated decreased CIDP at C4-5, C5-6 and C6-7 during cervical traction while CIDP increased during chin to sternum postures across all IVD levels. Supine cervical IVD responses in magnitude and direction of CIDP values during chin to neck, protraction, occiput to neck, occiput to thorax, and retraction. Increased CIDP tended to occur during chin to neck postures and then demonstrated decreasing trends during protraction, occiput to neck, occiput to thorax and retraction.

Abbreviations

CIDP	Cervical intradiscal pressure
IVD(s)	Intervertebral disc(s)
ROM	Range of motion

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

The roles of each author are detailed below according to the Contributor Roles Taxonomy (CRediT).Marc T. Crawford – conceptualization, data and curation, formal analysis, investigation, methodology, validation, visualization, writing – original draft, writing – review and editing; Jean-Michel Brismée – conceptualization, formal analysis, methodology, project administration, supervision, writing – review and editing; Marc-Olivier St-Pierre – investigation, methodology; Nicholas Bellot – investigation; Phillip S. Sizer – conceptualization, methodology, supervision, writing – review and editing; Stéphane Sobczak – conceptualization, investigation, methodology, project administration, resources, supervision, writing – review and editing.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study protocol was approved by research standards of the département d'anatomie à l'Université du Québec à Trois-Rivières Ethics Subcommittee for the use of cadaveric material (SCELERA-21-06). Consent for participation in the body donation program for teaching and research at the Université du Québec à Trois-Rivières was provided by all donors or their family members in the presence of two witnesses according to the government of Québec Ministère de la Santé et des Services sociaux guidelines.

Consent for publication
Written consent for publication was obtained from the individuals photographed in Figs. 1 and 4.

Competing interests
The authors declare no competing interests.

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