Al-Habib *et al.*
Journal of Orthopaedic Surgery and Research (2025) 20:437
https://doi.org/10.1186/s13018-025-05851-8

Journal of Orthopaedic Surgery and Research

RESEARCH

Open Access

Targeted anterior expansion of the cervical facet joints achieves indirect foraminal decompression and reduces spondylolisthesis via a posterior approach: a cadaveric study

Amro Al-Habib[1*], Sami AlEissa[2] and Ayman Al-Jazaeri[3]

Abstract

Background In this cadaveric study, we aimed to assess the effects of distraction at the anterior end of the cervical facet joints (CFJ), achieved via a posterior cervical approach (PCA), on intervertebral neural foraminal height (IVFH) and segmental alignment. A novel cervical expandable facet implant (CeLFI) was used to facilitate anterior expansion within the CFJ.

Methods This study was conducted in three time periods (2018, 2019, and 2024). The CeLFI was primarily placed at the CSPL levels or at the non-fused C3–7 levels if no CSPL was present. Pre- and post-implantation outcomes were assessed using cervical spine radiography and computed tomography (CT) scan. Changes in facet joint space (FJS) height, IVFH, interspinous distance (ISD), intervertebral disc height (IVDH), and cervical alignment were assessed.

Results CeLFI insertion ($n = 12$) resulted in an increase in the mean IVFH (+1.5 mm left; +2 mm right, both $p < 0.001$), FJS height (+2.41 mm left; 2.53 mm right, both $p < 0.001$), ISD (+2.83 mm, $p = 0.003$), and posterior IVDH (+1.16 mm $p = 0.001$). In the cadavers with CSPL ($n = 9$), a segmental reduction was observed, which remained stable in flexion–extension radiographs. Two cadavers also showed unbuckling of the posterior interspinous ligaments on post-insertion CT. No significant changes in overall cervical alignment were observed after CeLFI insertion.

Conclusions Indirect cervical intervertebral foraminal decompression and reduction of cervical segmental spondylolisthesis were achieved via a PCA with targeted distraction at the anterior end of the CFJ. This novel concept is promising but requires further clinical studies to evaluate its benefit for patients with degenerative cervical spine disease.

Keywords Cervical expandable facet implant, Cervical foramen expansion, Cervical lordosis, Cervical spondylolisthesis, Cervical stenosis, Radiculopathy

*Correspondence:
Amro Al-Habib
amro.alhabib@gmail.com; aalhabib@ksu.edu.sa
[1] Division of Neurosurgery, Department of Surgery, College of Medicine, King Saud University and King Saud University Medical City, Riyadh, Saudi Arabia
[2] Department of Orthopedics, King Abdulaziz Medical City and King Saud Bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia
[3] Department of Surgery, College of Medicine, King Saud University and King Saud University Medical City, Riyadh, Saudi Arabia

Background

Cervical spondylosis (CS) is a degenerative disease characterized by changes affecting the intervertebral discs, leading to buckling of the intervertebral ligaments and facet arthropathy [1, 2]. These changes contribute to intervertebral foraminal narrowing and spinal canal stenosis, resulting in cervical radiculopathy and cervical spondylotic myelopathy (CSM) [1–4]. CSM, affecting 15% of patients with CS, is the most common non-traumatic cause of myelopathy in individuals over 55 years old, with a hospitalization rate of 4.04 per 100,000 people per year and an increasing rate of surgical intervention [1–3, 5].

In advanced cases, cervical spondylolisthesis (CSPL) may develop, particularly at levels C3–4 and C4–5 [6–8]. CSPL accounts for approximately 12% of CSM cases [6] and contributes to its clinical burden [1, 8]. Treatment options for patients with neurological deficits or unsuccessful conservative therapy include anterior, posterior, or combined surgical approaches [3, 9].

Posterior cervical approaches (PCAs) have several advantages and limitations in treating CS. While PCAs are preferred to reduce complications associated with extended anterior cervical approaches (e.g., dysphagia and pseudoarthrosis), anterior approaches are favored for their effectiveness in restoring intervertebral foraminal height (IVFH) and spinal alignment [10, 11]. Furthermore, PCA is limited in its ability to provide indirect decompression of the intervertebral foramina. Surgery for CSPL using a PCA often involves multiple levels or a combination of anterior and posterior approaches [12]. Although recently introduced cervical facet spacers (CFS), placed via a PCA, have been shown to improve symptoms associated with cervical radiculopathy and myelopathy [6, 13–16], they lack a mechanism to reduce CSPL and may further destabilize the cervical facet joint (CFJ). Consequently, some studies on CFS have excluded patients with CSPL due to concerns that CFS may exacerbate spondylolisthesis and kyphosis [9].

To address these limitations of PCA, this study investigated the effects of targeted expansion in the anterior CFJ using a novel cervical expandable facet implant (CeLFI). We hypothesized that this anterior expansion mechanism could reduce CSPL and provide indirect intervertebral foraminal decompression.

Methods

Study design and setting

This cadaveric study was performed by the same investigators at a university hospital during three periods (2018, 2019, and 2024) based on cadaver availability. The cadavers were received frozen at the anatomy department and were prepared following a defrosting procedure.

Study population and eligibility criteria

Cadavers with an intact cervical spine and without fusion on initial computed tomography (CT) were included using convenient sampling.

Study procedures: Index level

The index level was the segment with CSPL (Fig. 1a), representing an advanced form of segmental degeneration and instability. The CSPL level was defined as the anterior translation of the rostral vertebra relative to the adjacent vertebra on the dynamic lateral radiograph (manual manipulation of the cervical spine) [6, 7]. For cadavers without CSPL, a corresponding non-fused cervical spine level was selected, demonstrating segmental motion and widening of the interspinous space on the manual dynamic radiograph. CSPL was not induced to avoid potential damage to the CFJ and interference with CeLFI insertion.

CeLFI

CeLFI consists of a low-profile expandable facet cage that expands at the anterior end of the FJS. The three-dimensionally-printed titanium implant features 8-mm upper and lower plates enclosing a thick central wedge (Fig. 2) with a 2-cm closed height. Advancing the wedge forward increases the anterior end height to 3 or 4 mm while maintaining the original posterior height (Fig. 1b). A wider cylindrical proximal end protrudes from the posterior surface of the CFJ (Fig. 2), reducing the risk of anterior implant migration after placement, while the wedge prevents posterior migration. The proximal end is designed to interlock with a deployment device for a firm, stable grip, with implant expansion achieved by pushing the internal wedge forward once positioned in the facet.

Surgical procedure

Cadavers were positioned prone, with the head resting on a ring and the neck in a neutral position. The posterior surface of the cervical spine was exposed from C2 to C7. The FJS was accessed through an incision in the posterior aspect of the CFJ capsule and progressively dilated using 1-mm and 2-mm dilators. All dilators were 10 mm wide and long, featuring a tapered blunt anterior end and a proximal stopper to prevent overshooting beyond the FJS. After CeLFI insertion, lateral mass screws (LMS) were placed at the same level to assess potential interference with screw placement (Fig. 1c–e).

Study variables, radiologic evaluation, and outcome assessment

Following CeLFI insertion, radiography was performed in flexed and extended positions (manual manipulation) to evaluate CeLFI stability and maintenance of segmental reduction of CSPL. The following variables were assessed using CT (1.2-mm slices; CereTom Mobile CT, Neurologica Corp., Danvers, MA, USA) before and after CeLFI insertion: IVFH (sagittal CT), intervertebral disc height

Fig. 1 Lateral cervical spine X-ray of Cadaver-2 showing C3–4 spondylolisthesis Reduction of the C3–4 spondylolisthesis was achieved by inserting a cervical expandable facet implant (CeLFI) device into the C3–4 facet space bilaterally (**a**, **b**). Manual flexion (**c**) and extension (**d**) of the cadaver's cervical spine demonstrated a maintained reduction of C3–4 spondylolisthesis and stability of the CeLFI device. Lateral mass screws were inserted to evaluate potential combination with the CeLFI device, but rods were not applied at this stage to test segmental stability during flexion–extension. The final (**e**) lateral X-ray illustrates the feasibility of combining the CeLFI device with lateral mass screws and rod fixation

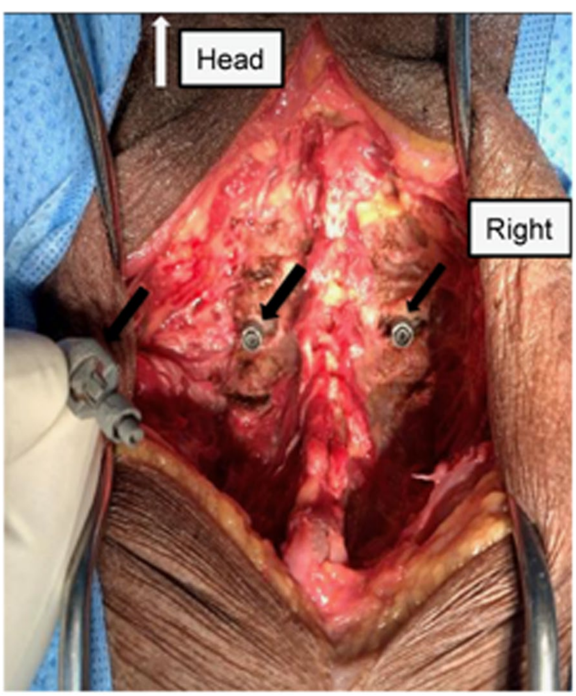

Fig. 2 Posterior cervical spine exposure in a cadaver showing CeLFI placement. Note: CeLFI, cervical expandable facet implant; black arrows

(IVDH; sagittal CT at the posterior and anterior ends of the intervertebral disc), FJS height (anterior end on sagittal CT), and interspinous distance (ISD; sagittal CT at the base of the spinous processes). Additionally, implant subsidence into the adjacent vertebrae was evaluated, defined as ≥ 3 mm [10, 11].

The effects of CeLFI on cervical spine alignment were assessed using the cervical lordotic C2–7 angle (CL; Cobb angle between the lower endplates of C2 and C7) [9, 17].

Data analysis

All statistical analyses were performed using R (version 4.3.2) and R-Studio (version 2023.12.1 + 402; Boston, MA, USA). Continuous data normality was assessed using the Shapiro–Wilk test. Normally distributed data are presented as means ± standard deviations, while non-normally distributed data are reported as medians and interquartile ranges (IQRs). Paired t-tests were used for paired samples when data were normally distributed; otherwise, the Wilcoxon signed-rank test was applied. For unpaired samples, either the independent samples t-test (normally distributed data) or the Mann–Whitney U test (non-normally distributed data) was used.

Ethical considerations

The study commenced following an approval from the institution's ethics review board (project number E-21–6260). All cadavers were obtained from a certified source (Science Care, Arizona, USA).

Results

Study sample selection

Of 13 initially selected cadavers, one was excluded owing to extensive bone fusion across all cervical facets. CT was performed on nine of the remaining cadavers, while other three were not scanned owing to CT machine's unavailability during the procedure. Radiograph data from all 12 cadavers were included in the relevant analysis.

Baseline data and segmental alignment before and after CeLFI insertion

CSPL was found in nine cadavers: at C3–4 in six, C4–5 in two, and C5–6 in one (Table 1). In the remaining three cadavers without CSPL, C3–4 was selected for CeLFI insertion because it was not fused and corresponded to most cases in the CSPL group. Reduction in spondylolisthesis was achieved after CeLFI insertion at all levels with CSPL (Fig. 1b). Lateral dynamic cervical radiographs after insertion showed stable CeLFIs in all cadavers and preserved segmental reduction in cadavers with CSPL (Fig. 1c, d). The LMS and rods could be easily integrated into the construct with CeLFI (Fig. 1e, Fig. 3).

No significant changes were observed in CL before (median, -21.5; IQR, -28.8 to -3) or after (median, -21; IQR, -29.5 to -4.25; $p=0.584$) CeLFI insertion (Fig. 4). Two cadavers (6 and 10, Table 1) had a kyphotic angle at baseline (+10 and +2, respectively), remaining the same after CeLFI insertion. No implant subsidence was observed.

Table 1 Impact of CeLFI insertion in 12 cadavers with and without cervical spondylolisthesis, on the lordotic C2–7 angle, based on lateral C-spine radiograph

Cadaver number (Index level)	CSPL status	C2–7 Angle		
		Before (°)	After (°)	Change (°)
1 (C4–5)	Yes	- 30	- 30	0
2 (C3–4)	Yes	- 28	- 28	0
3 (C3–4)	Yes	- 12	- 17	- 5
4 (C4–5)	Yes	- 16	- 19	- 3
5 (C5–6)	Yes	- 30	- 30	0
6 (C3–4)	Yes	+ 10	+ 10	0
7 (C3–4)	No CSPL	**	**	**
8 (C3–4)	Yes	**	**	**
9 (C3–4)	Yes	0	0	0
10 (C3–4)	Yes	+ 2	+ 2	0
11 (C3–4)	No CSPL	- 29	- 23	+ 6
12 (C3–4)	No CSPL	- 27	- 42	***

CeLFI, cervical expandable facet implant; CSPL, cervical spondylolisthesis

The (-) sign indicates increased lordotic angle. For example, cervical lordosis increased by 3° in cadaver 4. In contrast, the (+) sign indicates reduced lordosis; for example, lordosis reduced by 6° in cadaver 11

** Measurement was not possible owing to difficulty in visualizing the lower endplate of C7 clearly on lateral radiograph

*** Measurement of C2–7 lordotic angle in Cadaver 12 was not included here because of the significant change observed in the cervical spine position during lateral radiograph acquisition before and after CeLFI insertion

CeLFI Insertion and IVFH, ISD, IVDH, and FJS

CeLFI insertion significantly increased mean IVFH (left, 1.5 mm; right, 2 mm; both $p<0.001$, Table 2), mean ISD (2.83 mm; $p=0.003$, Table 3 and Fig. 5), and mean posterior IVDH (1.16 mm; $p=0.001$, Fig. 5). The increase in anterior IVDH after CeLFI insertion was not significant (0.48 mm; $p=0.218$). The posterior IVDH increased more than the anterior IVDH (1.16 and 0.48 mm, respectively, Table 3 and Fig. 5), but showed no significant difference ($p=0.11$). Following CeLFI expansion, the mean height

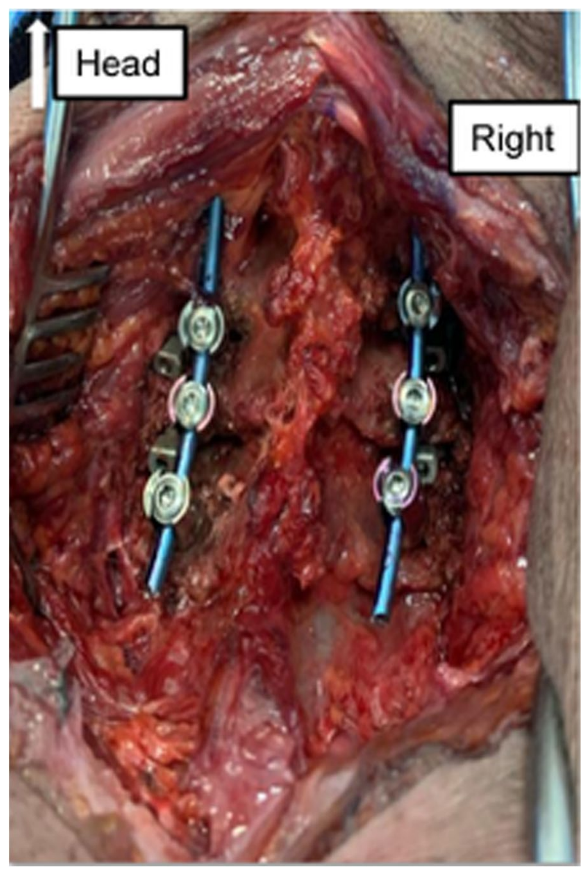

Fig. 3 Insertion of lateral mass screws and rod fixation following CeLFI insertion at multiple levels. Note: CeLFI, cervical expandable facet implant

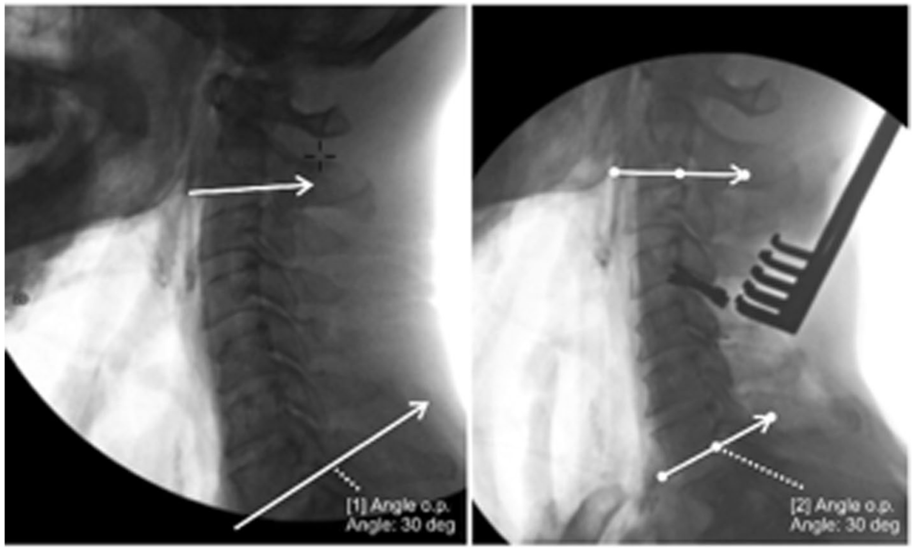

Fig. 4 Lateral radiographs of Cadaver 1 before (left) and after (right) CeLFI insertion in C4–5. Note: CeLFI, cervical expandable facet implant. No change in the C2–7 cervical lordotic angle is observed

Table 2 Changes in the IVFH following CeLFI insertion based on CT imaging evaluation

Cadaver number (Index level)	CSPL (When present)	Left IVFH (mm)		Change (mm)	Right IVFH (mm)		Change (mm)
		Before	After		Before	After	
2 (C3–4)	Yes	10.6	11.8	+ 1.2	10.2	13.2	+ 3
3 (C3–4)	Yes	9.1	10.1	+ 1	7.4	10.5	+ 3.1
4 (C4–5)	Yes	9.3	10.3	+ 1	8.9	11.4	+ 2.5
7 (C3–4)	No CSPL	7.77	10	+ 2.23	9.12	9.94	+ 0.82
8 (C3–4)	Yes	11.4	13.8	+ 2.4	11.6	12.8	+ 1.2
9 (C3–4)	Yes	8.3	9.66	+ 1.36	7.97	9.67	+ 1.7
10 (C3–4)	Yes	9.7	11.1	+ 1.4	7.5	10.1	+ 2.6
11 (C3–4)	No CSPL	8.41	10.7	+ 2.29	8.64	10.8	+ 2.16
12 (C3–4)	No CSPL	10.8	11.5	+ 0.7	7.75	8.56	+ 0.81
Average measures for all nine cadavers (SD)		9.5 (± 1.24)	11 (± 1.27)	+ 1.5 (± 0.64)	8.8 (± 1.39)	10.8 (± 1.49)	+ 2 (± 0.89)

CeLFI Cervical expandable facet implant, *CSPL* Cervical spondylolisthesis, *CT* Computed tomography, *IVFH* Intervertebral foraminal heights, *SD* Standard deviation

of the anterior end of the FJS increased significantly (left, 2.41 mm; right, 2.53 mm; both $p < 0.001$; Table 4). The increase in FJS height was slightly greater at the anterior end than at the posterior end, though this difference was not statistically significant (left, 0.41 mm; right, 1.1 mm; $p = 0.37$ and 0.103, respectively; Table 5).

Of the nine cadavers with available CT data, two (Cadavers 3 and 4) exhibited initial interspinous ligament buckling. Following CeLFI insertion and increased ISD flattening of the posterior ligamentous, a bulge was observed in both cadavers (Fig. 5). Post-insertion CT confirmed proper CeLFI positioning within the facet joint and verified that the implant remained clear of the cervical transverse foramina in all cadavers (Fig. 6).

Discussion

The current study demonstrated the potential for providing indirect intervertebral decompression and reducing CSPL via a PCA. This was achieved by expanding the anterior end of the CFJ using CeLFI. After CeLFI insertion via PCA, a reduction of the CSPL segments was observed and maintained on flexion–extension radiographs, a unique outcome attributed to this expansion mechanism [13–16]. Additionally, FJS height and IVFH

Table 3 Segmental changes in the ISD and IVDH (both at the posterior and anterior ends of the intervertebral disc space) following CeLFI insertion based on CT imaging

Cadaver number and instrumented index level	ISD (mm)		Change (mm)	Posterior IVDH (mm)		Change (mm)	Anterior IVDH (mm)		Change (mm)
	Before	After		Before	After		Before	After	
2nd (C3–4)	0.39	0.69	+ 0.3	2.39	3.45	+ 1.06	5.96	6.94	+ 0.98
3rd (C3–4)	1.89	5.35	+ 3.46	2.52	3.81	+ 1.29	3.86	5.6	+ 1.74
4th (C4–5)	2.02	7.63	+ 5.61	1.89	3.8	+ 1.91	4.86	4.1	- 0.76
7th (C3–4)	3.75	7.07	+ 3.32	**	**	**	**	**	**
8th (C3–4)	6.45	7.36	+ 0.91	**	**	**	**	**	**
9th (C3–4)	4.19	4.31	+ 0.12	3.09	3.68	+ 0.59	5.47	5.59	+ 0.12
10th (C3–4)	0.9	4.3	+ 3.4	4.9	5.3	+ 0.4	4.2	5.3	+ 1.1
11th (C3–4)	1.1	6.19	+ 5.09	1.4	3	+ 1.6	2.1	1.6	- 0.4
12th (C3–4)	1.2	4.5	+ 3.3	1.5	2.8	+ 1.3	3.4	4.0	+ 0.6
Mean (SD)	2.43 (± 1.98)	5.27 (± 2.16)	2.83 (± 1.98)	2.53 (± 1.2)	3.69 (± 0.81)	1.16 (± 0.53)	4.26 (± 1.31)	4.73 (± 1.7)	0.48 (± 0.88)

CeLFI Cervical expandable facet implant, *CT* Computed tomography, *ISD* Interspinous distance, *IVDH* Intervertebral disc height

** IVDH could not be measured due to image artifact

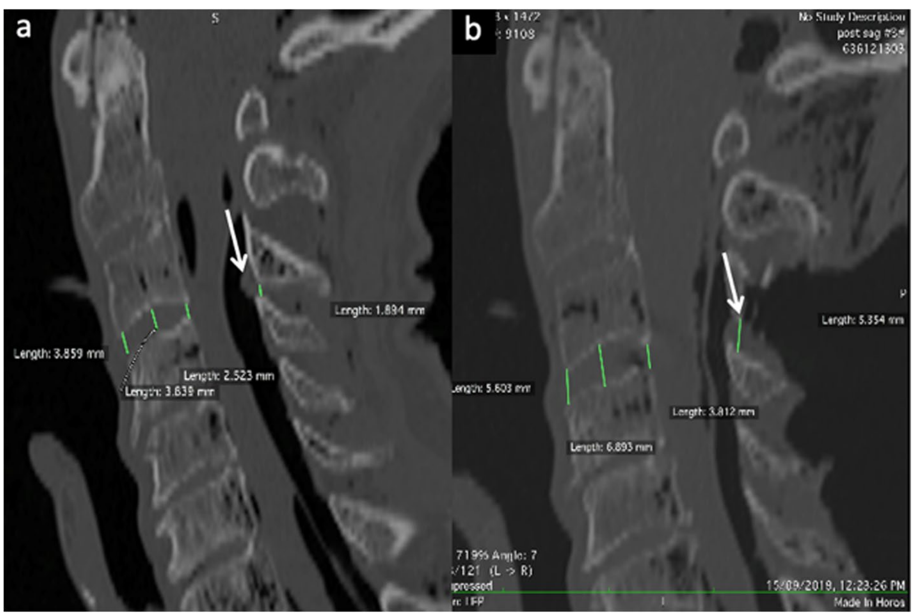

Fig. 5 Computed tomography (CT) scan before insertion of the cervical expandable facet implant (CeLFI) device (**a**), showing buckling of the posterior ligaments at C3–4 into the spinal canal (white arrow). Following insertion of the CeLFI device (**b**), an increase in both the intervertebral disc height and interspinous distance was observed. This was accompanied by the un-buckling of the posterior ligaments (white arrow)

increased, consistent with other CFSs [13, 15, 17, 18]. Following expansion of the anterior CFJ, both IVDH and ISD increased, contributing to spinal canal widening by reducing intervertebral ligamentous buckling—a mechanism also seen in other CFSs [19]. By reducing CSPL and creating more space around the nerve roots and spinal cord, this approach can alleviate symptoms associated with cervical radiculopathy and myelopathy.

The CeLFI design offers advantages over conventional fixed-height CFSs. The thin profile (2 mm) of the CeLFI minimizes interference with joint stability and prevents excessive dilation and distraction. The anterior expansion mechanism ensures implant stability when pressed against the cortical endplates of the facet joint, counteracting posterior migration during neck flexion, as posterior migration is often the path of least resistance

Table 4 Segmental changes in the height of the anterior end of the facet joint space before and after CeLFI insertion based on CT imaging

Cadaver (implanted level)	Left facet height (mm)		Left facet height change (mm)	Right facet height (mm)		Right facet height change (mm)
	Before	After		Before	After	
2nd (C3–4)	2.95	3.95	+ 1	2.04	6.07	4.03
3rd (C3–4)	1.51	3.15	+ 1.64	1.78	4.06	2.28
4th (C4–5)	1.65	4.45	+ 2.8	2.26	3.65	1.39
7th (C3–4)	1.85	5.26	+ 3.41	1.96	4.99	3.03
8th (C3–4)	1.41	3.97	+ 2.56	1.87	4.84	2.97
9th (C3–4)	1.71	5.36	+ 3.65	1.42	4.8	3.38
10th (C3–4)	1.7	4.35	+ 2.65	2.3	2.92	0.62
11th (C3–4)	1.1	3.6	+ 2.5	1.6	3.6	2
12th (C3–4)	2.3	3.8	+ 1.5	1.6	4.7	3.1
Mean (SD)	1.8 (± 0.54)	4.21 (± 0.73)	+ 2.41 (± 0.88)	1.87 (± 0.3)	4.4 (± 0.94)	+ 2.53 (± 1.6)

Measurements (in mm) were performed on sagittal CT images

CeLFI Cervical expandable facet implant, *CT* Computed tomography, *SD* Standard deviation

Table 5 Height measurements of the facet joints (posterior and anterior ends) post-CeLFI insertion using CT imaging

Cadaver (implanted level)	Left facet height (mm)		Difference	Right facet height (mm)		Difference
	Posterior end	Anterior end		Posterior end	Anterior end	
2 (C3–4)	3.92	3.95	+ 0.03	4.38	6.07	+ 1.69
3 (C3–4)	3.13	3.15	+ 0.02	3.52	4.06	+ 0.54
4 (C4–5)	3.24	4.45	+ 1.21	2.35	3.65	+ 1.3
7 (C3–4)	5.39	5.26	-0.13	5.68	4.99	-0.69
8 (C3–4)	4.43	3.97	-0.46	2.62	4.84	+ 2.22
9 (C3–4)	4.0	5.36	+ 1.36	4.29	4.8	+ 0.51
10 (C3–4)	3.9	4.35	+ 0.45	2.54	2.92	+ 0.38
11 (C3–4)	3.6	3.6	0	0.2	3.6	+ 3.4
12 (C3–4)	3.5	3.8	+ 0.3	4.3	4.7	+ 0.4
Mean (± SD)	3.90 (0.688)	4.21 (0.732)	0.3089 (0.61)	3.32 (1.6)	4.4 (0.941)	1.083 (1.215)
P-value			0.37[#]			0.103[#]

CeLFI, cervical expandable facet implant, *CT* Computed tomography, *SD* Standard deviation. The (+) sign indicates more height gained in the anterior end of the facet joint space and the (-) sign indicates more height gained in the posterior end of the facet joint space

[20]. No positional changes of the CeLFI were observed during flexion and extension, further supporting its stability.

Our findings highlight a unique benefit of CeLFI's mechanisms in patients with CSPL. Compared to posterior decompressive procedures (e.g., foraminotomy or laminectomy), which reduce CSPL through extensive bone resection, neck manipulation, and multilevel instrumentation, CeLFI provides indirect decompression and segment reduction without compromising posterior stabilizing structures. The anterior expansion mitigates the displacement of the rostral vertebra relative to the adjacent vertebra, leveraging the oblique anatomy of the CFJ. The resulting reduction and stabilization of the CSPL segment may reduce the need to involve additional vertebrae or use combined anterior and posterior approaches [6]. Consequently, CeLFI has the potential to lower surgical risks associated with more extensive procedures for CSPL. Furthermore, the unique anterior expansion mechanism of CeLFI reduces spondylolisthesis compared to other CFSs. Compared to anterior cervical approaches, CeLFI avoids complications, such as dysphagia and pseudoarthrosis, while improving foraminal height. However, further clinical studies are necessary to confirm its benefits in patients and to compare it with current cervical fixation techniques.

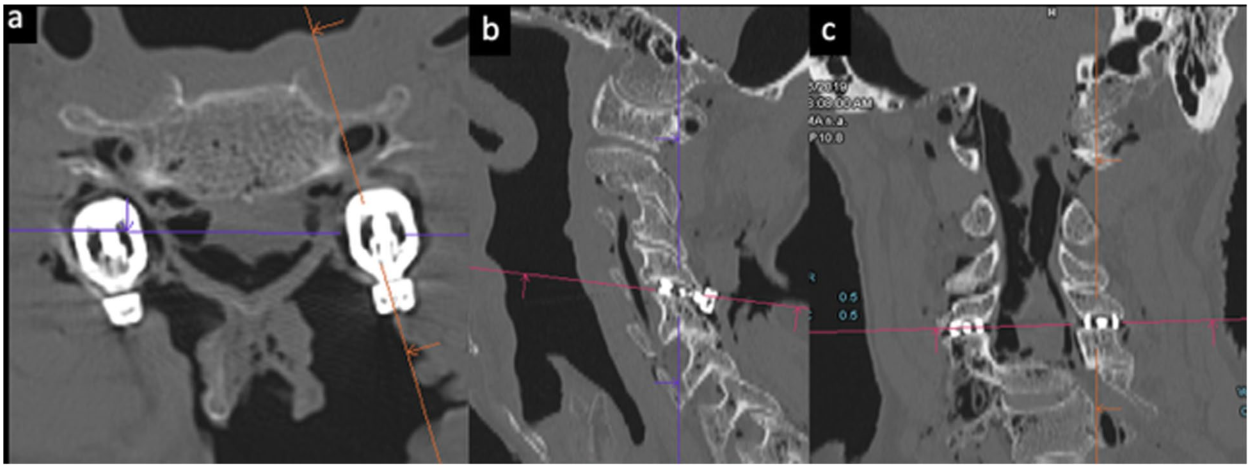

Fig. 6 Computed tomography scan demonstrating the position of the cervical expandable facet implant (CeLFI) in axial (**a**), sagittal (**b**), and coronal (**c**) planes within the facet joint and away from the intervertebral transverse foramina

Cadaveric and biomechanical studies on CFS

The added value of CSPL reduction with anterior CFJ expansion warrants further biomechanical investigation. Previous biomechanical studies have shown positive results for other CFSs in supporting cervical spine segmental stability. In a cadaver study, Voronov et al. demonstrated that bilateral CFSs provided cervical segmental stability comparable to constructs using LMS and rods [20]. Similarly, Hah et al. showed in a cervical pseudoarthrosis model that posterior CFSs significantly supported loose anterior cervical constructs, improving segmental stability [21]. These findings underscore the utility of CFSs in addressing stability, especially when spinal fusion is challenging, as seen in patients with CSPL who often require combined cervical approaches to achieve adequate stabilization [12].

Consistent with previous biomechanical studies evaluating CFSs, CeLFI was designed to achieve a 3- or 4-mm expansion, increasing neural foraminal height while enhancing segmental cervical stability [16]. Maulucci et al. conducted a biomechanical cadaver study and reported that inserting 2-, 3-, or 4-mm spacers into the CFJ increased the foraminal area [17]. However, 2-mm spacers alone did not provide sufficient segmental stiffness, suggesting the need for supportive external instrumentation. In contrast, 3- and 4-mm CFSs provided more segmental stiffness and resulted in a larger foraminal cross-sectional area. The use of a 4-mm CFS across three levels reduced intact cervical segment kinetics by 85% [17]. In the current study, CeLFI expansion to 3 or 4 mm increased IVFH in all cadavers, with segment and implant stability confirmed on flexion–extension radiographs. Further biomechanical studies are necessary to determine the optimal implant height for achieving both indirect decompression and the required segmental stability.

Clinical outcomes after CFS insertion, including adjacent segment disease

Our results align with previous studies showing that CFJ expansion enlarges the intervertebral neural foramina with minimal impact on cervical lordosis. Clinical studies have reported symptom improvement in cervical myelopathy and radiculopathy, as well as successful fusion in patients with degenerative disc disease, following foraminal enlargement with CFS [13]. Goel et al. even observed a regression of degenerative changes after CFS insertion without laminectomy, while McCormack et al. reported a 90% fusion rate and minimal segmental lordosis loss in patients with radiculopathy using DTRAX implants [15, 18]. Similarly, Tan et al. reported improved outcomes without significant changes in cervical lordosis, and Siemionow et al. demonstrated foraminal enlargement with CFS [8, 16, 19, 22]. However, the complexity of assessing cervical lordosis and its relationship to clinical outcomes [8, 22, 23] necessitates clinical studies that include radiologic evaluations of overall spinal alignment.

Strengths and limitations

The changes observed in cervical spine segments following CeLFI insertion were based on fresh cadavers, which closely resemble the response of living tissue. The controlled environment allowed for adequate surgical exposure and detailed imaging through CT and radiography. However, there are limitations to consider. While the sample size may be appropriate for a cadaver study, it limits the generalizability of the results to the broader patient population. Additionally, while all cadavers were adults, the lack of data on their exact age and osteoporotic status may lead to an underestimation of CeLFI's potential benefit in providing additional support for segment stability in patients with osteoporosis, particularly older patients. The biomechanical properties of osteoporotic bone could influence the stability and efficacy of bone fixation, which should be considered in future studies. Furthermore, a detailed biomechanical analysis of implant stability, beyond the flexion–extension radiographs, was not conducted, which could offer a more comprehensive understanding of CeLFI's long-term performance. In this study, the head was not fixed in a rigid headrest during cadaver positioning. Although all efforts were made to avoid inadvertent neck movements, such movements may have occurred, potentially resulting in CSPL reduction. To address this limitation, radiography was performed with the neck in flexion and extension positions. The segments with CSPL remained reduced, even when the neck was in the flexed position, confirming that the reduction achieved with CeLFI was maintained and not dependent on the neck position during radiography.

The study has limitations in evaluating potential adverse events, as complications related to implant insertion, such as vertebral artery injury, nerve root injury, or device migration, are best assessed in a clinical setting. Previous clinical studies on CFS have reported neurologic complication rates comparable to those of anterior cervical discectomy and fusion (4.8%) and posterior cervical fusion with LMS (9.89%) [24–34]. Siemionow et al. reported a perioperative complication rate of 3.4% in patients treated with CFS, with no reports of vertebral artery injury or device failure [35]. In a recent retrospective case series of 25 patients with CFS, Garcia et al. reported that 3.3% of their facet spacers required repositioning, and the implant was removed in two patients due to C5 palsy and new weakness [36]. Further clinical studies are needed to evaluate the complication profiles specific to CeLFI compared to other CFS implants in patients with degenerative cervical spine disease.

Conclusions

In conclusion, our results demonstrate that targeted expansion in the anterior part of the CFJ increased intervertebral spaces and reduced CSPL. The segmental reduction achieved with CeLFI in this study was maintained on flexion–extension radiographs. With this novel expansion mechanism, effective indirect neural decompression via a PCA was achieved by improving IVFH, increasing IVDH, and reducing ligamentous buckling without significantly altering cervical lordosis. These results suggest a potential benefit in improving surgical outcomes for patients with degenerative cervical spine disease by extending the utility of PCAs and potentially reducing the need for combined cervical approaches. Future biomechanical and clinical studies are needed to validate these findings in living patients with cervical spondylosis and spondylolisthesis.

Abbreviations

CeLFI	Cervical expandable facet implant
CFS	Cervical facet spacers
CFJ	Cervical facet joint
CSM	Cervical spondylotic myelopathy
CSPL	Cervical spondylolisthesis
CS	Cervical spondylosis
CT	Computed tomography
IQRs	Interquartile ranges
IVFH	Intervertebral foraminal height
IVDH	Intervertebral disc height
LMS	Lateral mass screws
PCA	Posterior cervical approach

Acknowledgements

We would like to thank Dr. Fawaz Almotairi (MD, College of Medicine, King Saud University, Saudi Arabia) for his valuable participation in the cadaver work in this study.

Authors' contributions

Amro Al-Habib: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, and Writing – review & editing; Sami AlEissa: Conceptualization, Methodology, Writing – review & editing, Funding acquisition, Validation, and Writing – review & editing; Dr. Ayman Al-Jazaeri: Conceptualization, Data curation, Formal Analysis, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, and Writing – review & editing. All authors reviewed the manuscript.

Funding

The current research project received direct support from the Dean's office of the College of Medicine, King Saud University, Riyadh, Saudi Arabia.

Data availability

The data generated during and/or analyzed during the present study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study commenced following approval from the institution's ethics review board (project number E-21–6260). All cadavers were obtained from a certified source (Science Care, Arizona, USA).

Consent for publication

Not applicable.

Competing interests

The authors own the US patent of the CeLFI device under investigation in the study (US 11,648,129 B2 and US 10,687,955 B2).

Received: 7 February 2025 Accepted: 23 April 2025
Published online: 01 May 2025

References

1. Clarke MJ, Zadnik PL, Groves ML, Sciubba DM, Witham TF, Bydon A, et al. Fusion following lateral mass reconstruction in the cervical spine. J Neurosurg Spine. 2015;22:139–50.

2. David G, Mohammadi S, Martin AR, Cohen-Adad J, Weiskopf N, Thompson A, et al. Traumatic and nontraumatic spinal cord injury: pathological insights from neuroimaging. Nat Rev Neurol. 2019;15:718–31.
3. Hejrati N, Moghaddamjou A, Marathe N, Fehlings MG. Degenerative cervical myelopathy: Towards a personalized approach. Can J Neurol Sci. 2022;49:729–40.
4. Hejrati N, Pedro K, Alvi MA, Quddusi A, Fehlings MG. Degenerative cervical myelopathy: Where have we been? Where are we now? Where are we going. Acta Neurochir (Wien). 2023;165:1105–19.
5. Bakhsheshian J, Mehta VA, Liu JC. Current diagnosis and management of cervical spondylotic myelopathy. Global Spine J. 2017;7:572–86.
6. Suzuki A, Daubs MD, Inoue H, Hayashi T, Aghdasi B, Montgomery SR, et al. Prevalence and motion characteristics of degenerative cervical spondylolisthesis in the symptomatic adult. Spine (Phila Pa 1976). 2013;38:E1115–20.
7. Kawasaki M, Tani T, Ushida T, Ishida K. Anterolisthesis and retrolisthesis of the cervical spine in cervical spondylotic myelopathy in the elderly. J Orthop Sci. 2007;12:207–13.
8. Passias PG, Oh C, Jalai CM, Worley N, Lafage R, Scheer JK, et al. Predictive model for cervical alignment and malalignment following surgical correction of adult spinal deformity. Spine (Phila Pa 1976). 2016;41:E1096-E1103.
9. Passias PG, Tretiakov PS, Smith JS, Lafage R, Diebo B, Scheer JK, et al. Are we improving in the optimization of surgery for high-risk adult cervical spine deformity patients over time. J Neurosurg Spine. 2023;39:628–35.
10. Mende KC, Eicker SO, Weber F. Cage deviation in the subaxial cervical spine in relation to implant position in the sagittal plane. Neurosurg Rev. 2018;41:267–74.
11. Karikari IO, Jain D, Owens TR, Gottfried O, Hodges TR, Nimjee SM, et al. Impact of subsidence on clinical outcomes and radiographic fusion rates in anterior cervical discectomy and fusion: a systematic review. J Spinal Disord Tech. 2014;27:1–10.
12. Nouri A, Kato S, Badhiwala JH, Robinson M, Mejia Munne J, Yang G, et al. The influence of cervical spondylolisthesis on clinical presentation and surgical outcome in patients with DCM: Analysis of a Multicenter Global Cohort of 458 Patients. Global Spine J. 2020;10:448–55.
13. Goel A, Shah A. Facetal distraction as treatment for single- and multilevel cervical spondylotic radiculopathy and myelopathy: a preliminary report. J Neurosurg Spine. 2011;14:689–96.
14. Tan LA, Straus DC, Traynelis VC. Cervical interfacet spacers and maintenance of cervical lordosis. J Neurosurg Spine. 2015;22:466–9.
15. McCormack BM, Bundoc RC, Ver MR, Ignacio JM, Berven SH, Eyster EF. Percutaneous posterior cervical fusion with the DTRAX Facet System for single-level radiculopathy: results in 60 patients. J Neurosurg Spine. 2013;18:245–54.
16. Siemionow K, Janusz P, Glowka P. Cervical cages placed bilaterally in the facet joints from a posterior approach significantly increase foraminal area. Eur Spine J. 2016;25:2279–85.
17. Maulucci CM, Sansur CA, Singh V, Cholewczynski A, Shetye SS, McGilvray K, et al. Cortical bone facet spacers for cervical spine decompression: effects on intervertebral kinetics and foraminal area. J Neurosurg Spine. 2016;24:69–76.
18. Goel A, Vaja T, Shah A, Rai S, Dandpat S, Vutha R, et al. Outcome of osteophytes after only-fixation as treatment for multilevel cervical spondylosis-a minimum of 12 months follow-up. World Neurosurg. 2021;146:e876–87.
19. Goel A, Shah A. Atlantoaxial facet locking: treatment by facet manipulation and fixation. Experience in 14 cases. J Neurosurg Spine. 2011;14:3–9.
20. Voronov LI, Siemionow KB, Havey RM, Carandang G, Patwardhan AG. Biomechanical evaluation of DTRAX(®) posterior cervical cage stabilization with and without lateral mass fixation. Med Devices (Auckl). 2016;9:285–90.
21. Hah RJ, Alluri R, Anderson PA. Biomechanical Analysis of an Anterior Cervical discectomy and fusion pseudarthrosis model revised with machined interfacet allograft spacers. Global Spine J. 2020;10:973–81.
22. Yang K, Li XY, Wang Y, Kong C, Lu SB. Mechanisms of compensatory for cervical lordosis changes after laminectomy with fusion. BMC Surg. 2022;22:129.
23. Ling FP, Chevillotte T, Leglise A, Thompson W, Bouthors C, Le Huec JC. Which parameters are relevant in sagittal balance analysis of the cervical spine? A literature review. Eur Spine J. 2018;27:8–15.
24. Guo Q, Bi X, Ni B, Lu X, Chen J, Yang J, et al. Outcomes of three anterior decompression and fusion techniques in the treatment of three-level cervical spondylosis. Eur Spine J. 2011;20:1539–44.
25. Uribe JS, Sangala JR, Duckworth EA, Vale FL. Comparison between anterior cervical discectomy fusion and cervical corpectomy fusion using titanium cages for reconstruction: analysis of outcome and long-term follow-up. Eur Spine J. 2009;18:654–62.
26. Song KJ, Lee KB, Song JH. Efficacy of multilevel anterior cervical discectomy and fusion versus corpectomy and fusion for multilevel cervical spondylotic myelopathy: a minimum 5-year follow-up study. Eur Spine J. 2012;21:1551–7.
27. Lin Q, Zhou X, Wang X, Cao P, Tsai N, Yuan W. A comparison of anterior cervical discectomy and corpectomy in patients with multilevel cervical spondylotic myelopathy. Eur Spine J. 2012;21:474–81.
28. Yonenobu K, Fuji T, Ono K, Okada K, Yamamoto T, Harada N. Choice of surgical treatment for multisegmental cervical spondylotic myelopathy. Spine (Phila Pa 1976). 1985;10:710–6.
29. Burke JP, Gerszten PC, Welch WC. Iatrogenic vertebral artery injury during anterior cervical spine surgery. Spine J. 2005;5:508–14; discussion 514.
30. Pateder DB, Carbone JJ. Lateral mass screw fixation for cervical spine trauma: associated complications and efficacy in maintaining alignment. Spine J. 2006;6:40–3.
31. Sekhon LH. Posterior cervical lateral mass screw fixation: analysis of 1026 consecutive screws in 143 patients. J Spinal Disord Tech. 2005;18:297–303.
32. Graham AW, Swank ML, Kinard RE, Lowery GL, Dials BE. Posterior cervical arthrodesis and stabilization with a lateral mass plate. Clinical and computed tomographic evaluation of lateral mass screw placement and associated complications. Spine (Phila Pa 1976). 1996;21:323–8.
33. Al Barbarawi MM, Allouh MZ. Cervical lateral mass screw-rod fixation: Surgical experience with 2500 consecutive screws, an analytical review, and long-term outcomes. Br J Neurosurg. 2015;29:699–704.
34. Hwang IC, Kang DH, Han JW, Park IS, Lee CH, Park SY. Clinical experiences and usefulness of cervical posterior stabilization with polyaxial screw-rod system. J Korean Neurosurg Soc. 2007;42:311–6.
35. Siemionow KB, Glowka P, Blok RJ, Gillespy MC, Gundanna MI, Smith WD, et al. Perioperative complications in patients treated with posterior cervical fusion and bilateral cages. J Craniovertebr Junction Spine. 2017;8:342–9.
36. Garcia JH, Haddad AF, Patel A, Safaee MM, Pennicooke B, Mummaneni PV, et al. Management of malpositioned cervical interfacet spacers: An institutional case series. Cureus. 2021;13:e20450.

Publisher's Note