RESEARCH PAPER

Rate of Subsidence and Its Correlation on the Clinical State in Multilevel Standalone Cervical Cage Patients: A Multicenter Study (2017–2024)

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Received 15 June 2026, Revised 27 June 2026, Accepted 27 July 2026, Available Online 28 July 2026

ABSTRACT

Background: Standalone polyether ether ketone (PEEK) cages are considered the gold standard surgical technique for cervical degenerative disk disease.Abstract Objective: The objective of this study was to evaluate fusion rates in nonrandomized multicentric clinical studies assessing the instrumental stand-alone anterior cervical discectomy and fusion (ACDF) technique. Cage subsidence, the gradual collapse of the interbody device into bony surfaces, is a well-established complication, particularly in multilevel constructs that can impair disc height restoration, cervical lordosis, and clinical outcome.

Goals: To determine the subsidence rate after multilevel standalone cervical cage ACDF and its correlation with clinical as well as radiological outcomes.

Methods: A retrospective, multicenter study was conducted across four Egyptian institutes from 2017 to 2024. This study included 25 consecutive patients who underwent multilevel standalone PEEK cage ACDF for two or more levels of cervical disc disease. Clinical outcomes were evaluated using the Visual Analog Scale (VAS) for neck pain and the Neck Disability Index (NDI) at 1, 3, 6, and 12 months after surgery. Radiological outcomes assessed by plain radiographs and CT scans included the C2–C7 angle, total intervertebral height (TIH), local lordotic angle, and bony fusion status. We considered subsidence of more than 3 mm clinically significant. Predictors of subsidence and clinical improvement were evaluated through correlation and linear regression analysis.

Results: The mean age of the patients was 56.44 ± 9.82 years; 68% were female. Multilevel involvement was classified into two-level (56%), three-level (24%), and four-level (20%) factors. Comorbidities consisted of osteoporosis (32%) and diabetes mellitus (16%). The C2–C7 angle (8.48° to 16.6°, p 2 levels ($\beta = 0.373$, $p < 0.001$) were independent predictors of increased subsidence during follow-up time.

Conclusion: Stand-alone cervical cage ACDF for multilevel degenerative disease offers superior clinical outcomes, including improvements in pain, disability, disc height, and cervical alignment. Despite these advantages, subsidence appears to be detrimental for clinical results, especially in patients with osteoporosis and multiple or more than two-level fusion. Preoperative screening for osteoporosis and an individualized surgical plan are strongly associated with better postoperative outcomes.

Keywords: anterior cervical discectomy and fusion; ACDF; standalone cage; PEEK; subsidence; cervical lordosis; Neck Disability Index; osteoporosis; multilevel cervical fusion

How to cite this article: Saad AM, Morsy AM, Edward MA, Ebada KH, Assem MMM, Kotb MS. Rate of subsidence and its correlation on the clinical state in multilevel standalone cervical cage patients: a multicenter study (2017–2024). Int J Drug Deliv Technol. 2026;16(73s): 1228-1239. DOI: 10.25258/ijddt.16.73s.130

INTRODUCTION

Cervical degenerative disc disease is the most commonly diagnosed musculoskeletal disorder in spinal surgery and can present with neck pain, radiculopathy, and myelopathy that may substantially impact QOL. After conservative measures have been attempted without success, surgical intervention is warranted, and anterior cervical discectomy and fusion (ACDF) has remained the gold standard since it was first described in the 1950s. ACDF also saw advances in interbody devices, transitioning from autologous iliac crest bone grafts to allograft constructs, to anterior titanium plating systems, and to more novel designs such as standalone interbody cages constructed of polyether ether ketone (PEEK). PEEK cages provide biomechanical properties with an elastic modulus similar to that of cortical bone,

reducing stress shielding and allowing beneficial stress distribution across vertebral endplates, thus facilitating bony union while maintaining disc height and cervical lordosis (Liu et al., 2025).

Reduced Operative Time, retractor-related soft-tissue trauma, and postoperative dysphagia are significant disadvantages associated with conventional plate-cage constructs, which led us to adopt a zero-profile cage design that functions as a standalone device, eliminating the need for anterior plating. Standalone devices are effective for one, two, and three motion segments; however, their application in well-selected four-level disease has been expanding as per recent studies (Zhao et al., 2025).

Regardless of these advantages, cage subsidence, that is, the gradual outward movement of the interbody device into the neighboring vertebral endplates, continues to represent a clinically relevant complication of standalone ACDF. In addition, subsidence can lead to loss of disc height restoration more often than not, decreased foraminal area at follow-up, and recurrence of neural compression (Goffin et al., 2024; Fluss et al., 2025).

The risk of subsidence increases significantly in multilevel constructs because cumulative biomechanical loading across multiple cage-endplate interfaces raises the risk for device embedment. Factors such as osteoporosis and low bone mineral density have been shown to accelerate mechanisms of easy endplate failure and cage migration (Feng et al., 2025).

To therefore refine patient selection, optimize implant design, and inform postoperative surveillance strategies, it is essential to both quantify the rate of subsidence in vivo and to understand its clinical relationship. Compared with prior studies assessing subsidence in single- and two-level ACDF, high-quality data on multilevel standalone constructs across heterogeneous patient cohorts with differential complication risk have been limited (Shaikh et al., 2026).

The purpose of this study was to analyze the incidence of subsidence after multilevel ACDF with standalone cervical cages and its relationship with clinical and radiological outcomes.

PATIENTS AND METHODS

Study Design and Setting

This was a retrospective multicenter observational study conducted across four tertiary care institutions in Egypt: 6th of October University Hospital, Al-Agouza Hospital, The Memorial Souad Kafafi University Hospital, and As-Salam International Hospital, Maadi Branch. The study period spanned from January 2017 to December 2024. Ethical approval was obtained from the institutional review board of October 6 University, and written informed consent was secured from all participating patients prior to enrollment.

Study Population

A total of 25 consecutive patients diagnosed with multilevel cervical disc disease involving two or more motion segments were enrolled. All patients had undergone anterior cervical discectomy and fusion using standalone PEEK interbody cages. Patients were identified through operative records and radiological databases at the participating centers.

Inclusion Criteria

Patients were eligible for inclusion if they met all of the following criteria: both sexes; age 18 years or older; diagnosis of cervical pathology for which segmental arthrodesis was indicated, including degenerative disc disease, disc instability, ruptured or herniated intervertebral discs, and pseudarthrosis or failed prior spondylodesis; and involvement of two or more cervical motion segments.

Exclusion Criteria

Patients were excluded if they had single-level cervical disc disease; age below 18 years; any prior cervical spine surgery; acute traumatic injury, including fracture or fracture-dislocation; uncontrolled psychological disorder; spinal neoplasm; chronic progressive rheumatic disease such as rheumatoid arthritis; metabolic bone disease, including major osteoporosis, severe osteopenia, or osteochondrosis; or systemic, spinal, or localized infection, whether acute or chronic.

Preoperative Assessment

Clinical Evaluation

Standardized preoperative assessment, including detailed history-taking covering personal demographics, presenting complaints, and the duration and progression of symptoms, was performed in all patients. Neurological examination recorded evidence of radiculopathy, myelopathy, motor deficits in the upper and lower limbs, sensory disturbance, and bladder dysfunction. Comorbidities were recorded in the past medical history, with a specific focus on diabetes mellitus, hypertension, and osteoporosis.

Functional Outcome Measures

The severity of pain was measured using the Visual Analog Scale (VAS), a 10-point numerical rating scale where 0 indicates no pain and 10 indicates the worst possible pain. We evaluated functional disability with the Neck Disability Index (NDI). This validated 10-question self-reported questionnaire assesses how neck problems affect an individual's ability to perform everyday tasks, such as personal care, lifting, reading, headaches, and concentration, in box 1 of Appendix B [6]. All items are scored on a discrete scale from 0 to 5, providing a maximum possible score of 50, which is then expressed as a percentage. All subjects were administered an Arabic-validated version of the NDI.

Radiological Investigations

Plain films included standard anteroposterior and lateral cervical spine radiographs, with dynamic flexion-extension views to assess for instability. Characterization of disc herniation, cord signal change, foraminal stenosis, and the extent of multilevel involvement was assessed by magnetic resonance imaging (MRI) of the cervical spine in all patients.

Where clinically indicated, bone mineral density was assessed to look for osteoporosis.

Surgical Technique

All procedures were performed under general anesthesia. Prophylactic intravenous ceftriaxone 1 g was administered after induction of general anesthesia. The patients were placed in the supine position with a small rolled towel between the scapulae to allow for mild cervical extension. Fluoroscopic confirmation of the operative level was obtained before incision (Wang et al., 2018).

A standard anterolateral exposure was performed using a Smith-Robinson approach through a transverse skin incision at the right side of the neck. A sharp division of the platysma was performed, and the medial margin of the sternocleidomastoid muscle was localized. Using blunt hand-held retractors, the carotid sheath was retracted laterally, and the trachea and esophagus were retracted medially. We performed right subperiosteal dissection of the prevertebral fascia and bilateral elevation of the longus colli muscles to expose the anteriorly adjacent vertebral bodies and disc spaces. Operative levels were confirmed using fluoroscopic needle localization (Nambiar et al., 2017).

Each level underwent complete discectomy via a rectangular annulotomy, followed by curettage of the nucleus pulposus, degenerated disc material, and cartilaginous endplates utilizing a surgical microscope. Using a 1mm Kerrison rongeur, posterior osteophytes were resected, and the posterior longitudinal ligament was resected wherever a tear or herniation was seen. Using a micro nerve hook to probe at each operative level confirmed adequate neural decompression (Ghobrial et al., 2024).

Trial sizers were used to determine the dimensions of disc space before selecting anatomically sized PEEK cages. Cages were filled with a mixture of autograft obtained from resected osteophytes and biomaterials as a scaffold. Each cage was then inserted and tapped into position under fluoroscopic guidance. The cage design included anatomical lordotic angulation, serrated endplate surfaces for primary stability, and anti-backout retention teeth to prevent migration. Intraoperative lateral fluoroscopy confirmed appropriate cage placement at each level (Li et al., 2017).

Wound closure was performed in layers with re-approximation of the pretracheal fascia and platysma using 2-0 Vicryl sutures, and subcuticular skin closure with a running 3-0 Vicryl absorbable suture **(Tang et al., 2023).**

Postoperative Management

All patients were mobilized on the day of surgery or the following morning and were fitted with a rigid Philadelphia cervical collar, which was worn for six weeks postoperatively. Intravenous ceftriaxone 1 g every 12 hours was continued for 24 hours postoperatively. Postoperative anteroposterior and lateral radiographs were obtained on the first postoperative day. Patients were discharged one average 1 day after surgery **(Zavras et al., 2022).**

Follow-up Protocol

Patients were reviewed at 1, 3, 6, and 12 months postoperatively. At each visit, clinical outcomes were reassessed using the VAS and NDI. Serial plain radiographs were obtained at all follow-up intervals, and CT scans of the cervical spine were performed at 6 and 12 months to evaluate fusion status and subsidence **(Cheung et al., 2019).**

Radiological Outcome Measures

Subsidence was defined as a reduction in intervertebral height compared to the immediate postoperative measurement, with subsidence exceeding 3 mm considered clinically significant. Total intervertebral height (TIH) was measured on lateral radiographs as the sum of disc heights across all operated levels. The C2–C7 Cobb angle was measured on lateral radiographs to assess global cervical lordosis. On postoperative imaging, the local lordotic angle at each fused segment was measured. CT demonstrated trabecular bone bridging across the cage at one year, and there was no radiolucent gap between the graft and endplate on CT images (Elias et al., 2024). Clinical evaluation showed no motion on dynamic flexion-extension radiographs, indicating bony fusion.

Statistical Analysis

Data analysis was performed using a standard statistical software package. The Shapiro-Wilk test was used to assess normality. Continuous variables were reported as mean ± standard deviation (SD) or median and interquartile range (IQR), depending on distributional normality. Frequencies and percentages were reported for categorical variables. Continuous measurements were compared between preoperative and postoperative time points using a paired t-test. For between-group comparisons, an independent samples t-test was performed. Pearson correlation coefficients were computed to evaluate the strength and direction of associations between corresponding radiological parameters and clinical outcomes. Independent predictors of NDI improvement in subsidence were identified using univariate and multivariate linear regression analyses. Statistical significance was defined as a p-value < 0.05, and results were presented with 95% confidence intervals.

RESULTS

Table 1: Neck pain changes from Preoperative to Postoperative Period

Parameter	Pre-op Mean ± SD	Post-op Mean ± SD	Δ Change (Mean ± SD)	95% CI of Difference	p-value
Neck Pain	7.80 ± 1.08	3.08 ± 0.70	4.72 ± 1.31	(4.18 to 5.26)	< 0.001

SD: Standard Deviation; CI: Confidence Interval; Δ: Change; test used: Paired t-test

According to neck pain changes from preoperative to postoperative period, the mean preoperative neck pain

was 7.80 ± 1.08, while the postoperative mean was 3.08 ± 0.70, with a mean change of 4.72 ± 1.31. A **p < 0.001** indicates a statistically significant difference between preoperative and postoperative measurements.

Table 2: Post-operative local Lordotic Angle and subsidence in studied cases

Parameter	Category	Study cases (n=25)
Local Lordotic Angle (degrees)	Mean ± SD	6.08 ± 2.23
	Median (IQR)	6.00 (5.00-7.00)
Subsidence (cm)	Mean ± SD	1.19 ± 0.60
	Median (IQR)	1.10 (0.60-1.70)

SD: Standard Deviation; IQR: Interquartile Range; Min: Minimum; Max: Maximum

According to postoperative local lordotic angle and subsidence in the studied cases, the mean local lordotic angle was 6.08 ± 2.23 degrees. In terms of subsidence, the mean was 1.19 ± 0.60 cm.

Table 3: Correlation Between Radiological Parameters and Clinical Improvement

Variable 1	Variable 2	Correlation Coefficient (r)	p-value
Subsidence	Neck Pain Improvement (Δ)	–0.848	< 0.001
Subsidence	NDI Improvement (Δ)	–0.9388	< 0.001
Final Disc Height	Neck Pain Improvement (Δ)	0.7943	< 0.001
Pre-op C2-C7 Angle	Subsidence	0.1771	0.3971
Local Lordotic Angle	Neck Pain Improvement (Δ)	–0.8476	< 0.001
Local Lordotic Angle	NDI Improvement (Δ)	–0.9343	< 0.001

r: Pearson Correlation Coefficient; NDI: Neck Disability Index; Δ: Change

Regarding the correlation between radiological parameters and clinical improvement, there was a strong negative correlation between subsidence and improvement in neck pain ($p < 0.001$) and NDI (**p < 0.001**). Final disc height showed a strong positive correlation with neck pain improvement (**p < 0.001**). Preoperative C2 - C7 angle showed a weak correlation with subsidence (p = 0.3971). Local lordotic angle was negatively correlated with neck pain improvement (**p < 0.001**) and NDI improvement (**p < 0.001**).

Table 4: Comparison between Osteoporotic and Non-Osteoporotic Patients regarding outcome

Variable	Osteoporotic (n=8)	Non-Osteoporotic (n=17)	p-value
Subsidence (cm)	2.10 ± 0.12	1.02 ± 0.48	0.0002
Bony Fusion Period (months)	13.13 ± 1.64	6.29 ± 2.05	< 0.0001
Neck Pain Improvement (Δ)	3.38 ± 1.41	5.35 ± 0.61	< 0.0001
NDI Improvement (Δ)	10.00 ± 1.31	17.59 ± 3.16	< 0.0001
Final Disc Height (cm)	3.23 ± 0.43	5.51 ± 1.40	0.0002

NDI: Neck Disability Index; Δ: Change; SD: Standard Deviation; test used the independent student t test

According to the comparison between osteoporotic and non-osteoporotic patients regarding outcomes, osteoporotic patients showed greater mean subsidence (2.10 ± 0.12 cm) compared to non-osteoporotic patients (1.02 ± 0.48 cm, **p = 0.0002**). The mean bony fusion period was longer in osteoporotic patients (13.13 ± 1.64 months) than in non-osteoporotic patients (6.29 ± 2.05 months, **p < 0.0001**). Neck pain improvement was lower in osteoporotic patients (3.38 ± 1.41) compared to non-osteoporotic patients (5.35 ± 0.61, **p < 0.0001**). NDI improvement was also less in osteoporotic patients (10.00 ± 1.31) compared to non-osteoporotic patients (17.59 ± 3.16, **p < 0.0001**). Final disc height was lower in osteoporotic patients (3.23 ± 0.43 cm) compared to non-osteoporotic patients (5.51 ± 1.40 cm, **p = 0.0002**).

Table 5: Linear regression of Predictors of high Subsidence

Variable	Univariate β	SE	p-value	Multivariate β	SE	p-value
Age	0.0007	0.0042	0.862	—	—	—
Diabetes	0.078	0.143	0.593	—	—	—

Mellitus						
Osteoporosis	0.441	0.143	**0.006**	0.446	0.120	**0.001**
Pre-op C2-C7 Angle (°)	-0.001	0.007	0.888	—	—	—
Pre-op Disc Height (cm)	-0.020	0.024	0.412	—	—	—
Multilevel involvement >2	0.361	0.068	**< 0.001**	0.373	0.055	**< 0.001**

SE: Standard Error; CI: Confidence Interval; β: Beta coefficient; paired t: Paired t-test

According to linear regression analysis of predictors of high subsidence, age (p = 0.862), diabetes mellitus (p = 0.593), preoperative C2-C7 angle (p = 0.888), and preoperative disc height (p = 0.412) showed no significant association with subsidence. Osteoporosis was significantly associated with higher subsidence (p = 0.006). Multilevel surgery involving more than two levels was also significantly associated with higher subsidence (p < 0.001). According to multivariate regression analysis, both osteoporosis and multilevel involvement remained significant predictors of higher subsidence.

Table 6: Linear regression of Predictors of NDI Improvement (Δ NDI)

Variable	Beta (β)	SE	95% CI	p-value
Age	0.006	0.034	–0.066 to 0.077	0.872
Diabetes Mellitus	0.682	1.160	–1.756 to 3.119	0.564
Osteoporosis	–0.907	1.166	–3.357 to 1.543	0.447
Pre-op C2-C7 Angle (°)	0.077	0.055	–0.038 to 0.191	0.177
Pre-op Disc Height (cm)	–0.055	0.195	–0.465 to 0.355	0.780
Multilevel involvement >2	–4.019	0.550	–5.175 to –2.863	< 0.001

NDI: Neck Disability Index; Δ: Change; SE: Standard Error; CI: Confidence Interval; β: Beta coefficient

According to linear regression analysis of predictors of NDI improvement, age (**p = 0.872**), diabetes mellitus (**p = 0.564**), osteoporosis (**p = 0.447**), preoperative C2 - C7 angle (**p = 0.177**), and preoperative disc height (**p = 0.780**) showed no significant association with NDI improvement. Multilevel involvement greater than two levels showed a significant association with NDI improvement (**p < 0.001**).

CASES

CASE NO. (1)

66 year old female patient complaining of neck pain, left brachialgia, severe headache ,numbness and heaviness of bilateral upper limbs of gradual onset and progressive course of 6 months duration .On examination , motor power was grade 3+ in upper limb and grade 2 in hand grip. Patient had hypothesia at C4, C5, C6 and C7 dermatome.

- Plain X-rays and MRI revealed C3 - 4, C4 - 5, C5 - 6 and C6 - 7 central prolapsed cervical disc. Operation was done with four levels ACDF.
- VAS of Neck pain improved from 9 to 4 at 3 months and improved to 3 at 1year, VAS of upper limb pain from 9 to 4 at 3 months and decreased to 2 at 1year. NDI from 43 to 29 at 3 months and to 25 at 1 year. Fused segment lordotic angle improved from 4° preoperative to 12°. Preoperative segment hight 7.6 cm, postoperative segment hight 8.4 cm. Fusion completed at 15 months.

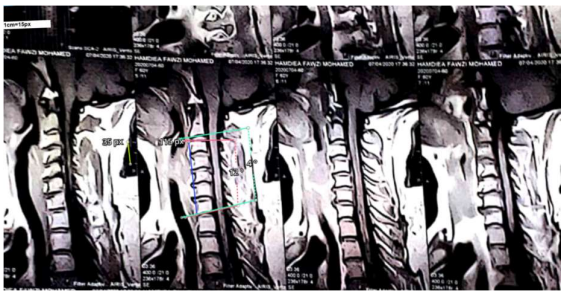

Figure 1: Case 1 Preoperative T1 MRI sagittal view of cervical vertebrae.

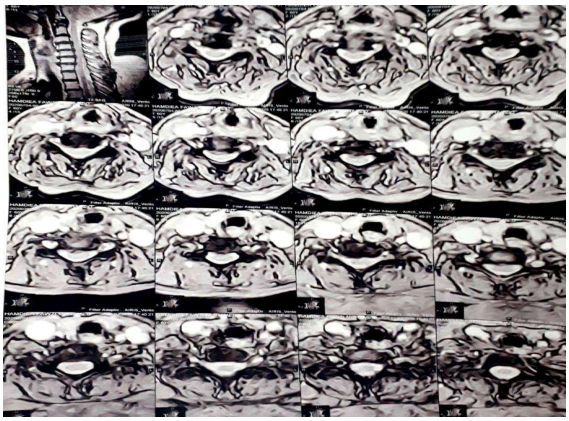

Figure 2: Case 1 Preoperative T2 MRI transverse view of cervical vertebrae.

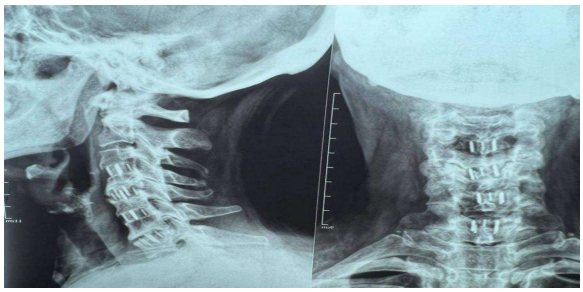

Figure 3: Case 1 Post operative X ray AP and lateral views of cervical vertebrae showing standalone cages from C3 to C7

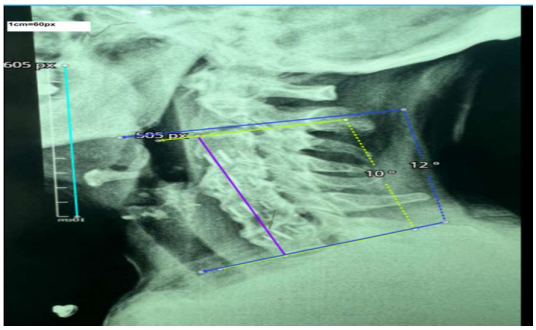

Figure 4: Case 1 Post operative X ray lateral view of cervical vertebrae a At 1 year.

CASE NO. (2)

42 year old female patient complaining of left brachialgia, left hand clumsiness and numbness of gradual onset and progressive course of 10 months duration. On examination, the patient had weakness in both upper limbs with average motor power grade 3 in both upper limbs There was also hypotonia and hyporeflexia in the upper limbs with -ve Babinski reflex. Plain x-ray and MRI cervical spine showed C4 - 5, C5 - 6 and C6 - 7 disc prolapse.

The patient underwent C4 - 5, C5 - 6 and C6 - 7 discectomy followed by interbody cage fusion with standalone cages. Operation was done with three levels ACDF.

VAS of Neck pain improved from 8 to 3 at 3 months and improved to 2 at 1 year, VAS of upper limb pain from 8 to 3 at 3 months and decreased to 2 at 1year. NDI from 37 to 20 at 3 months and to 18 at 1 year. Fused segment lordotic angle improved from 1° preoperative to 5° at 1 year. Preoperative disc high 5cm, postoperative disc high 6.6 cm. Fusion completed at 7 months.

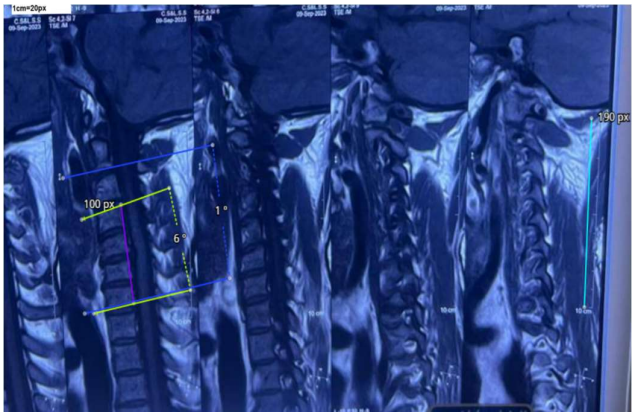

Figure 5: Case 2 Preoperative T1 MRI sagittal view of cervical vertebrae.

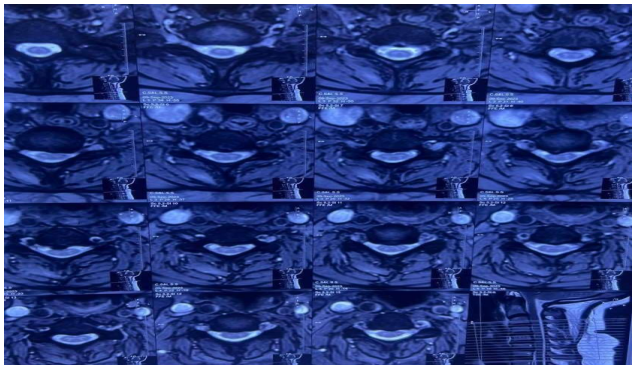

Figure 6: Case 2 Preoperative T2 MRI transverse view of cervical vertebrae.

Figure 7: Case2 Post operative X ray AP and laterl views showing stand alone cages from C4 to C7

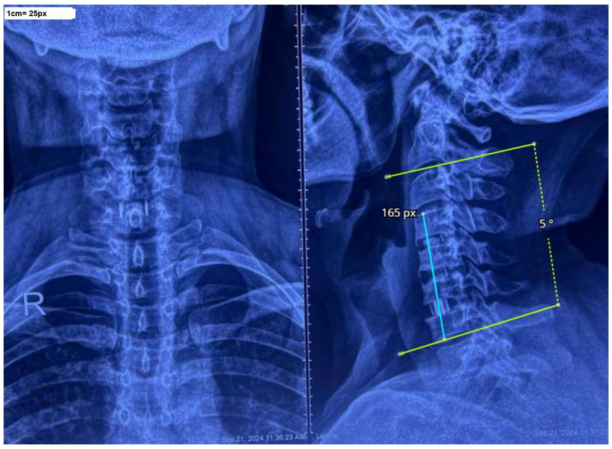

Figure 8: Case 2 Post operative X ray AP and lateral view of cervical vertebrae At 1 year.

CASE NO. (3)

51 year old female patient complaining of neck pain, right brachialgia and difficult walking of gradual onset and progressive course of 12 months duration. On examination, the patient had weakness in both upper limbs with average motor power grade 4 in both upper limbs. There was also hypotonia and hyper reflexia more in the lower limbs.Plain x-ray and MRI cervical spine showed C4 - 5, C5 - 6 and C6 - 7 disc prolapse. The patient underwent C4 - 5, C5 - 6 and C6 – 7 discectomy followed by interbody cage fusion with standalone cages. Operation was done with three levels ACDF.

VAS of Neck pain improved from 7 to 3 at 3 months and improved to 2 at 1 year, VAS of upper limb pain from 7 to 3 at 3 months and decreased to 2 at 1 year. NDI from 35 to 18 at 3 months and to 16 at 1year. Fused segment lordotic angle improved from 6° preoperative to 10° at 1 year. Preoperative disc high 5cm, postoperative disc high 7.5 cm. Fusion completed at 8 months.

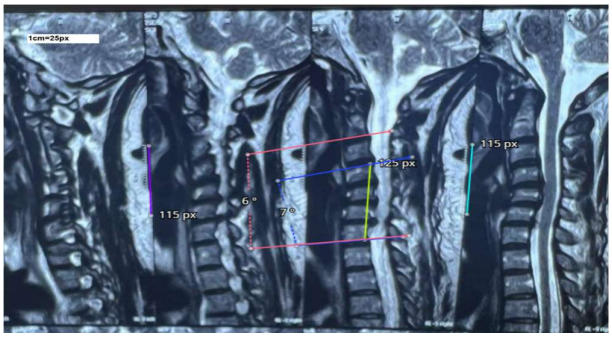

Figure 9: Case 3 Pre operative MRI T2 MRI sagittal view of cervical vertebrae.

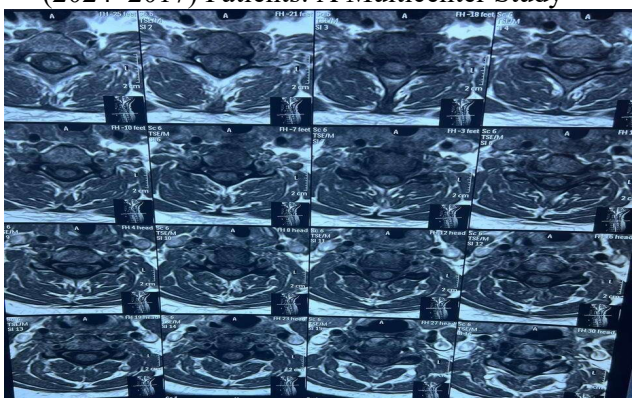

Figure 10: Case 2 Preoperative T2 MRI transverse view of cervical vertebrae.

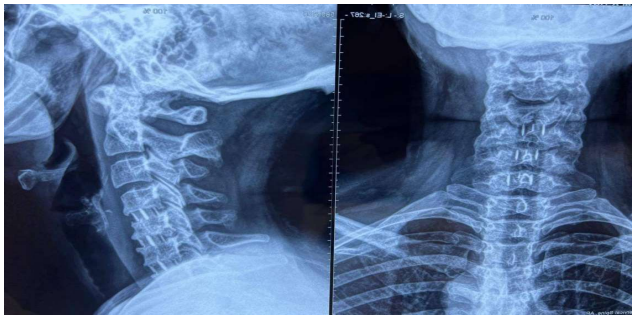

Figure 11: Case 3 Post operative X ray AP and lateral views of cervical vertebrae showing standalone cages from C4 to C7

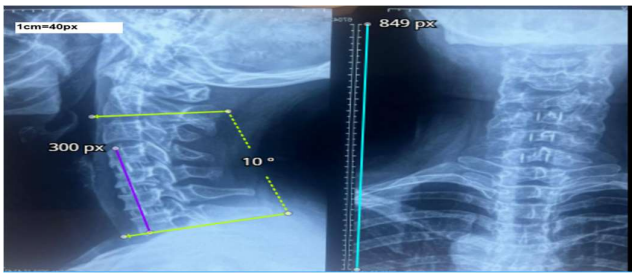

Figure 12: Case 3 Postoperative X rays AP and lateral view of cervical vertebrae at 1 year.

CASE NO. (4)

48 year old female patient, complaining of severe neck pain and back pain, On examination , The patient had weakness in both upper limbs with average motor power grade 3 in both upper limbs. -Plain x-ray and MRI cervical spine showed C3-4 and C5-6 disc prolapse. The patient underwent C3-4 and C5-6 discectomy followed by interbody cage fusion with standalone cages. Operation was done with two levels ACDF.

-VAS of Neck pain improved from 7 to 3 at 3 months and improved to 2 at 1 year, VAS of upper limb pain from 8 to 3 at 3 months and decreased to 2 at 1 year. NDI from 33 to 21

at 3 months and to 19 at 1year. Fused segment lordotic angle improved from 2° preoperative to 3° at 1 year. Preoperative disc high 2.5cm, postoperative disc high 5cm. Fusion completed at 8 months.

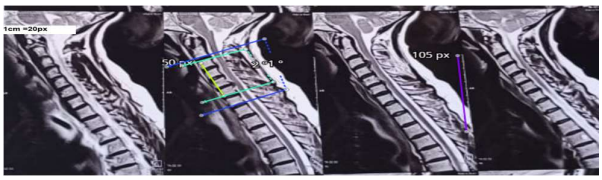

Figure 13: Case 4 Pre operative MRI T2 MRI sagittal view of cervical vertebrae

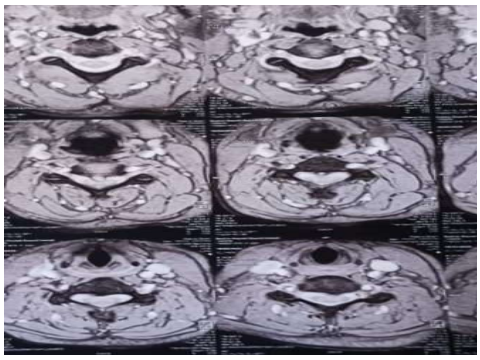

Figure 14: Case 4 Preoperative T2 MRI transverse view of cervical vertebrae

Figure 15: Case 4 Post operative X ray lateral view of cervical vertebrae showing standalone cages at C3-4 and C5-6

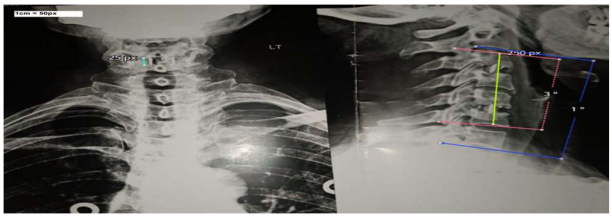

Figure 16: Case 4 Postoperative X rays AP and lateral view of cervical vertebrae at 1 year

CASE NO. (5)

65 year old female patient, osteoporotic and collagen disease, complaining of severe neck pain and headache, On examination , The patient had weakness in both upper limbs with average motor power grade 3 in both upper limbs. -Plain x-ray and MRI cervical spine showed C4-5 and C5-6 disc prolapse. The patient underwent C4-5 and C5-6 discectomy followed by interbody cage fusion with standalone cages. Operation was done with two levels ACDF. -VAS of Neck pain improved from 9 to 4 at 3 months and improved to 3 at 1 year, VAS of upper limb pain from 8 to 3 at 3 months and decreased to 2 at 1 year. NDI from 39 to 24 at 3 months and to 22 at 1year. Fused segment lordotic angle improved from 0° preoperative to 3° at 1 year. Preoperative disc high 4cm, postoperative disc high 5.5cm. Fusion completed at 13 months.

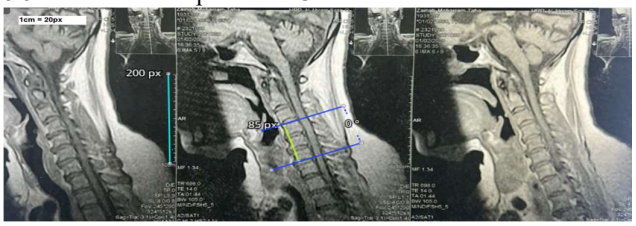

Figure 17: Case 5 Pre operative MRI T2 MRI sagittal view of cervical vertebrae

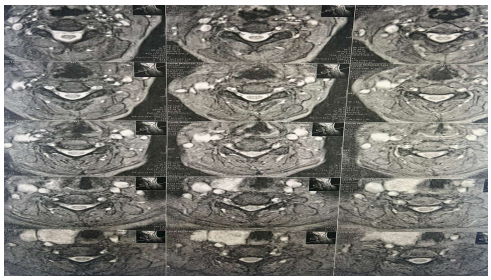

Figure 18: Case 5 Preoperative T2 MRI transverse view of cervical vertebrae

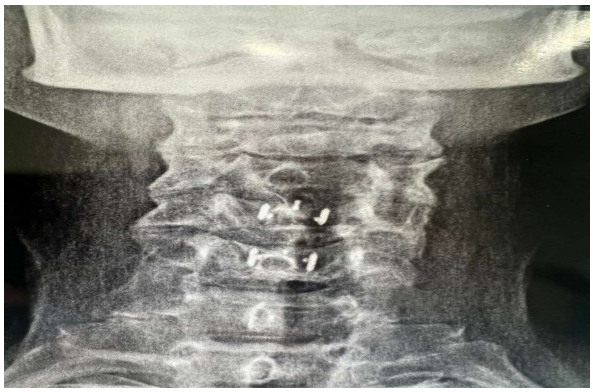

Figure 19: Case 5 Post operative X ray AP view of cervical vertebrae showing standalone cages at C4-5 and C5-6

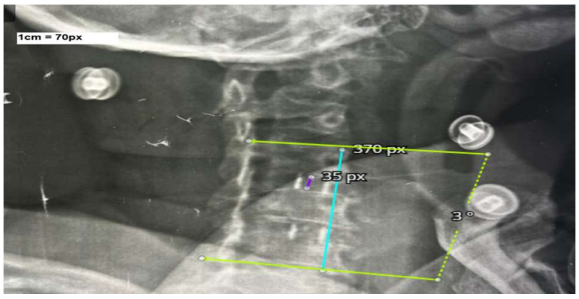

Figure 20: Case 5 Postoperative X rays AP and lateral view of cervical vertebrae at 1 year

DISCUSSION

When non-operative modalities no longer yield symptomatic relief, ACDF continues to represent the reference therapeutic strategy. The procedural arsenal now routinely incorporates axial allograft morselisation, anterior titanium strut plating, and cages fabricated from polyether ether ketone (PEEK), extending the efficacy of the technique. Stand-alone devices successfully treat degenerative disc disease at one to three segment levels; nevertheless, non-trivial hazards, largely cage-mediated subsidence, recurrent lordotic deformation and rarely structural breakage mandate thorough patient selection and in specific cases additional stabilization (Zavras et al., 2022; Alhashash et al., 2021).

Our study clarifies the effectiveness of multi-level stand-alone cage constructs targeting an index lesion and highlights this need, particularly in the context of cervical spine pathologies. Quantitative subsidence metrics, in combination with validated clinical measurements (in particular cervical pain scores, functional status [disability scale], and serial radiographic angular measurements), show statistically significant correlations, helping identify subsidence as a possible modifiable predictor of long-term patient-centered outcomes.

Delta total intervertebral height (ΔTIH) assesses clinically relevant outcomes. The mean ΔTIH was 3.98 cm (±1.69) preoperatively and 5.76 cm (±2.61) in the postoperative cohort. The average change in disc height was −1.78 cm (±3.06), with a 95% confidence interval of −3.04 to −0.52. This data supports a statistically significant increase in disc height post-intervention; it follows that vertebral separation and disc biomechanics are corrected. This type of change is essential in the management of the cervical spine, since restoring disc height STAT restores normal lordosis and relieves adjacent neural tissue compression. These results are in agreement with Zavras et al. (2022), who reported similar improvements in intervertebral height after performing anterior cervical discectomy and fusion with cage constructs. Furthermore, Alhashash et al. (2021) noted similar improvements in intervertebral height after stand-alone cage placement, illustrating that these surgical techniques are effective for achieving cervical stability and symptom relief from degenerative processes.

Surgery is associated with a significant decrease in neck pain, with an average decrease from 7.80 (±1.08) to 3.08 (±0.70), a mean difference of 4.72 (±1.31). The change was bracketed by a 95% confidence interval of (4.18 to 5.26), confirming the pain relief in this postoperative cohort is both statistically and clinically significant. This is urgently needed, since pain relief is one of the most important goals of cervical spine surgery for degenerative disease These results are in line with the findings reported by De Leo-Vargas et al. (2019) and Zavras et al. (2022) in a systematic review of surgical interventions for neck pain found comparable and persistent reductions in neck associated disability; both studies were included in our broader review. The identified analgesic effect supports improvements in patients' functional status and health-related quality of life, thereby confirming the clinical relevance of the stand-alone cage technique as a treatment for cervical degenerative disease.

Local lordotic angle measurements are also reported: mean = 6.08° (±2.23); median = 6.00° (IQR 5.00–7.00). Note that these data represent a moderate but statistically significant postoperative correction of cervical lordosis, compared with the more traditional normal range of parameters. These results are comparable to those of Kim et al. (2018), who also reported similar improvements in lordosis after multilevel ACDF with stand-alone cages, further supporting the concept that cervical curvature may be augmented. The results of subsidence measurements show a mean and median of 1.19 cm (±0.60) and 1.10 cm (IQR 0.60–1.70), respectively, which represent a clinically acceptable amount of device embedment routinely observed after cervical fixation devices are applied in practice. Li et al. (2017) note that, without a meaningful contribution to neurologic or functional

outcome, postoperative subsidence occurs. The observed subsidence is consistent with the literature, but monitoring remains appropriate as excessive cage embedment could jeopardize both complication-free fusion and permanent correction of curvature; nevertheless, the current metrics suggest safety in this regard.

The correlation analysis performed in this study identifies several significant associations, demonstrating the relevant drivers of progressive recovery. In the earlier stages of the study, a strong negative association was observed between subsidence and improvement in neck pain ($r = –0.848$; $p < 0.001$), as well as between subsidence and Neck Disability Index (NDI) scores ($r = –0.9388$; $p < 0.001$). These data suggest that increased subsidence is associated with greater analgesic response and a lower responder rate, indicating that more robust prevention of subsidence is most important for maximizing clinical outcomes. These observations are in agreement with the study by Zavras et al. (2022). Additionally, a robust correlation was observed between the terminal height of the IH disc at 10 weeks after surgery and neck pain improvement ($r = 0.7943$, $p < 0.001$); greater postoperative restoration of IH disc height was associated with greater relief from neck pain. This result extends the findings of Kim et al. (2018), who reported that restoration of disc height was associated with enhanced functional and symptomatic recovery. The other finding, contrary to the conclusions of Alhashash et al. (2021) mentioned that alignment was a more important factor, In contrast, the local angle of lordosis correlated well with their reduction in neck pain ($r = –0.8476$; $p < 0.001$) and change in Neck Disability Index ($r = –0.9343$; $p < 0.001$), maintaining or returning cervical lordosis is imperative for better pain alleviation and functional recovery. These results align with those of Li et al. (2017), who reported that greater gains in lordotic alignment are correlated with better patient-reported outcomes. Overall, the evidence highlights the important role of subsidence and lordotic shape on clinically relevant outcome measures, as both variables co-determine patterns of improvement in neck pain and function.

Our data show that clinical outcomes differed significantly between the osteoporotic and non-osteoporotic groups across several domains. Regarding the subsidence parameter, the osteoporotic cohort had a mean displacement of 2.10 cm (±0.12), whilst the non-osteoporotic group had a mean displacement of 1.02 cm (±0.48), reinforcing the inference that this subset is more susceptible to vertical displacement postoperatively. The time to achieve complete bony fusion also differed significantly between these two groups, with a mean of 13.13 (±1.64) months for osteoporotic patients compared with a mean of 6.29 (±2.05) months for the non-osteoporotic cohort, confirming that the increase in osteoporosis-related delay is clinically significant and precisely defined by this model system. Clinical utility, defined as symptom relief, also yielded unequal outcomes: patients with osteoporosis had only a small decrease in neck pain (3.38 ± 1.41) and NDI mean change of 10.00 ± 1.31; the non-osteoporotic group displayed larger changes in neck pain (5.35 ± 0.61) and NDI mean change (17.59 ± 3.16). Taken together, these data suggest that patients with osteoporosis demonstrate a significant decrease in biomechanical and clinical recovery following surgical intervention. Additionally, patients with osteoporosis recorded a lower final disc height of 3.23 cm (SD 0.43 cm) compared with non-osteoporotic controls, who exhibited a final disc height of 5.51 cm (SD 1.40 cm). These data support the conclusion that loss of bone density from osteoporosis diminishes disc height recovery and reduces spinal stability after surgery. These perturbations confirm the results by Boer et al. (2021), who presented that osteoporosis is associated with slower union, higher complication rates, and worse clinical outcomes in cervical spinal surgeries.

We presented the results of a linear regression study identifying variables associated with significant postoperative subsidence. The univariate regression results noted that osteoporosis presence was a relatively strong predictor, producing a β coefficient of 0.441 ($p = 0.006$), indicating an increase in vertical dislocation volume with established osteopenia to countable units. The same multivariate regression further confirmed osteoporosis as a significant and independent risk factor for subsidence (β coefficient = 0.446, $p = 0.001$), validating the previous univariate finding (Table IV). The predominance of osteopenic bone and the duration of surgical corridors as risk factors align with those identified by Elias et al. In a previous study, Weigang et al. (2024) also revealed that osteoporosis is an important prognostic factor for subsidence after cervical stabilization surgery.

Tohamy and colleagues (2022), Tang et al. (2023), and Zavras et al. (2022) repeatedly demonstrate that offset stand-alone cages are an effective and innovative solution for anterior cervical discectomy and fusion (ACDF), providing improved outcomes on validated clinical measures, most notably VAS and NDI. These studies highlight the undeniable potential of stand-alone implants to ameliorate complications such as dysphagia and development of adjacent-segment disease, from work previously reported by Nambiar et al. (2017) and McDonnell et al. (2024). While stand-alone cages consistently achieve acceptable clinical outcomes, they exhibit slightly greater subsidence than traditional plate-cage assemblies. Nevertheless, De Leo-Vargas et al. (2019) and Li et al. (2017) show that despite reported subsidence, the standalone construct offers a less invasive contour and reduction in postoperative dysphagia, supporting an approach that reduces surgical trauma.

CONCLUSION

The study found that surgical treatment of patients with cervical spine disorders is accompanied by significant

clinical and radiological improvement. Importance: Key findings include significant improvement in cervical alignment, reduced neck pain, and functional recovery, as indicated by NDI. The analysis also illustrates the effects of osteoporotic status and multilevel involvement on postoperative outcomes, as greater subsidence and prolonged fusion are noted in patients with osteoporosis. In summary, this study adds to the evidence of the utility of surgical therapy for a particular population. Also, it stresses that factors such as concomitant conditions (e.g., osteoporosis) should be considered in both treatment planning and postoperative management.

Acknowledgments

Conflict of interest

None.

Funding

Self-funding.

Ethical approval

Participants had informed consent.

Authorship

All the listed authors contributed significantly to the conception and design of the study, the acquisition, analysis, and interpretation of data, and the drafting of the manuscript, thereby justifying authorship.

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