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GRAND ROUNDS

Vertebral body fracture after anterior cervical discectomy and fusion with zero-profile anchored cages in adjacent levels: a cautionary tale

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Abstract

Background context Zero-profile (also called self-locking, anchored or stand-alone cages) have been recently proposed as an interesting alternative for anterior cervical discectomy and fusion (ACDF), as they are supposed to reduce the rates of post-operative cage extrusion without necessarily incurring in the additional surgical time and increased rates of dysphagia associated with plating. Nevertheless, the exact indications of zero-profile anchored cages have not yet been established in the literature.

Purpose To report the first case of a vertebral body fracture between the blades of zero-profile anchored cages after ACDFs in adjacent levels and to review the available literature on hardware-related complications after multilevel ACDFs with zero-profile anchored cages.

Study design Case report and systematic literature review.

Methods The authors report the first case of a vertebral body fracture between the blades of zero-profile anchored cages after ACDFs in adjacent levels. The patient presented with refractory mechanical neck pain at the 1-month post-operative follow-up, ultimately requiring a posterior instrumented fusion. A comprehensive systematic literature review on the available data regarding the safety, complications as well as radiological and clinical outcomes of zero-profile anchored cages is also performed.

Results In the reported case, the use of zero-profile anchored cages in adjacent levels on the cervical spine led to a fracture of the vertebral body between the cages at the 1-month follow-up, with anterior avulsion of the part of the vertebral body where the blades from the two cages converged. According to the systematic literature review which included 409 patients from 10 different clinical series (with a total cumulative follow-up of approximately 535 patients-year), there were only two reported hardware-related complications after ACDF with zero-profile anchored cages, none of them involving fracture at the level of convergence of blades or screws.

Conclusions Although hardware-related complications after the use of zero-profile anchored cages seem to be rare events, future biomechanical and clinical studies are warranted in order to evaluate the safety of employing such devices for the treatment of multilevel degenerative disc disease in the cervical spine.

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Case presentation

A 52-year-old man presented to the outpatient clinic with history of 3 months of refractory neck pain and right side upper and lower extremities numbness. The patient denied any loss of balance or associated bowel or bladder symptoms. At the initial consultation his visual analogue scale (VAS) for neck pain was 60/100 and 30/100 for arm pain. His neck disability index (NDI) was 42/100. There was no significant past medical or family history, although the patient was a smoker (1/2 pack per day).

At the neurological examination the patient presented normal strength (5/5) in both upper and lower extremities and no sensory deficits. The reflexes were brisk in the upper extremities (+2 on the right and +3 on the left). Lower extremity reflexes were also increased bilaterally (+3) with non-sustained ankle clonus. The patient's gait was also slightly spastic. There were also positive Lhermitte's and Spurling's sign. Nevertheless Hoffmann's and Babinski's signs were negative bilaterally.

Diagnostic imaging section

The magnetic resonance image (MRI) of the cervical spine demonstrated a large C3–C4 disc herniation with severe spinal canal stenosis. The adjacent level C4–C5 also demonstrated a disc protrusion toward the left causing moderate spinal canal stenosis (Fig. 1).

Rationale for treatment and evidence-based literature

Despite the growing interest in new technologies for cervical arthroplasty in the last years [1–3], anterior cervical discectomy and fusion (ACDF) possesses the status of a well-established procedure with excellent long-term clinical and radiological results in the treatment of cervical radiculopathy and myelopathy due to soft disc herniation or spondylosis in both single and multiple levels [4–7]. The main goals of such procedure include: decompression of the spinal cord and nerve roots, restoration of mechanical stability, maintenance or improvement in the spinal alignment and fusion. The most commonly utilized intervertebral devices include autografts, allografts, polymethylmethacrylate and intervertebral cages (titanium or PEEK cages), with or without the addition of an anterior cervical plate [1–11].

Although initial studies have demonstrated that clinical outcomes between anterior cervical discectomy (ACD) alone and anterior cervical discectomy and fusion (ACDF) may be similar [9–11], ACDF has been shown to be superior to isolated ACD in terms of preserving segmental lordosis and achieving a successful fusion [8, 12]. According to a systematic review on the issue, there seems to be little difference in relation to the clinical outcomes between ACDF with interbody cages and autografts, although the rates of fusion (but also the complications rates) seems to be higher with autografts [13]. Comparing autografts and allografts, the difference in clinical and radiological outcomes seems to be negligible [14, 15]. Therefore, in those centers where allografts from cadaver bone banks are available, this seems to be the preferred option in order to avoid the morbidity and complications associated with autograft bone harvesting [15].

In relation to the benefits of adding a plate to the construct [anterior cervical discectomy and fusion with plating (ACDFP)] when treating one or two levels of degenerative disc disease in the cervical spine, several studies have suggested that instrumentation may lead to higher rates of fusion and lower subsidence rates than those observed in patients treated with cages in isolation [12, 14, 16–20]. As an expected effect of a more rigid construct, some series have also demonstrated that the incidence of adjacent segment degeneration may be higher in patients treated with instrumentation (ACDFP) in comparison to stand-alone cages (ACDF) [21]. Nevertheless, in most studies the clinical outcomes have been demonstrated to be similar between both groups [12, 14, 16–19]. When comparing the new dynamic plates (fixed-holes) with classic static plates (slotted-holes), a recent literature review has demonstrated that the clinical outcomes of both plates seems to be similar, although the rates of hardware failure seems to be higher with the use of static plates [22].

Regarding the type of cages, some studies have suggested that the use of polyetheretherketone (PEEK) cages may result in lower rates of subsidence than those observed in studies with the older titanium cages, with such superiority in maintaining intervertebral height and cervical lordosis leading to better clinical outcomes in the long-term follow-up [23, 24].

As several large series have demonstrated acceptable fusion rates and pain improvement at the long-term with the use of stand-alone cages [25–28], the real necessity of plating has been questioned, especially when dealing with one or two levels degenerative disc disease and in the absence of any major mechanical instability or deformity. In fact, it has already been demonstrated that,

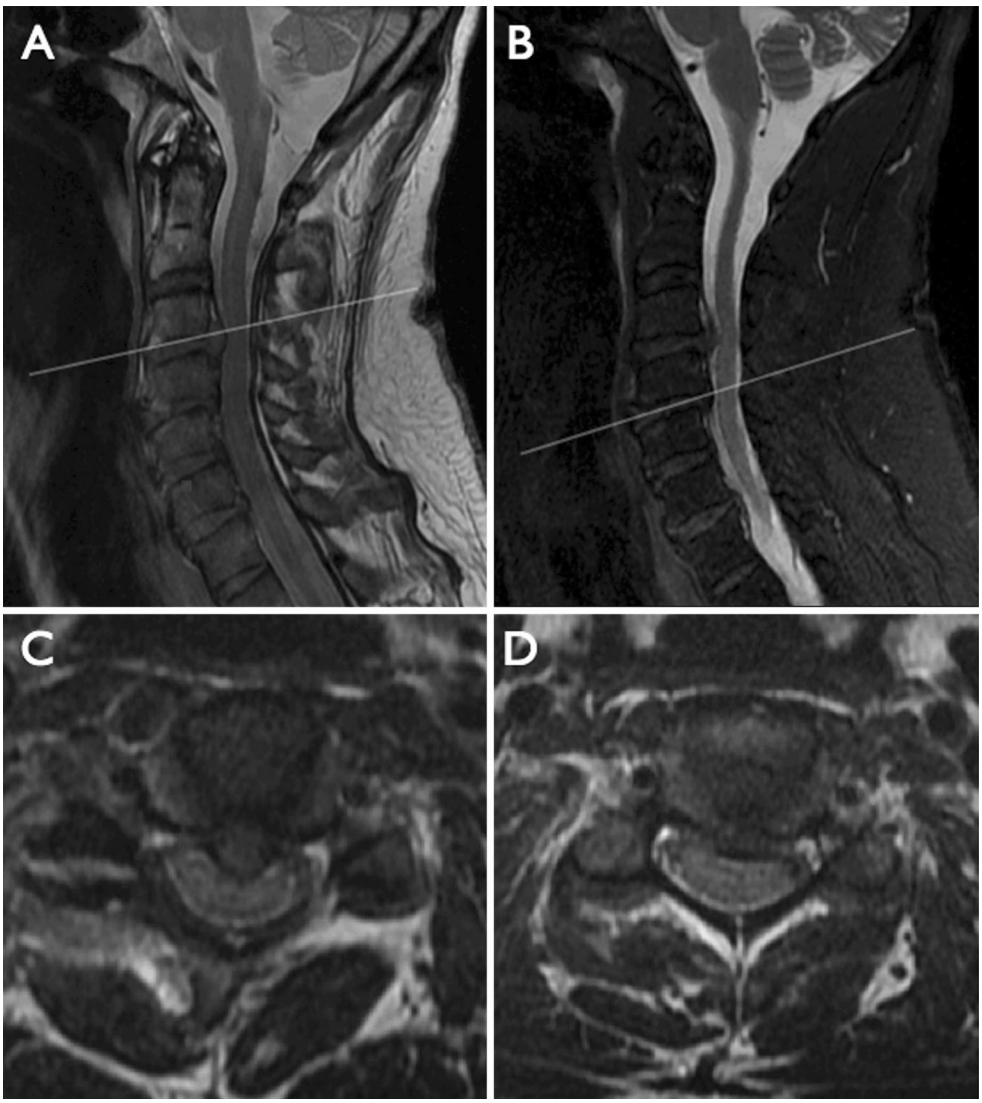

Fig. 1 MRi of the cervical spine in a patient with signs of myelopathy (spastic gait and hyperreflexia) demonstrating a large C3–C4 disc herniation causing severe spinal canal stenosis (sagittal: **a** and axial: **c**), as well as a disc protrusion toward the left causing moderate spinal canal stenosis at the adjacent C4–C5 level (sagittal: **b** and axial: **d**)

although providing higher biomechanical stability, anterior cervical plates are also associated with increasing rates of dysphagia [29, 30], pharyngeal and esophageal lesions [31], adjacent disc degeneration [21], and longer operative time.

Recently, zero-profile (also called self-locking, stand-alone or anchored cages) have been proposed as an alternative to classic anterior cervical plating [32–40]. This type of implants would, at least theoretically, reduce the rates of intervertebral cage extrusion and increase the fusion rates by providing additional biomechanical strength in comparison to stand-alone cages, with an almost negligible increase in operative time and without incurring in the increased rates of postoperative dysphagia associated with plating. Nevertheless, due to the novelty of such devices, there are no specific guidelines regarding its indications or contraindications, nor long-term follow-up studies in terms of clinical and radiographic outcomes and complication rates.

Although there are several types of zero-profile anchored cages [32–41], these devices can be basically divided into those which use a cage linked to a plate through which the screws are implanted, and those in which the cage is built with slots through which angled blades can be placed in the adjacent vertebral bodies.

Initial biomechanical studies comparing various models of zero-profile anchored cages demonstrated that they are

able to provide equivalent biomechanical stability to that obtained with conventional plating [42–44]. It is important to emphasize, however, that cervical zero-profile anchored cages have only been recommended as an alternative to ACDF and plating in the setting of degenerative disease, as studies have demonstrated that such devices may not provide satisfactory biomechanical stability in the setting of traumatic flexion-distraction injuries [45]. It is also important to emphasize that none of the published biomechanical studies tested the spinal stability of zero-profile anchored cages when used in more than one level, neither the load effect and biomechanical consequences to the vertebral body located between the two adjacent levels in which such devices are used.

Preliminary clinical data have demonstrated good clinical and radiological results with the use of zero-profile anchored cages, with outcomes that are comparable to those of historical controls of ACDF with and without plating [33–41]. In relation to the rates of dysphagia, there are conflicting data in the literature. Most comparative studies have demonstrated lower incidence of dysphagia with zero-profile anchored cages when compared with plating [34, 36–38, 46], although some failed to demonstrate a statistically significant difference [40].

First operative procedure

The patient was submitted to a two-level ACDF using zero-profile anchored cervical cages (ROI-C® Cervical cage/VerteBRIDGE Plating Technology/LDR-Austin-US), Fig. 2. The post-operative X-rays demonstrated good positioning of the cages and the patient presented significant improvement of both axial and radicular pain as well as associated neurological symptoms.

Outcome

Initial follow-up

One month after the surgical procedure the patient presented to the emergency department with new complaints of neck pain, however without any radicular pain or associated weakness. There was no complaint of dysphagia. The plain cervical X-Rays demonstrated a fracture of the C4 vertebral body, with anterior avulsion of the portion of the vertebral body where the blades from the cages converged (Fig. 3b–d).

There was also a slight posterior displacement of the C4 vertebral body with some loss of lordosis in comparison to previous films. The cervical MRI did not show any sign of spinal cord compression (Fig. 3a).

Second surgery and follow-up

Due to the vertebral body fracture as well as the retropulsion of the C4 vertebral body and the loss of cervical lordosis, the authors decided to proceed with a C3–C5 posterior instrumentation. The post-operative X-Rays demonstrated optimal placement of the posterior instrumentation (Fig. 4). The patient presented significant improvement of his neck pain at the post-operative period. As the patient did not want an additional surgery for revision of the anterior construct and removal of the avulsed bony fragment, the authors decide to follow him conservatively and the patient was kept in a soft collar for 3 months.

At the 8 months follow-up the patient had already been discharged from physical therapy as was following a home exercise program. He had also returned to work and demonstrated no neck pain. His strength was normal in

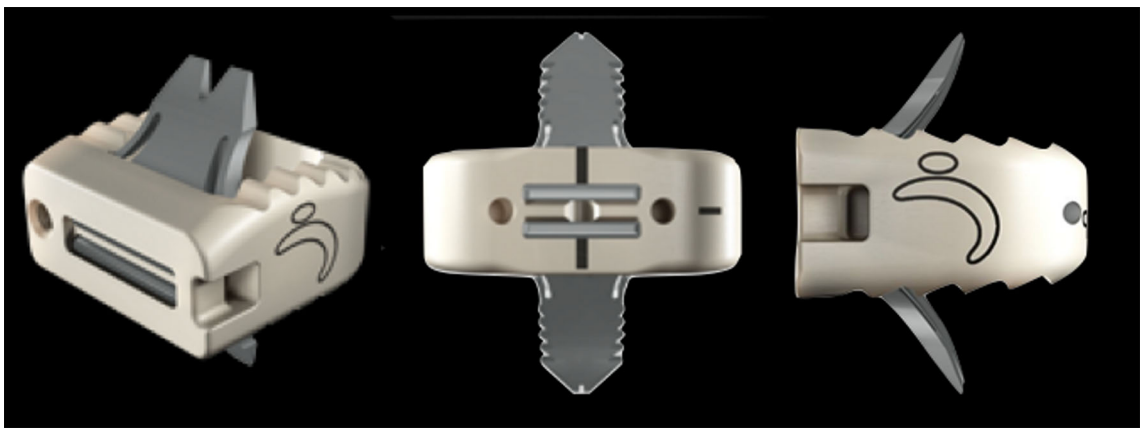

Fig. 2 Oblique, AP and lateral views of the zero-profile anchored cage used in the patient reported in this article (ROI-C® Cervical cage/VerteBRIDGE Plating Technology/LDR-Austin/US)

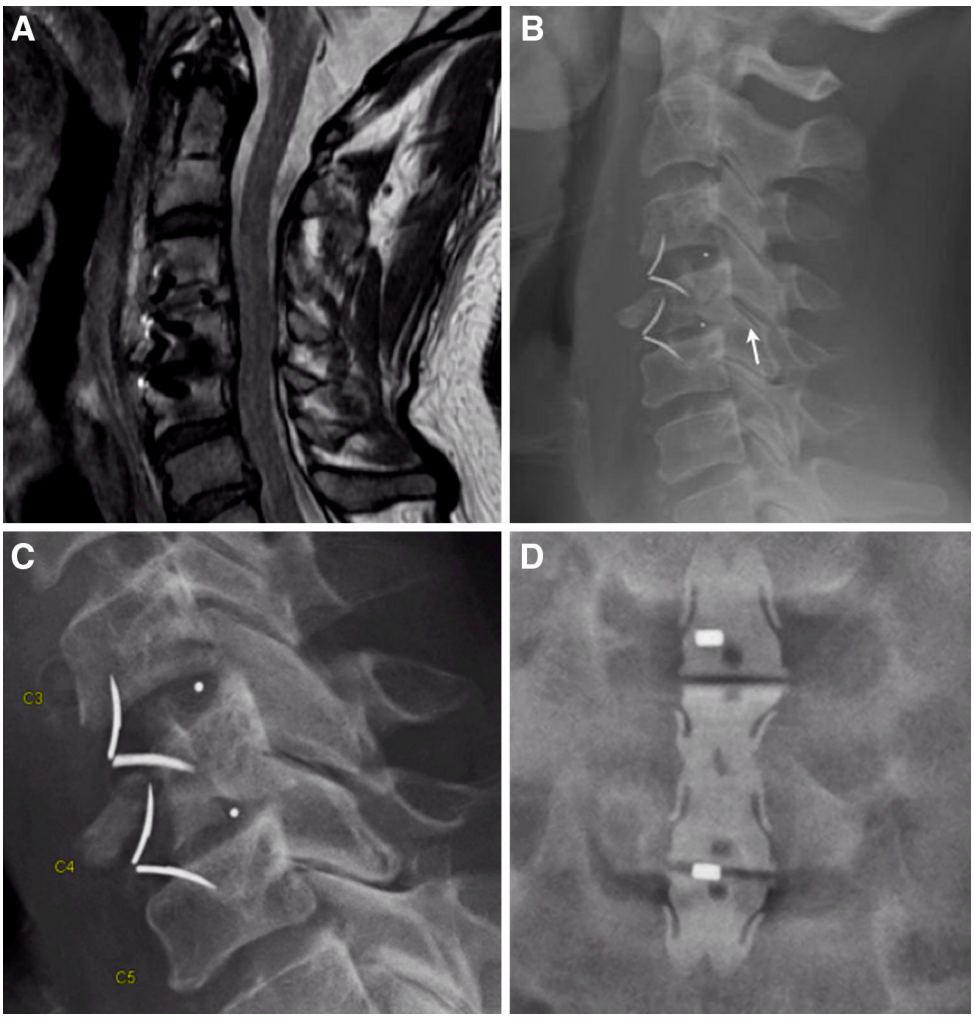

Fig. 3 Plain X-Rays performed 1-month after the C3–C4 and C4–C5 ACDF with zero-profile anchored cages when the patient presented to the emergency department with new onset of neck pain, demonstrating a fracture in the C4 vertebral body fracture as well as loss of lordosis and slight retrolisthesis (arrow in the posterior cortex of the C4 vertebral body) (**b**). Closer lateral (**c**) and AP (**d**) views demonstrating avulsion of the anterior portion of the C4 vertebral body where the blades from both cages converged. The MRi of the cervical spine (**a**—sagittal T2) demonstrated no evidence of spinal cord compression

both upper and lower extremities, although the deep tendon reflexes were still slightly brisk on the right in comparison to the left side.

The last follow-up X-rays demonstrated stable posterior C3–C5 instrumentation without any signs of pseudarthrosis and fusion in progression. The avulsed fragment of the anterior portion of the C4 vertebral body did not present any further displacement. At the last available clinical follow-up (14 months after the second surgical procedure) the patient was pain-free and already back to his regular physical activities.

Literature review

In 2011, Scholz et al. [39] first described their clinical experience with 38 patients submitted to ACDF using a zero-profile anchored cage system. All patients achieved good clinical results and radiological fusion at follow-up. No hardware-related complication was observed. Similarly, in 2012 Kasliwal and O'Toole [35] reported good clinical results and no implant-related complications in 16 patients in whom anchored cages were used. Azab et al. [32] reported similar good outcomes without any hardware-related complications in a larger series of 84 patients submitted to ACDF with a zero-profile cage. Recently, Barbagallo et al. [33] reviewed the records of 85 patients submitted to ACDF with a zero-profile cage-plate system. In a maximum follow-up of 4 years, the fusion rates were 94.5 and 92 %, as assessed by X-Rays or computed tomography, respectively.

Three other retrospective studies compared clinical and radiological results between patients submitted to ACDF with anchored cages and those submitted to a standard ACDF with plating [34, 37, 38]. The mean follow-up in such studies were 12 [37], 13.9 [34], and 18.6 months [38]. In these studies, similar clinical and radiological outcomes were observed between the conventional plating group and the zero-profile anchored cage group [34, 37, 38]. Vanek et al. [40] also demonstrated comparable clinical and radiological in 44 patients submitted to zero-profile

Table 1 Systematic review of the clinical and radiographic outcomes as reported in published series of zero-profile anchored cages available in the literature

Study	Type of study	Device	Sample	Follow-up	Clinical outcomes	Radiological outcomes	Dysphagia	Hardware-related complications	Other complications
Li et al. [36]	Prospective randomized	Zero-P synthes	23 patients Zero-P × 23 patients cage and plate	24 months	Significant improvement in JOA and VAS scores. No significant difference between the groups	No instability at follow-up	Zero-P patients had greater reduction in dysphagia at all follow-ups	None	None
Vanek et al. [40]	Prospective comparative	Zero-P synthes	55 patients Zero-P × 33 patients cage and plate	24 months	Significant improvement in NDI (mean 61 %). No significant difference between the groups	No instability at follow-up	Not reported	None	None
Miao et al. [37]	Prospective comparative	Zero-P synthes	39 patients Zero-P × 50 patients cage and plate	12 months	Significant improvement in JOA and VAS scores. Incidence and duration of post-operative dysphagia lower in the Zero-P patients	No instability at follow-up	Lower incidence and shorter symptoms of dysphagia in the Zero-P group	None	None
Qi et al. [38]	Retrospective comparative	Zero-P synthes	83 patients Zero-P × 107 patients cage and plate	18.6 months	Significant improvement in NDI and VAS scores. No significant difference between the groups	No instability at follow-up	No patient in Zero-P group and 5 patients in the cage and plate group had dysphagia at 6 months	None	Cerebrospinal fluid leak (2/83)
Hofstetter et al. [34]	Retrospective comparative	LDR device	35 patients LDR × 35 patients cage and plate	13 months	Significant improvement in JOA scores. No significant difference between the groups	95.2 % fusion rate	Dysphagia more frequent in the cage and plate group	Migration of blade (1/35)	Paraspinal abscess (1/35) Surgery due to adjacent level disease (2/35)
Barbagallo et al. [33]	Retrospective Case series	Zero-P synthes	85 patients treated/32 patients analyzed	20–48 months	Significant improvement in VAS, SF36 and NDI scores	92 % fusion rate on CT scans	No dysphagia at final follow-up	Screw displacement (1/32)	Postoperative hematoma (1/32). Malposition of screw (1/32)
Azab et al. [32]	Retrospective Case series	Zero-P synthes	75 patients	12–16 months	Significant improvement in JOA and VAS scores. No significant difference between the groups	All patients with radiological fusion by 3 months	76 % mild dysphagia in early postoperative period. No dysphagia after 3 months	None	Hoarseness (1/75) and superficial wound infection (1/75)
Kasliwal and O'Tolle [35]	Retrospective Case series	COALITION, Globus Medical	16 patients	6–10 months	Significant improvement in NDI and VAS scores	95 % fusion rate	No dysphagia after 3 months	None	Transient neurological symptoms (1/16). Surgery for adjacent segment disease (1/16)

Table 1 continued

Study	Type of study	Device	Sample	Follow-up	Clinical outcomes	Radiological outcomes	Dysphagia	Hardware-related complications	Other complications
Zhou et al. [28]	Retrospective Case series	LDR device, Troyes	15 patients	15–27 months	Significant improvement in JOA scores. Odom's criteria excellent in 26.7 %, good 60.0 % and fair 13.3 %	93.3 % fusion rate	Not reported	None	No
Scholz et al. [39]	Retrospective Case series	Zero-P synthes	38 patients	6–11 months	Significant improvement in NDI and VAS scores	No instability at follow-up	62 % minor dysphagia in early postoperative period. 1/38 minor dysphagia at 6 months	None	Hoarseness (1/38)

anchored cages when compared to 33 patients submitted to ACDFP with a dynamic plate system. Similar findings were also observed in a recent randomized prospective study by Li et al. [36] which compared 23 patients submitted to ACDF using a zero-profile device and 23 patients submitted to ACDF using standard cages and plate. In such study, at the 2-year follow-up, both groups achieved similar clinical improvement and fusion rates.

In all these series, most of the reported postoperative complications in the zero-profile anchored cage group were related to the anterior neck approach itself and not specifically to this type of implant. Besides dysphagia, previous reports on the complications after ACDF using zero-profile anchored cages have already documented the occurrence of postoperative hematoma requiring surgical evacuation [33], cerebrospinal fluid leakage [38], infection [32, 34], adjacent level disease [34], hoarseness [32], transient neurological deficit [35],[19] pseudarthrosis [35], and small subsidences (less than 2 mm) [35]. In most series, the overall incidence of complications after ACDF with zero-profile anchored cages seems to be comparable to those reported in previous series of ACDF with stand-alone cages [30, 47].

In fact, hardware-related complications with the use of zero-profile anchored cages have been rarely reported in the literature. In a comprehensive review of the current literature on the postoperative complications after the use of zero-profile anchored cages, we found documented clinical and radiological follow-up for 409 patients in 10 different series, with a total cumulative follow-up of approximately 535 patients-year (Table 1) [32–41]. In all these patients only two reported implant-related complications were found [33, 34]. In their series, Barbagallo et al. [33] reported a case of screw displacement 1 month after the use of a zero-profile cage-plate anchored system in a patient under steroid therapy for many years. Hofstetter et al. [34] also reported one case of a blade migration in the 6 months follow-up after the use of a zero-profile anchored cage, but which did not require further surgical intervention.

Although previous series evaluating the use of zero-profile anchored cages have included patients with multi-level degenerative disc disease in which these new devices were used in adjacent segments [32, 33, 37–40], there is no previous report of hardware-related complication in such patients.

Therefore, despite the fact that, when used in adjacent levels, all types of zero-profile anchored cages would lead to convergence of either blades or screws in the vertebral body localized between the two implants, there have been no discussion in the previous literature or any formal contra-indication regarding the use of zero-profile anchored cages for the treatment of degenerative disease in

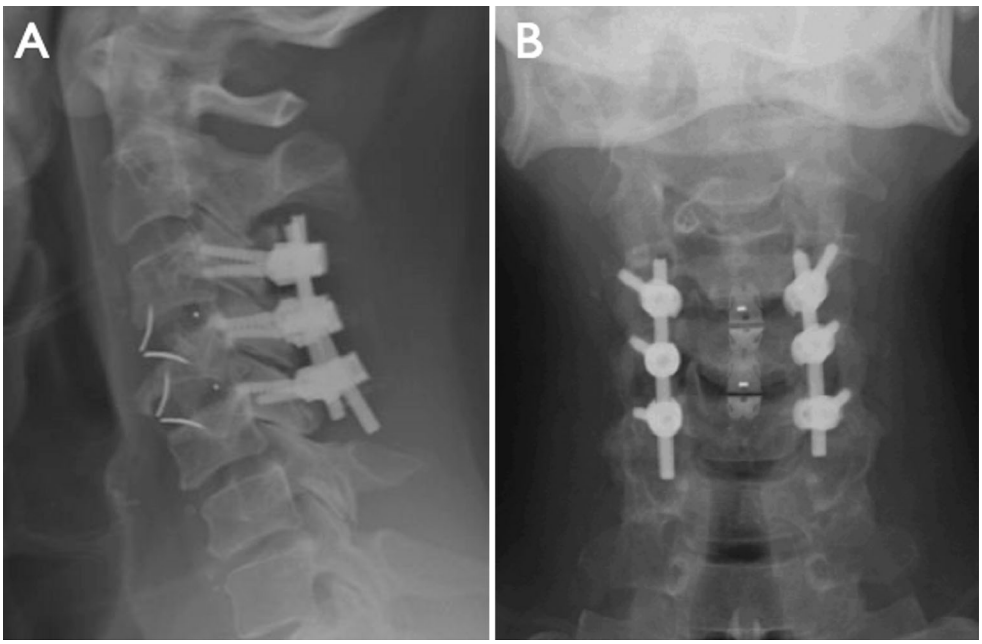

Fig. 4 Eight-months post-operative follow-up after the posterior C3–C5 instrumentation and fusion which was performed in order to stabilize the levels involved in the hardware-related complication of the previous two-level ACDF with zero-profile anchored cages. The patient presented significant clinical improvement and the X-Rays (**a** lateral and **b** AP) demonstrate fusion in progress and no evidence of failure of the posterior instrumentation

adjacent segments. In fact, in some series the authors have reported the performance of up to three-level ACDFs using zero-profile anchored cages [33, 38, 41].

Nevertheless, according to the reported experience, fracture of the intermediate vertebral body where blades (or screws) from above and below converge, may be a significant complication of the use of zero-profile anchored cages for the treatment of multilevel cervical degenerative disc disease. Ultimately, future experimental and clinical studies are warranted in order to evaluate both the biomechanical effects in the intermediate vertebra during implantation of such devices in adjacent levels as well as the long-term complication rates of the use of zero-profile anchored cages in multiple adjacent levels.

Final considerations

Although zero-profile anchored cages (either with blades or screws) may constitute an interesting strategy for increasing the biomechanical strength of interbody cages without the necessity of plating, the use of such systems for treatment of cervical multilevel degenerative disc disease in adjacent levels may lead to an increased risk of hardware-related complications, especially on the vertebral bodies in which the blades/screws from adjacent levels converge.

Despite the fact that, according to the performed literature review, hardware-related complications after the use of zero-profile anchored cages seem to be rare events, future biomechanical and clinical studies are warranted in order to evaluate the safety of employing such devices for the treatment of multilevel degenerative disc disease in the cervical spine.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests and that no funding was received for this work.

References

1. Miao J, Yu F, Shen Y, He N, Kuang Y, Wang X, Chen D (2014) Clinical and radiographic outcomes of cervical disc replacement with a new prosthesis. Spine J 14(6):878–883. doi: 10.1016/j.spinee.2013.07.439
2. Mummaneni PV, Amin BY, Wu JC, Brodt ED, Dettori JR, Sasso RC (2012) Cervical artificial disc replacement versus fusion in the cervical spine: a systematic review comparing long-term follow-up results from two FDA trials. Evid Based Spine Care J 2012(3):59–66
3. Qureshi SA, Koehler SM, Lu Y, Cho S, Hecht AC (2013) Utilization trends of cervical artificial disc replacement during the FDA investigational device exemption clinical trials compared to anterior cervical fusion. J Clin Neurosci 20:1723–1726
4. Burkhardt JK, Mannion AF, Marbacher S, Dolp PA, Fekete TF, Jeszenszky D, Porchet F (2013) A comparative effectiveness study of patient-rated and radiographic outcome after 2 types of decompression with fusion for spondylotic myelopathy: anterior cervical discectomy versus corpectomy. Neurosurg Focus 35:E4
5. Hermansen A, Hedlund R, Vavruch L, Peolsson A (2013) Positive predictive factors and subgroup analysis of clinically relevant improvement after anterior cervical decompression and fusion for

cervical disc disease: a 10- to 13-year follow-up of a prospective randomized study: clinical article. J Neurosurg Spine 19:403–411
6. Liu Y, Qi M, Chen H, Yang L, Wang X, Shi G, Gao R, Wang C, Yuan W (2012) Comparative analysis of complications of different reconstructive techniques following anterior decompression for multilevel cervical spondylotic myelopathy. Eur Spine J 21:2428–2435
7. Parker SL, Godil SS, Shau DN, Mendenhall SK, McGirt MJ (2013) Assessment of the minimum clinically important difference in pain, disability, and quality of life after anterior cervical discectomy and fusion: clinical article. J Neurosurg Spine 18:154–160
8. Barlocher CB, Barth A, Krauss JK, Binggeli R, Seiler RW (2002) Comparative evaluation of microdiscectomy only, autograft fusion, polymethylmethacrylate interposition, and threaded titanium cage fusion for treatment of single-level cervical disc disease: a prospective randomized study in 125 patients. Neurosurg Focus 12:E4
9. Bertalanffy H, Eggert HR. Clinical long-term results of anterior discectomy without fusion for treatment of cervical radiculopathy and myelopathy. A follow-up of 164 cases. Acta Neurochir (Wien) l90:127–135
10. Donaldson JW, Nelson PB (2002) Anterior cervical discectomy without interbody fusion. Surg Neurol 57:219–224
11. Hauerberg J, Kosteljanetz M, Bøge-Rasmussen T, Dons K, Gideon P, Springborg JB, Wagner A (2008) Anterior cervical discectomy with or without fusion with ray titanium cage: a prospective randomized clinical study. Spine (Phila Pa 1976) 33:458–464
12. Xie JC, Hurlbert RJ (2007) Discectomy versus discectomy with fusion versus discectomy with fusion and instrumentation: a prospective randomized study. Neurosurgery 61:107–116
13. Jacobs W, Willems PC, Kruyt M, van Limbeek J, Anderson PG, Pavlov P, Bartels R, Oner C (2011) Systematic review of anterior interbody fusion techniques for single- and double-level cervical degenerative disc disease. Spine (Phila Pa 1976) 36:E950–E960
14. Oh JK, Kim TY, Lee HS, You NK, Choi GH, Yi S, Ha Y, Kim KN, Yoon do H, Shin HC (2013) Stand-alone cervical cages versus anterior cervical plate in 2-level cervical anterior interbody fusion patients: clinical outcomes and radiologic changes. J Spinal Disord Tech 26:415–420
15. Samartzis D, Shen FH, Goldberg EJ, An HS (2005) Is autograft the gold standard in achieving radiographic fusion in one-level anterior cervical discectomy and fusion with rigid anterior plate fixation? Spine (Phila Pa 1976) 30:1756–1761
16. Fraser JF, Hartl R (2007) Anterior approaches to fusion of the cervical spine: a metaanalysis of fusion rates. J Neurosurg Spine 6:298–303
17. Kaiser MG, Haid RW Jr, Subach BR, Barnes B, Rodts GE Jr (2002) Anterior cervical plating enhances arthrodesis after discectomy and fusion with cortical allograft. Neurosurgery 50:229–236
18. Samartzis D, Shen FH, Lyon C, Phillips M, Goldberg EJ, An HS (2004) Does rigid instrumentation increase the fusion rate in one-level anterior cervical discectomy and fusion? Spine J 4:636–643
19. Song KJ, Taghavi CE, Lee KB, Song JH, Eun JP (2009) The efficacy of plate construct augmentation versus cage alone in anterior cervical fusion. Spine (Phila Pa 1976) 34:2886–2892
20. Wang JC, McDonough PW, Endow KK, Delamarter RB (2000) Increased fusion rates with cervical plating for two-level anterior cervical discectomy and fusion. Spine (Phila Pa 1976) 25:41–45
21. Ji GY, Oh CH, Shin DA, Ha Y, Kim KN, Yoon do H, Yudoyono F (2015) Stand-alone cervical cages versus anterior cervical plates in 2-level cervical anterior interbody fusion patients: analysis of adjacent segment degeneration. J Spinal Disord Tech 28(7):E433–E438. doi:10.1097/BSD.0b013e3182a355ad
22. Li H, Min J, Zhang Q, Yuan Y, Wang D (2013) Dynamic cervical plate versus static cervical plate in the anterior cervical discectomy and fusion: a systematic review. Eur J Orthop Surg Traumatol 23:S41–S46
23. Chen Y, Wang X, Lu X, Yang L, Yang H, Yuan W, Chen D (2013) Comparison of titanium and polyetheretherketone (PEEK) cages in the surgical treatment of multilevel cervical spondylotic myelopathy: a prospective, randomized, control study with over 7-year follow-up. Eur Spine J 22:1539–1546
24. Niu CC, Liao JC, Chen WJ, Chen LH (2010) Outcomes of interbody fusion cages used in 1 and 2-levels anterior cervical discectomy and fusion: titanium cages versus polyetheretherketone (PEEK) cages. J Spinal Disord Tech 23:310–316
25. Chiang CJ, Kuo YJ, Chiang YF, Rau G, Tsuang YH (2008) Anterior cervical fusion using a polyetheretherketone cage containing a bovine xenograftp: three to five-year follow-up. Spine (Phila Pa 1976) 33:2524–2428
26. Cho DY, Lee WY, Sheu PC (2004) Treatment of multilevel cervical fusion with cages. Surg Neurol 62:378–385
27. Mastronardi L, Ducati A, Ferrante L (2006) Anterior cervical fusion with polyetheretherketone (PEEK) cages in the treatment of degenerative disc disease. Preliminary observations in 36 consecutive cases with a minimum 12-month follow-up. Acta Neurochir (Wien) 148:307–312
28. Zhou J, Xia Q, Dong J, Li X, Zhou X, Fang T, Lin H (2011) Comparison of stand-alone polyetheretherketone cages and iliac crest autografts for the treatment of cervical degenerative disc diseases. Acta Neurochir (Wien) 153:115–122
29. Cho SK, Lu Y, Lee DH (2013) Dysphagia following anterior cervical spinal surgery: a systematic review. Bone Joint J 95-B:868–873
30. Fountas KN, Kapsalaki EZ, Nikolakakos LG, Smisson HF, Johnston KW, Grigorian AA, Lee GP, Robinson JS Jr (2007) Anterior cervical discectomy and fusion associated complications. Spine (Phila Pa 1976) 32:2310–2317
31. Kuo YC, Levine MS (2010) Erosion of anterior cervical plate into pharynx with pharyngotracheal fistula. Dysphagia 25:334–337
32. Azab W, Abdel-Razek M, Ali A, Abdelrahman A, Salaheldin W, Nasim K, Attia H, Soliman D (2012) Outcome evaluation of a zero-profile implant for anterior cervical diskectomy with fusion. Turk Neurosurg 22:611–617
33. Barbagallo GM, Romano D, Certo F, Milone P, Albanese V (2013) Zero-P. a new zero-profile cage-plate device for single and multilevel ACDF. A single Institution series with four years maximum follow-up and review of the literature on zero-profile devices. Eur Spine J 22:S868–S878
34. Hofstetter CC, Kesavabhotla K, Boockvar JA (2015) Zero-profile anchored spacer reduces rate of dysphagia compared to ACDF with anterior plating. J Spinal Disord Tech 28:E284–E290. doi:10.1097/BSD.0b013e31828873ed
35. Kasliwal MK, O'Toole JE (2012) Integrated intervertebral device for anterior cervical fusion: an initial experience. J Craniovertebr Junction Spine 3:52–57
36. Li Y, Hao D, He B, Wang X, Yan L (2015) The efficiency of zero-profile implant in anterior cervical discectomy fusion: a prospective controlled long-term follow-up study. J Spinal Disord Tech 28:398–403. doi:10.1097/BSD.0000000000000032
37. Miao J, Shen Y, Kuang Y, Yang L, Wang X, Chen Y, Chen D (2013) Early follow-up outcomes of a new zero-profile implant used in anterior cervical discectomy and fusion. J Spinal Disord Tech 26:E193–E197
38. Qi M, Chen H, Liu Y, Zhang Y, Liang L, Yuan W (2013) The use of a zero-profile device compared with an anterior plate and cage in the treatment of patients with symptomatic cervical spondylosis: a preliminary clinical investigation. Bone Joint J 95-B:543–547

39. Scholz M, Schnake KJ, Pingel A, Hoffmann R, Kandziora F (2011) A new zero-profile implant for stand-alone anterior cervical interbody fusion. Clin Orthop Relat Res 469:666–673
40. Vanek P, Bradac O, Delacy P, Lacman J, Benes V (2013) Anterior interbody fusion of the cervical spine with Zero-P spacer: prospective comparative study-clinical and radiological results at a minimum 2 years after surgery. Spine (Phila Pa 1976) 38:E792–E797
41. Zhou J, Li X, Dong J, Zhou X, Fang T, Lin H, Ma Y (2011) Three-level anterior cervical discectomy and fusion with self-locking stand-alone polyetheretherketone cages. J Clin Neurosci 18:1505–1509
42. Majid K, Chinthakunta S, Muzumdar A, Khalil S (2012) A comparative biomechanical study of a novel integrated plate spacer for stabilization of cervical spine: an in vitro human cadaveric model. Clin Biomech (Bristol, Avon) 27:532–536
43. Scholz M, Reyes PM, Schleicher P, Sawa AG, Baek S, Kandziora F, Marciano FF, Crawford NR (2009) A new stand-alone cervical anterior interbody fusion device: biomechanical comparison with established anterior cervical fixation devices. Spine (Phila Pa 1976) 34:156–160
44. Stein MI, Nayak AN, Gaskins RB 3rd, Cabezas AF, Santoni BG, Castellvi AE (2014) Biomechanics of an integrated interbody device versus ACDF anterior locking plate in a single-level cervical spine fusion construct. Spine J 14:128–136
45. Wojewnik B, Ghanayem AJ, Tsitsopoulos PP, Voronov LI, Potluri T, Havey RM, Zelenakova J, Patel AA, Carandang G, Patwardhan AG (2013) Biomechanical evaluation of a low profile, anchored cervical interbody spacer device in the setting of progressive flexion-distraction injury of the cervical spine. Eur Spine J 22:135–141
46. Yang L, Gu Y, Liang L, Gao R, Shi S, Shi J, Yuan W (2012) Stand-alone anchored spacer versus anterior plate for multilevel anterior cervical diskectomy and fusion. Orthopedics 35:e1503–e1510
47. Pitzen TR, Chobok J, Stulik J, Ruffing S, Drumm J, Sova L, Kucera R, Vyskocil T, Steudel WI (2009) Implant complications, fusion, loss of lordosis, and outcome after anterior cervical plating with dynamic or rigid plates: two-year results of a multicentric, randomized, controlled study. Spine (Phila Pa 1976) 34:641–646