Eur Spine J (2012) 21:1374–1382
DOI 10.1007/s00586-011-2131-9

ORIGINAL ARTICLE

Cage subsidence does not, but cervical lordosis improvement does affect the long-term results of anterior cervical fusion with stand-alone cage for degenerative cervical disc disease: a retrospective study

Wen-Jian Wu · Lei-Sheng Jiang · Yu Liang · Li-Yang Dai

Received: 10 April 2011 / Revised: 18 August 2011 / Accepted: 18 December 2011 / Published online: 29 December 2011

Abstract
Objective Clinical outcomes of the stand-alone cage have been encouraging when used in anterior cervical discectomy and fusion (ACDF), but concerns remain regarding its complications, especially cage subsidence. This retrospective study was undertaken to investigate the long-term radiological and clinical outcomes of the stand-alone titanium cage and to evaluate the incidence of cage subsidence in relation to the clinical outcome in the surgical treatment of degenerative cervical disc disease.
Methods A total of 57 consecutive patients (68 levels) who underwent ACDF using a titanium box cage for the treatment of cervical radiculopathy and/or myelopathy were reviewed for the radiological and clinical outcomes. They were followed for at least 5 years. Radiographs were obtained before and after surgery, 3 months postoperatively, and at the final follow-up to determine the presence of fusion and cage subsidence. The Cobb angle of C2–C7 and the vertebral bodies adjacent to the treated disc were measured to evaluate the cervical sagittal alignment and local lordosis. The disc height was measured as well. The clinical outcomes were evaluated using the Japanese Orthopaedic Association (JOA) score for cervical myelopathy, before and after surgery, and at the final follow-up. The recovery rate of JOA score was also calculated. The Visual Analogue Scale (VAS) score of neck and radicular pain were evaluated as well. The fusion rate was 95.6% (65/68) 3 months after surgery.
Results Successful bone fusion was achieved in all patients at the final follow-up. Cage subsidence occurred in 13 cages (19.1%) at 3-month follow-up; however, there was no relation between fusion and cage subsidence. Cervical and local lordosis improved after surgery, with the improvement preserved at the final follow-up. The preoperative disc height of both subsidence and non-subsidence patients was similar; however, postoperative posterior disc height (PDH) of subsidence group was significantly greater than of non-subsidence group. Significant improvement of the JOA score was noted immediately after surgery and at the final follow-up. There was no significant difference of the recovery rate of JOA score between subsidence and non-subsidence groups. The recovery rate of JOA score was significantly related to the improvement of the C2–C7 Cobb angle. The VAS score regarding neck and radicular pain was significantly improved after surgery and at the final follow-up. There was no significant difference of the neck and radicular pain between both subsidence and non-subsidence groups.
Conclusions The results suggest that the clinical and radiological outcomes of the stand-alone titanium box cage for the surgical treatment of one- or two-level degenerative cervical disc disease are satisfactory. Cage subsidence does not exert significant impact upon the long-term clinical outcome although it is common for the stand-alone cages. The cervical lordosis may be more important for the long-term clinical outcome than cage subsidence

Keywords Anterior cervical discectomy and fusion · Stand-alone cage · Cervical spine · Complication · Subsidence · Cervical alignment

W.-J. Wu · L.-S. Jiang · L.-Y. Dai (✉)
Department of Orthopedic Surgery, Xinhua Hospital, Shanghai Jiaotong University School of Medicine, 1665 Kongjiang Road, 200092 Shanghai, China
e-mail: chinaspine@163.com

W.-J. Wu · Y. Liang (✉)
Department of Orthopaedic Surgery, Ruijin Hospital, Shanghai Jiaotong University School of Medicine, 197 Ruijin Er Road, Shanghai 200025, China
e-mail: liangyu@sh163.net

Introduction

Since it was first introduced by Smith and Robinson [24] 50 years ago, anterior cervical discectomy and fusion (ACDF) has become a standard procedure for the operative treatment of degenerative cervical disc disease associated with radiculopathy or myelopathy. Although there is still controversy about the necessity of fusion after anterior cervical discectomy [25], most authors agree that fusion stabilizes the cervical spine and maintains the disc height, while decompressing the spinal cord and roots [1, 30]. However, autogenous tricotical iliac bone, which is widely used in ACDF as interbody graft, is associated with donor-site morbidity as well as graft problems [23, 27].

Different types of interbody fusion cages have been developed to address abovementioned issues. An interbody fusion cage provides immediate postoperative stability, maintains disc height, and therefore achieves fusion. The anterior plate system is often added in order to promote fusion and reduce the risk of graft extrusion and collapse [20, 21]. Clinical outcomes have been encouraging when cages are applied with or without additional fixation in single- and two-level procedures and even in three- and four-level surgeries [16, 19]. However, there are also debates about the use of cervical cages in a stand-alone style for anterior cervical arthrodesis in relation to complications, among which the most frequent is cage subsidence [10]. Until now, there are few studies for long-term results of the stand-alone cages for ACDF. The only study involving follow-up period of more than 5 years was a retrospective series of 146 patients reported by Hida et al. [14]. The authors followed up patients undergoing ACDF with stand-alone titanium cages, two kinds of hollow, threaded, and cylindrical cages, and found 7% of cage subsidence in their series. No studies have documented the long-term results of other types of cages used for ACDF in the stand-alone fashion.

The purpose of this study is to investigate the long-term safety and effectiveness of the stand-alone titanium box cages for ACDF based on a minimum 5-year follow-up, with special emphasis on the incidence of cage subsidence, and the possible relevance to the clinical outcome. We hypothesized that postoperative cage subsidence and sagittal alignment of the cervical spine would correlate with the clinical outcome.

Materials and methods

A retrospective study was conducted on patients undergoing ACDF with stand-alone cage for degenerative cervical disc disease. This study was approved by our Institutional Research Board.

Patient population

From Jan 2002 to Jun 2005, ACDF using a titanium box cage (SynCage C, Synthes USA, Paoli, PA, USA) was performed in 67 consecutive patients. Of the 67 patients, 10 were lost to follow-up. A total of 57 patients (34 males, 23 females) at 68 levels were included in this study with a minimum follow-up of 5 years. The mean age of these patients at operation was 47.2 years (range 23–70 years). Indications for surgery included progressive radiculopathy and/or myelopathy resulting from one- to two-level cervical degenerative disc disease after failed conservative treatment. Patients with more than two-level developmental stenosis of the cervical spine, continuous or combined ossification of the posterior longitudinal ligament, prior cervical spine surgery, and significant osteoporosis (T score <-2.5 at DEXA examination) were considered contraindicated.

Forty-six patients had a one-level fusion, and 11 patients a two-level fusion. C5–C6 was the most frequently treated level (C3–C4, 5 cases; C4–C5, 14 cases; C5–C6, 36 cases; and C6–C7, 13 cases).

Surgical technique and postoperative care

ACDF was performed via a standard anterolateral approach from the right side. With distraction screws placed into the adjacent vertebral bodies, distraction was applied using a Caspar distractor. The disc material was removed with the posterior longitudinal ligament opened and removed if necessary. The cartilage end-plates were removed with curettage while the bony end-plates were protected from drilling or curetting procedure.

After decompression was complete, an appropriate sized cage filled with autologous cancellous bone harvested from anterior iliac crest was implanted as a stand-alone device. The size of cage was determined by intraoperative evaluation using a trial cage in order to achieve the initial stability. After implantation of the cage, the Caspar distractor was released and the stability of the cage was confirmed.

Postoperatively, the patients were encouraged to resume their normal activities as soon as possible with a soft collar to avoid over-extension for 6 weeks.

Radiological assessment

Routine anteroposterior and lateral views were made preoperatively, 1–2 days postoperatively, at 3 months postoperatively and final follow-up. Lateral flexion/extension radiographs were obtained at 3 months postoperatively and at final follow-up. Fusion was defined as a lack of motion between the vertebral bodies and cages on flexion/extension radiographs and the absence of any dark halo around a cage on both anteroposterior and lateral radiographs; or bone bridging the intervertebral space through or around the cage [15].

Based on the lateral radiographs of the cervical spine at the neutral position, the sagittal alignment of the cervical spine was evaluated using the Cobb angle between C2 and C7. The improvement of the sagittal alignment was defined by ΔCobb angle (C2–C7 Cobb angle at the follow-up − C2–C7 Cobb angle before surgery). The Cobb angle of the vertebral bodies adjacent to the involved disc (local Cobb angle) was measured to evaluate the local lordosis. The local ΔCobb angle (local Cobb angle at the follow-up − local Cobb angle after surgery) was calculated to evaluate the change of the local lordosis and influence of cage subsidence upon sagittal alignment of the cervical spine. The anterior and posterior disc space heights of the surgical level were measured.

The occurrence of subsidence was investigated. Subsidence is defined as loss of height of more than 2 mm at any of the two measured disc heights [10].

All radiographic documents were reviewed by an independent observer.

Clinical evaluation

The Japanese Orthopaedic Association (JOA) score for cervical myelopathy was recorded before and after surgery, and at the final follow-up. A full score was defined as 17 points, 8 for upper and lower motor functions, 6 for sensory functions, and 3 for bladder rectal function. The recovery rate of JOA score, which indicates the degree of normalization after surgery, was calculated as (postoperative score − preoperative score) × 100/[17 (full score) − preoperative score] (%). Neck and radicular pain was evaluated using the Visual Analogue Scale (VAS) before and after surgery, and at the final follow-up.

Statistical analysis

Descriptive data are represented as means ± standard deviation (minimum–maximum). Repeated measure ANOVA or paired *t* test were used for comparison between pre- and postoperative continuous variables. When a statistical significance was shown by ANOVA, the post hoc Student–Newman–Keul's test was made. Parameters between the patients with and without subsidence were compared using unpaired *t* tests, Chi-square, or Fisher's exact test. Pearson correlation coefficient was used to measure the relationship between radiological and clinical outcome. SPSS software v16.0 was used for all statistical analyses. A P value of less than 0.05 was considered to be significant.

Results

All patients were followed up for at least 5 years, with the mean follow-up period of 6.58 ± 0.83 (range 5.17–7.83) years (Figs. 1, 2).

Radiological outcome

The fusion rate was 95.6% (65/68) 3 months after surgery. Subsidence took place in 13 cages (19.1%, 10 patients). There was one cage unfused in the group of subsidence and two cages unfused in the patients without subsidence 3 months after surgery. Statistical difference ($P < 0.05$) was noted between the fusion rate of patients with and without cage subsidence. One mild cage migration was noted 3 months after surgery with the level fused. Successful bone fusion was achieved in all patients at the final follow-up examination with no more subsidence identified.

Of 57 patients, 35 (61.4%) had a lordotic cervical spine, 13 (22.8%) a straight, and 9 (15.8%) a kyphotic preoperatively. After the operation, 39 patients (68.4%) had a lordotic, 9 patients (15.8%) a straight and 9 patients a kyphotic spine. At the last follow-up, 42 patients (73.7%) had a lordotic, 10 patients (17.5%) a straight, and 5 patients (8.8%) a kyphotic spine. C2–C7 Cobb angle was preoperatively 11.1 ± 13.6°, significantly improved to 13.6 ± 11.7° postoperatively ($P < 0.05$ vs. preoperatively) and 14.2 ± 12.6° at the last follow-up ($P < 0.05$ vs. preoperatively; $P > 0.05$ vs. postoperatively), indicating that the improved cervical lordosis was preserved. The mean improvement of C2–C7 Cobb angle (ΔCobb angle) at the final follow-up was 3.2 ± 10.1°. There was no significant difference of the ΔCobb angle ($P > 0.05$) between the subsidence (0.2 ± 9.9°) and non-subsidence (3.8 ± 10.3°) groups.

The Cobb angle between the two adjacent vertebral bodies was 3.4 ± 4.6° preoperatively, 7.0 ± 4.6° postoperatively, and 4.6 ± 4.1° at the final follow-up. The local lordosis was significantly improved after surgery, and the improvement was partially preserved at the final follow-up ($P < 0.05$). With regard to the disc with cage subsidence, the mean local ΔCobb angle (−3.2 ± 2.4°) was somewhat greater than that without subsidence (−2.3 ± 2.0°), showing no statistical significance ($P > 0.05$).

The disc height before and after surgery, and at the last follow-up are given in Table 1. The mean anterior disc height (ADH) and posterior disc height (PDH) of all patients, and of the subsidence and non-subsidence group were significantly increased after surgery, and then decreased at the final follow-up. At the follow-up, the mean preoperative ADH and PDH of all patients and the non-subsidence group were significantly increased ($P < 0.05$) than before surgery. For the patients with cage subsidence, both the mean ADH and PDH at the final follow-up were

Fig. 1 A 29-year-old female patient was treated with an ACDF at C5–C6. Preoperative plain radiograph showed slight lordosis of the cervical spine (**a**). MRI revealed a disc herniation at C5–C6 with spinal cord compression (**b**). Postoperative radiograph showed slight kyphotic alignment of cervical spine (**c**). The clinical outcome was satisfactory 5 years after surgery. The cage subsided but the segment was successfully fused. The cervical lordosis was preserved as shown by plain radiograph (**d**)

slightly higher than that before surgery although no statistical significance ($P > 0.05$) was shown.

The mean preoperative ADH and PDH were not statistically different ($P > 0.05$) between the subsidence and non-subsidence groups. The postoperative ADH of subsidence group was slightly greater than of the non-subsidence group with no statistical significance ($P > 0.05$), whereas the postoperative PDH of subsidence group was significantly greater than that of non-subsidence group ($P < 0.05$), indicating that the subsided levels might be distracted more during the surgery.

Clinical outcome

The clinical outcomes of these patients are summarized in Table 2. The JOA score of all patients, including both the

Fig. 2 A 66-year-old female patient with severe degeneration and good alignment of the cervical spine before surgery (**a**). MRI demostrated multi-level stenosis, with the level of C5–C6 and C6–C7 more severe (**b**). She underwent an ACDF at these two levels (**c**). Six years later, these two segments were fused with no cage subsidence (**d**). Both cervical alignment and clinical outcome was satisfactory

subsidence and non-subsidence group, were improved after surgery ($P < 0.05$) and then reduced at the final follow-up ($P < 0.05$) but remained better than before surgery ($P < 0.05$). The average JOA recovery rate was decreased from $42.5 \pm 17.6\%$ postoperatively to $37.0 \pm 18.5\%$ at final follow-up ($P < 0.05$). The average JOA score and JOA recovery rate of the two groups had no significant difference ($P > 0.05$) (Figs. 1, 2) at any time point. The JOA recovery rate was significantly ($\gamma = 0.347$, $P < 0.05$) related to the improvement of the C2–C7 Cobb angle (Fig. 3).

The neck and radicular pain of all patients both significantly relieved after surgery in term of the VAS. Although the neck pain slightly worsened at the final follow-up, no significant difference ($P > 0.05$) was noted. The neck and radicular pain of the two groups had no significant difference ($P > 0.05$) at any time points.

Table 1 Disc height in 57 patients treated with ACDF with stand-alone cage

Group	ADH (mm)			PDH (mm)		
	Preop	Postop	Final FU	Preop	Postop	Final FU
Subsidence	4.4 ± 1.4	8.1 ± 1.5$^{*,\#}$	4.8 ± 1.4§	4.0 ± 1.2	6.9 ± 1.3$^{*,\#,\S}$	4.1 ± 1.1§
($n = 13$)	(2.2–6.2)	(6.0–10.3)	(3.1–7.0)	(2.4–6.0)	(5.0–8.8)	(2.5–5.8)
Non-subsidence	4.2 ± 1.1$^{\#}$	7.6 ± 1.2$^{*,\#}$	6.8 ± 1.0*	3.8 ± 0.9$^{\#}$	6.3 ± 1.0$^{*,\#}$	5.5 ± 0.8*
($n = 55$)	(2.0–7.0)	(5.4–9.8)	(4.0–8.6)	(2.0–5.5)	(4.5–8.0)	(4.2–7.0)
Overall	4.3 ± 1.2$^{\#}$	7.7 ± 1.2$^{*,\#}$	6.5 ± 1.4*	3.9 ± 1.0$^{,\#}$	6.4 ± 0.9$^{*,\#}$	5.2 ± 1.1*
($n = 68$)	(2.1–7.2)	(5.3–9.8)	(3.2–9.2)	(2.0–6.2)	(4.5–9.0)	(2.5–7.2)

Preop preoperative, *Postop* postoperative, *FU* follow-up, *ADH* anterior disc height, *PDH* posterior disc height

* $P < 0.05$ versus preop

$^{\#}$ $P < 0.05$ versus final FU

§ $P < 0.05$ versus non-subsidence group

Table 2 Clinical outcomes of 57 patients treated with ACDF with stand-alone cage

Group	Overall ($n = 57$)	Subsidence ($n = 10$)	Non-subsidence ($n = 47$)
JOA score			
Preop	10.4 ± 2.1 (7–14)$^{\#}$	10.0 ± 2.2 (7–14)$^{\#}$	10.5 ± 2.1 (7–14)$^{\#}$
Postop	12.8 ± 2.2 (8–16)*	13.1 ± 2.3 (9–16)*	12.8 ± 2.2 (8–16)*
Final FU	12.6 ± 2.3 (9–16)*	12.8 ± 2.0 (9–15)*	12.6 ± 2.1 (9–16)*
Recovery rate of JOA Score (%)			
Postop	40.4 ± 17.5 (11.1–80)$^{\#}$	48.7 ± 18.2 (20–80)$^{\#}$	38.7 ± 17.0 (11.1–80)$^{\#}$
Final FU	37.1 ± 18.3 (0–80)	42.5 ± 15.1 (20–66.7)	35.8 ± 18.8 (0–80)
VAS of neck pain			
Preop	5.4 ± 1.7 (2–8)$^{\#}$	5.6 ± 2.0 (2–8)$^{\#}$	5.4 ± 1.6 (2–8)$^{\#}$
Postop	3.1 ± 1.2 (1–6)*	3.1 ± 1.0 (2–5)*	3.1 ± 1.2 (1–6)*
Final FU	3.5 ± 1.1 (1–5)*	3.9 ± 1.2 (2–5)*	3.4 ± 1.1 (1–5)*
VAS of radicular pain			
Preop	4.2 ± 1.1 (2–6)$^{\#}$	3.9 ± 1.2 (2–5)$^{\#}$	4.3 ± 1.0 (2–6)$^{\#}$
Postop	3.0 ± 0.7 (1–4)*	2.8 ± 0.6 (1–4)*	3.0 ± 0.8 (1–4)*
Final FU	2.8 ± 0.8 (1–4)*	2.6 ± 0.8 (1–4)*	2.9 ± 0.7 (1–4)*

Preop preoperative, *Postop* postoperative, *FU* follow-up

* $P < 0.05$ versus pre-op

$^{\#}$ $P < 0.05$ versus final FU

There were no cage-related complications and cage failure cases.

Discussion

To our knowledge, there are few reports of the long-term results of stand-alone cage used in ACDF. In the present study, stand-alone titanium box cages were used for the surgical treatment of one- or two-level cervical degenerative disc disease. Fifty-seven patients were followed up for at least 5 years. The fusion rate was 95.6% at 3 months postoperatively, and 100% at the final follow-up. After a minimum 5-year follow-up, the JOA score was found to be significantly improved with an average JOA recovery rate of 37.0%. Both the neck and radicular pain was significantly improved. There were no complications associated with the cages. All results suggest that the long-term clinical outcome of the stand-alone cages used in the surgical treatment of one- or two-level cervical spondylopathy is satisfactory.

There are several clinical studies supporting the use of stand-alone cage in ACDF, but reliability of this technique remains controversial. In a multicenter study [11] comparing the cylindrical cage with non-instrumented bone-only fusion, similar success rates were shown for the two techniques. Overall complication rate for the cage is lower. Cho et al. [4] used stand-alone PEEK cage in one-, two- and three-levels microdiscectomy for 40 patients. Radiological examination at 6 months after surgery revealed a fusion rate of 100%. The functional and neurological outcomes of PEEK cages were better than that of the autogenous iliac crest graft fusion. However, based on a systematic literature review, there is limited evidence supporting the use of a cervical interbody fusion device in place of autologous bone [31].

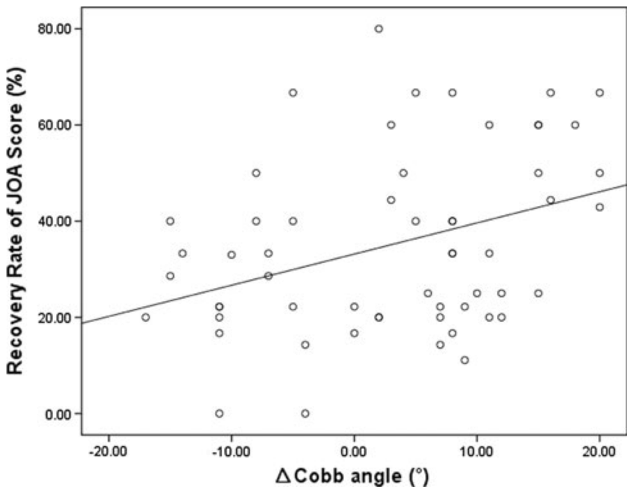

Fig. 3 Correlation between the improvement of C2–C7 Cobb angle and the recovery rate of JOA. The JOA recovery rate was significantly related to the improvement of the C2–C7 Cobb angle

One of the main concerns about stand-alone cage used for ACDF is the cage subsidence. During the process of bone remodeling, settlement of the cage of less than 2 mm into the vertebral bodies until fusion is to be expected [26]. If the cage subsides into the vertebral body, however, with disc collapse, foraminal height and the cervical alignment would fail to restore, thus influencing the clinical outcome. The incidence of cage subsidence and its consequences among the literatures were quite different. Gercek et al. [10] reported that 5 of 8 patients (9 levels, 62.5%) had radiological signs of cage subsidence and recommended additional stabilization is necessary to avoid this problem though cage subsidence did not correlate with clinical symptoms. In a prospective study [22], subsidence was present in 30 of the 67 (44.8%) fused segments of ACDF using a titanium cage, but the height of the foramen was well maintained among the subsidence cases. The occurrence of local kyphosis was rare and did not cause any clinical complications after 2 years follow-up. More recently, Kast et al. [17] in a randomized prospective study reported a subsidence rate of 29% using PEEK cage. In our series, the incidence of cage subsidence was 19.1% and less than that by the majority of other authors. All cases with cage subsidence were noted at a 3-month follow-up. For the subsidence cases, the disc height of the treated level at the final follow-up remained slightly greater than that before surgery. However, despite cage subsidence, the long-term clinical outcome of patients of subsidence group remained satisfactory.

Results of this study showed that the improvement of the JOA score significantly correlated with the improvement of the C2–C7 Cobb angle. This may indicate that preservation of the cervical lordosis would be more important for the long-term clinical outcome than cage subsidence itself. Normal lordotic alignment is one of the most important factors contributing to good motion and function of the cervical spine [29]. Postoperative kyphosis at a fused cervical motion segment has been reported frequently, especially in uninstrumented anterior fusion [28], with an incidence as high as 27.3% [13]. Sagittal malalignment after ACDF may relate to the cervical instability, postoperative axial pain, and the deterioration of neurological deficit, and may influence the functional recovery [7, 12]. The local loss of cervical lordosis may also alter dynamic kinematics of the cervical spine and increase biomechanical stress on the anterior vertebral elements in neighboring segments, thus promoting the progression of degenerative changes in the adjacent segments and deteriorating the long-term clinical outcome [2, 18].

Cage subsidence does not necessarily mean loss of local and general cervical lordosis. As we found, the change of the local and general alignment of subsidence and non-subsidence group was not significantly different. In fact, if the collapse of the anterior part of involved disc space is not greater than that of the posterior part, the local lordosis would be preserved, despite the disc space collapse. We cannot determine which part to subside, but we should adopt appropriate technique during the surgery by avoiding overdistracting the disc space and oversizing the cage, and carefully preparing the endplates, especially the anterior border of superior endplate where is less mineralized [3], thus reducing the incidence of cage subsidence and loss of normal alignment.

To increase fusion rate, prevent subsidence and restore cervical sagittal alignment, additional anterior cervical plating has been recommended for cage fixation [8, 10]. Study with finite element model showed that supplement of an anterior plate would provide much more stabilization capability than stand-alone cage [9]. However, rigid anterior cervical plate fixation may shield the mechanical load that is very important for fusion. On the other hand, there are some complications associated with anterior cervical plating [6]. Moreover, the cost of additional plating would increase the burden of the patient. Hwang et al. [16] performed three- and four-level interbody cage-assisted ACDF with or without plate fixation for degenerative cervical disc disease. They found that good neurological outcome was achieved in both groups, while the patients treated with stand-alone cage have lower complication rate and shorter hospital stay. In a prospective randomized study, Dai et al. [5] used carbon fiber or PEEK cages containing β-tricalcium phosphate in anterior cervical fusion and found that supplement with anterior plate fixation can increase the fusion rate and prevent cage subsidence but did not improve the 2-year outcome. In the current study, high fusion rate and good clinical outcome of stand-alone cage were shown after minimum 5-year follow-up. This may indicate that supplement of plate fixation is not necessary.

Conclusions

In summary, the clinical and radiological outcome of the stand-alone titanium box cage for the surgical treatment of one- or two-level degenerative cervical disc disease was satisfactory after a minimum 5-year follow-up. Subsidence is a common phenomenon for stand-alone cage fixation, but did not affect the long-term clinical outcome. Preservation of the cervical lordosis would be more important for the long-term clinical outcome than cage subsidence.

Conflicts of interest None.

References

1. Abd-Alrahman N, Dokmak AS, Abou-Madawi A (1999) Anterior cervical discectomy (ACD) versus anterior cervical fusion (ACF), clinical and radiological outcome study. Acta Neurochir 141:1089–1092
2. Barsa P, Suchomel P (2007) Factors affecting sagittal malalignment due to cage subsidence in standalone cage assisted anterior cervical fusion. Eur Spine J 16:1395–1400
3. Bartels RH, Donk RD, Feuth T (2006) Subsidence of stand-alone cervical carbon fiber cages. Neurosurgery 58:502–508
4. Cho DY, Liau WR, Lee WY, Liu JT, Chiu CL, Sheu PC (2002) Preliminary experience using a polyetheretherketone (PEEK) cage in the treatment of cervical disc disease. Neurosurgery 51:1343–1349
5. Dai LY, Jiang LS (2008) Anterior cervical fusion with interbody cage containing beta-tricalcium phosphate augmented with plate fixation: a prospective randomized study with 2-year follow-up. Eur Spine J 17:698–705
6. Demircan MN, Kutlay AM, Colak A, Kaya S, Tekin T, Kibici K, Ungoren K (2007) Multilevel cervical fusion without plates, screws or autogenous iliac crest bone graft. J Clin Neurosci 14:723–728
7. Ferch RD, Shad A, Cadoux-Hudson TA, Teddy PJ (2004) Anterior correction of cervical kyphotic deformity: effects on myelopathy, neck pain, and sagittal alignment. J Neurosurg 100: 13–19
8. Fraser JF, Hartl R (2007) Anterior approaches to fusion of the cervical spine: a metaanalysis of fusion rates. J Neurosurg Spine 6:298–303
9. Galbusera F, Bellini CM, Costa F, Assietti R, Fornari M (2008) Anterior cervical fusion: a biomechanical comparison of 4 techniques. Laboratory investigation. J Neurosurg Spine 9:444–449
10. Gercek E, Arlet V, Delisle J, Marchesi D (2003) Subsidence of stand-alone cervical cages in anterior interbody fusion: warning. Eur Spine J 12:513–516
11. Hacker RJ, Cauthen JC, Gilbert TJ, Griffith SL (2000) A prospective randomized multicenter clinical evaluation of an anterior cervical fusion cage. Spine 25:2646–2654
12. Harrison DD, Harrison DE, Janik TJ, Cailliet R, Ferrantelli JR, Haas JW, Holland B (2004) Modeling of the sagittal cervical spine as a method to discriminate hypolordosis: results of elliptical and circular modeling in 72 asymptomatic subjects, 52 acute neck pain subjects, and 70 chronic neck pain subjects. Spine 29:2485–2492
13. Heidecke V, Rainov NG, Burkert W (1998) Anterior cervical fusion with the Orion locking plate system. Spine 23:1796–1802
14. Hida K, Iwasaki Y, Yano S, Akino M, Seki T (2008) Long-term follow-up results in patients with cervical disk disease treated by cervical anterior fusion using titanium cage implants. Neurol Med Chir 48:440–446
15. Hwang SL, Hwang YF, Lieu AS, Lin CL, Kuo TH, Su YF, Howng SL, Lee KS (2005) Outcome analyses of interbody titanium cage fusion used in the anterior discectomy for cervical degenerative disc disease. J Spinal Disord Tech 18:326–331
16. Hwang SL, Lin CL, Lieu AS, Lee KS, Kuo TH, Hwang YF, Su YF, Howng SL (2004) Three-level and four-level anterior cervical discectomies and titanium cage-augmented fusion with and without plate fixation. J Neurosurg Spine 1:160–167. doi: 10.3171/spi.2004.1.2.0160
17. Kast E, Derakhshani S, Bothmann M, Oberle J (2009) Subsidence after anterior cervical inter-body fusion. A randomized prospective clinical trial. Neurosurg Rev 32:207–214
18. Katsuura A, Hukuda S, Saruhashi Y, Mori K (2001) Kyphotic malalignment after anterior cervical fusion is one of the factors promoting the degenerative process in adjacent intervertebral levels. Eur Spine J 10:320–324
19. Lied B, Roenning PA, Sundseth J, Helseth E (2011) Anterior cervical discectomy with fusion in patients with cervical disc degeneration: a prospective outcome study of 258 patients (181 fused with autologous bone graft and 77 fused with a PEEK cage). BMC Surg 10:10
20. Lowery GL, McDonough RF (1998) The significance of hardware failure in anterior cervical plate fixation: patients with 2- to 7-year follow-up. Spine 23:181–186
21. 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
22. Schmieder K, Wolzik-Grossmann M, Pechlivanis I, Engelhardt M, Scholz M, Harders A (2006) Subsidence of the wing titanium cage after anterior cervical interbody fusion: 2-year follow-up study. J Neurosurg Spine 4:447–453
23. Silber JS, Anderson DG, Daffner SD, Brislin BT, Leland JM, Hilibrand AS, Vaccaro AR, Albert TJ (2003) Donor site morbidity after anterior iliac crest bone harvest for single-level anterior cervical discectomy and fusion. Spine 28:134–139
24. Smith GW, Robinson RA (1958) The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. J Bone Joint Surg Am 40:607–624
25. Sonntag VK, Klara P (1996) Is fusion necessary after anterior cervical discectomy? Spine 21:1111–1113
26. Thome C, Krauss JK, Zevgaridis D (2004) A prospective clinical comparison of rectangular titanium cages and iliac crest autografts in anterior cervical discectomy and fusion. Neurosurg Rev 27:34–41
27. Thorell W, Cooper J, Hellbusch L, Leibrock L (1998) The long-term clinical outcome of patients undergoing anterior cervical discectomy with and without intervertebral bone graft placement. Neurosurgery 43:268–273
28. Troyanovich SJ, Stroink AR, Kattner KA, Dornan WA, Gubina I (2002) Does anterior plating maintain cervical lordosis versus conventional fusion techniques? A retrospective analysis of patients receiving single-level fusions. J Spinal Disord Tech 15:69–74
29. Villavicencio AT, Babuska JM, Ashton A, Busch E, Roeca C, Nelson EL, Mason A, Burneikiene S (2009) Prospective, randomized, double-blind clinical study evaluating the correlation of clinical outcomes and cervical sagittal alignment. Neurosurgery 68:1309–1316

30. Watters WC III, Levinthal R (1994) Anterior cervical discectomy with and without fusion: results, complications, and long-term follow-up. Spine 19:2343–2347
31. Wigfield CC, Nelson RJ (2001) Nonautologous interbody fusion materials in cervical spine surgery: how strong is the evidence to justify their use? Spine 26:687–694