

Is the improvement of cervical alignment really essential after three-level anterior cervical discectomy and fusion? A minimal 5-year follow-up

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Research article

Keywords: anterior cervical discectomy and fusion, cervical spondylotic myelopathy, anterior cage-with-plate, self-locked stand-alone cage, cervical alignment

Posted Date: January 8th, 2020

DOI: <https://doi.org/10.21203/rs.2.20402/v1>

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Abstract

Purpose: To identify the importance of sagittal alignment with self-locked stand-alone cage (SSC) and anterior cage-with-plate (ACP) system after 3-level anterior cervical discectomy and fusion (ACDF) on cervical spondylotic myelopathy (CSM) after minimal 5-year follow-up.

Methods: 38 patients with SSC system (SSC group) and 26 with ACP system (ACP group) from February 2007 to September 2013 were enrolled. Cervical alignment were C2-7 lordosis (CL), operated-segment CL (OPCL), upper and lower adjacent-segment CL (UCL and LCL) at preoperation (POP), immediate postoperation (IPO) and final follow-up (FFU). Clinical outcomes contained the neck disability index (NDI), the Japanese Orthopaedic Association (JOA) score and adjacent segment degeneration (ASD). Patients were divided into CL improved subgroup (IM subgroup) and non-improved subgroup (NIM subgroup).

Results: There were improvements on CL and OPCL in both groups. The change of CL and OPCL larger in ACP group ($P < 0.05$) but UAL and LAL were of no significance. NDI and JOA got improvement in both groups at IPO and FFU while ASD was in no difference between SSC and ACP. A total of 40 patients (18 vs 22) acquired CL improvement with a larger population in ACP group. There were no differences on the rate of ASD, NDI, JOA and their change between IM and NIM subgroup and the change of CL were not correlated with NDI, JOA and their change.

Conclusion: SSC and ACP both provide long-term efficacy on OPCL correction with little impact on adjacent segment. The improvement of CL after three-level ACDF seems not so essential.

Introduction

It was reported that anterior cervical discectomy and fusion (ACDF) has been considered a safe and effective surgical treatment for the treatment of cervical spondylotic myelopathy (CSM)[1–2]. The anterior cage-with-plate system (ACP) consisting of polyetheretherketone (PEEK) cage with titanium plates can support the stability of the cervical spine while probably with the side effects such as screw dislodgement, esophageal perforation and dysphagia[3]. However, anterior plating may also be associated with potential disadvantages and complications. The self-locked stand-alone cage (SSC), with two integrated self-locking clips and inserting into the vertebral body through the endplate, has been gradually clinically applied for CSM[4–5]. The comparisons on radiological and clinical outcomes between SSC and ACP system have been studied for years[4,6]. While there was still a vague on efficacy of operated or adjacent segment lordosis and the whole cervical alignment reconstruction between the two procedures, particularly in multi-level surgeries.

Cervical sagittal alignment was considered an important parameters and correlated to regional disability, general health scores[7]. In previous publications, one of the objectives was to improve or rebuilt cervical alignment with ACDF as it might be related to clinical outcomes[6–8]. A variety of disorders of cervical spine might begin with and lead to alignment pathology and abnormalities of the cervical spine [9], but others held negative attitude[10–11]. With a wider surgical exposure and more iatrogenic intervene in

multi-level ACDF, there was little knowledge about change of operated and global cervical alignment, and the relationship between cervical alignment and clinical outcomes.

Consequently, there came two questions: (1) Was there an equivalence on cervical alignment and clinical outcomes between SSC and ACP system? (2) Was the improvement of sagittal alignment as significant as reported before in cervical spine? Therefore, based on these confusions, the study performed a minimum 5-year follow-up on patients with CSM underwent consecutive three-level ACDF with SSC and ACP system.

1.materials And Methods

1.1Patient enrollment

This was a single-center retrospective and comparative study. The patients with CSM were selected based on the timing of presentation and were divided into two groups according to the surgical implants from February 2007 to September 2013. The patients performed with SSC was determined into SSC group while the cases with ACP implants were defined as ACP group.

The inclusion criteria were (1) patients with CSM required surgery with uncontrolled symptoms after 6-month conservation treatment; (2)consecutive three-level ACDF was performed; (3)the surgery method was either in SSC group or ACP group and (4)patients with intact radiographic and clinical outcomes. The exclusion criteria were followed by (1) patients' radiological parameters were too unclear to measure; (2) patients with a history of previous cervical surgery; (3) patients combined with other types of surgery such as artificial disc replacement or combined with SSC and ACP; (4)patients had operation for cervical spine tumor, fracture or infection; (5) patients who underwent follow-up less than 5 years. All patients have signed informed consent. This study was approved by the Institutional Ethics Committee of our hospital.

After a minimum 5-year follow-up, 38 patients were enrolled in SSC group and 26 patients were in ACP group, In comparison of the two groups, there were no significance in age, gender and body mass index (BMI). The mean follow-up was 67.5 ± 5.2 (m) (62m-75m) in SSC group and 69.2 ± 6.6 (m) (60m-77m) in ACP group. The most operated segments were C4-C7 (76.6%) with no significance between the two groups. There was no difference in intraoperative blood loss between the two groups but operation time was shorter in SSC group ($P < 0.05$)(**Table 1**).

1.2Surgical procedure

All of the surgeries were performed by the same senior surgeon. Patients were placed in a supine position after general anesthesia. A right-sided approach was utilized for both SSC and ACP surgeries and standard Smith-Robinson approach [12] to the cervical spine was performed. Bilateral discectomy and uncinated process resection was performed even with unilateral symptoms to remove osteophyte regrowth. After complete decompression, consecutive three cages were implanted. In SSC group, the

cages included zero profile anchored spacer MC+ (LDR, Troyes, France) and ROI-C (LDR, Troyes, France) while MC+ or Solis PEEK cages (Stryker, Michigan, USA) combined with anterior plates (DePuySynthes, New Jersey, USA) were served as ACP group (**Fig 1**). All patients were instructed to wear a soft collar for 2 months after ACDF.

1.3Cervical alignment evaluation

Cervical alignment was mainly evaluated by C2-7 lordosis (CL), as well as parameters including operated-segment cervical lordosis (OPCL), upper and lower adjacent-segment cervical lordosis (UCL and LCL). CL was the angle from lower endplate of C2 to lower endplate of C7, the positive value was defined as cervical lordosis whereas negative CL means kyphosis; OPCL was the angle from the upper endplate of cranial operated vertebrae to lower endplate of distal operated vertebrae; UCL was the angle from upper endplate of the cranial vertebrae of upper adjacent segment to lower endplate of the distal vertebrae of upper adjacent segment; LAL was the angle from upper endplate of the cranial vertebrae of lower adjacent segment to lower endplate of the distal vertebrae of lower adjacent segment (**Fig 2**). All parameters were measured from lateral standing plain radiographs, which were obtained at preoperation (POP), immediate postoperation (IPO) and the final follow-up (FFU).

1.4Clinical outcomes assessment

The clinical outcomes were evaluated with the neck disability index (NDI) score and the Japanese Orthopaedic Association (JOA) score, which were both evaluated at POP, IPO and FFU more than 5 years. The recovery rate (RR) of JOA was calculated by Hirabayashi method: $RR(\%) = (IPO \text{ or } FFU \text{ JOA} - POP \text{ JOA}) / (17 - POP \text{ JOA}) \times 100$.

In addition, complications such as reoperation, adjacent segment degeneration (ASD) were also recorded at IPO and FFU.

1.5Subgroup analysis

After a data synthesis of SSC and ACP group, subgroup analysis was performed based on the change of CL, which was calculated by CL at FFU minus CL at POP. A increase of CL represented improvement of cervical alignment while decrease of CL indicated deterioration of cervical alignment. At FFU, patients were also divides into CL improved group (IM subgroup) and non-improved group (NIM subgroup).

1.6Statistical analysis

The independent sample t test was used to compare cervical alignment parameters and clinical outcomes between SSC and ACP groups and between IM and NIM subgroups while paired t test and **variance** analysis were used to compare outcomes among POP, IPO and FFU within the same group. Chi-squared test or Fisher test was performed on dichotomous between the two groups. Pearson correlation analysis was utilized for the change of CL and clinical outcomes at FFU, respectively. The statistical

analysis was performed using SPSS 22.0 (International Business Machines Corporation, Armonk, NY, USA) and statistical significance was defined as $p < 0.05$.

2.results

2.1Comparisons between SSC and ACP groups

There were no significant differences on CL between SSC and ACP group at POP, IPO and FFU (all $P \geq 0.05$), but the change of CL at FFU was larger in ACP group ($P=0.026$); The CL was improved in ACP group at FFU contrasted with POP but not at IPO and in SSC group. OPCL were of no differences between the two groups but a more improvement was shown in ACP group ($P=0.014$); In addition, there were improvements on OPCL at IPO in both groups and at FFU in ACP group ($p=0.047$, $P=0.007$ and $P=0.019$, respectively). There was a significance on UCL at IPO between two groups ($P=0.037$) but no differences at POP and FFU, no difference on their change and no differences at IPO and FFU in the same group. There were no statistical differences on LAL between the two groups and at each period except for a less LAL in ACP group at FFU ($P=0.044$) (**Table 2**).

There were no differences in NDI between SSC and ACP group at POP, IPO and FFU, so were their change. While there were significant differences at IPO and FFU compared to POP, even an improvement at FFU compared to IPO (all $p < 0.01$). JOA and the RR of JOA were of no differences between SSC and ACP group, but there was also an improvement at IPO and FFU compared to POP (all $p < 0.01$) (**Table 3**).

There were no cases performed secondary operation in both groups except for one patient in SSC group with a second-stage surgery in posterior approach 2 weeks later after ACDF. The fusion rates were both 100 percent in the two groups at FFU. The fracture and slight displacement of one plate-screw occurred at IPO but with no progression and clinical symptom at FFU. There were respectively 7.89% (3/38) and 19.2% (5/26) cases with dysphagia in SSC and ACP group ($P=0.178$) while no one occurred at FFU. There were 63.2% cases suffered from ASD in SSC group at FFU while 61.5% in ACP group ($P=0.926$), where ASD in upper adjacent segment occurred in 8 cases in SSC group and 5 in ACP group ($P=0.859$) and ASD in lower adjacent segment occurred in 19 cases in SSC group and 14 in ACP group ($P=0.762$).

2.2Comparisons between IM and NIM subgroups

In total, there were 40 patients with cervical lordosis before ACDF with no difference in SSC (26/38) and ACP (14/26) group ($P=0.237$); After ACDF, 39 cases maintained lordosis in the two groups (25 vs 14) ($P=0.237$) and 21 patients got alignment-correction in SSC (10/38) and ACP (11/26) group with no difference ($P=0.181$). Eventually, a total of 40 patients (18 vs 22) acquired increase in CL with a larger population in ACP group ($P=0.003$).

There were 40 cases in IM subgroup while 24 cases in NIM subgroup. Table 4 (**Table 4**) showed there were no differences on NDI, the change of NDI, JOA and RR of JOA at FFU between the two subgroups, so was ASD (all $P \geq 0.05$). The largest increase of CL was 26° in the case from ACP group with a NDI

improvement of 26 and JOA RR of 75%, while the case with the largest decrease of -11.3° in NIM subgroup also showed a NDI improvement of 31 and JOA RR of 100% (**Fig 3**). According to correlation analysis, there was no correlation between the change of CL and NDI, JOA and their change ($P \geq 0.05$) (**Table 5**).

3.discussion

ACDF allows direct decompression of neural structures, reconstruction of cervical lordosis and stabilization of the operated segments[13]. Since the SSC system as a new-designed implant has been used for CSM, multiple studies mainly concentrated on the comparison between SSC and ACP in terms of surgery-related complications and clinical outcomes by a short- to middle- term cohort, having illustrated favorable outcomes[14–15]. Yun et al [16] conduct a 2-year follow-up on 2-level contiguous ACDF and showed compatible clinical outcomes and capacity of lordosis-maintenance between SSC and ACP. Shi et al [17] described a favorable outcomes on SSC on complications between the two procedures for 3-level CSM with 3-year follow-up. With different design concept between SSC and ACP system, the mechanism on cervical alignment reconstruction and on operated- or adjacent-segment effect still posed challenge. Therefore, this study focused on more elaborated measurements on global cervical alignment, operated- and adjacent- segment lordosis, as well as ASD, which firstly, with a long-term visit, demonstrated that ACP was slightly superior to SSC on CL and OPCL improvement, but with little and comparable impact on adjacent segment in both procedures.

Restoration of CL was achieved by posterior osteophylectomy, opening of the posterior longitudinal ligament and suitable selection of implants' sizes and shapes [6,16]. Our series suggested an effective outcomes on CL improvement by SSC and ACP. When comparing CL improvement between the two approaches, Chen et al [4] indicated SSC was inferior at restoring CL and may not provide better sagittal CL reconstruction in 3-level fixation with 24-36m follow-up. The titanium alloy plate was positioned in anterior vertebral line and the anterior intervertebral disk height might decrease less than posterior; in addition, the CL was restored by pulling the involved vertebrae towards the prebent lordotic ventral plate, which could make the segmental angle more improved [6]. While the zero-profile anchored spacer, consisting of a cage and single or two anchoring clips, showed less ability to restore CL than ACP [18]. On the other hand, a larger improvement on OPCL added more weights on CL reconstruction in three-level ACDF.

There was somewhat decrease on UCL and LCL in ACP group at IPO and FFU, which was considered a compensation by the adjacent segment for a much larger OPCL with ACP system to keep cervical balance. Secondly, biomechanical studies have revealed that SSC provides less stiffness of cervical spine as locking plate does in 2 or 3-level instrumentation [19]. As a consequence, SSC more closely matched the physiological elastic modulus of the vertebrae and resulted in greater load transfer to the interbody cages. The excessive stiffness of the metallic plate may incur stress shielding and uncomfortable kinematics on adjacent segments[20]. Then, the application of ROI-C in skip levels could maintain activity at a normal level between skip levels, thus not sacrificing any normal motion segments[21]. In addition,

hence accurate anterior osteophylectomy was essential to smoothen anterior surface of the adjacent vertebrae for ACP, which has also been advocated as a possible risk factor on loss of UCL and LCL[22]. In total, however, there was no much influence on adjacent segment lordosis in both approaches in this study.

One concern with multilevel ACDF was the potential for ASD with increased rigidity. Studies have shown that the presence of a plate was more likely to accelerate degenerative changes in adjacent segments[16,23]. However, a meta-analysis performed by Zhang et al [24] showed that there was no statistically significant difference in ASD incidence between the SSC and ACP groups with a multilevel ACDF with a short-term visit. Therefore, the precise cause of ASD was still unknown. During a long-term follow-up, our series provided comparable incidence of ASD between SSC and ACP although with a rate of more than 60%. While it was reported multi-level procedures may not be at a greater risk of developing ASD compared to single-level procedure[14]. Besides, the fact that no case with adjacent segment pathology for secondary surgery in either group and no significant change of UAL and LAL at FFU indicated the two approaches put little and comparable impact on the progression of ASD.

The comparisons on short-term clinical outcomes between SSC and ACP remained controversial. Njoku et al [8] and Yan et al [2] favored SSC had better effect on human pain relief and neurological function improvement. While Tong et al [25] showed SSC and ACP exerted similar efficacy in improving the functional and radiologic outcomes through a 2-year follow-up in a meta-analysis. Our data showed a significant improvement in clinical outcomes at the final visit contrasted with POP, even with that at immediate post-operation. The explanation might be the appropriate physiotherapy after surgery, the subjective adaption of patients and the edema elimination of nerve root promoted a further step on qualified adjusted life year.

It was considered that improvement and preservation of CL was a main goal in multilevel ACDF. Sagittal malalignment after ACDF may cause postoperative axial pain and worsening of neurologic deficits[21]. But a meta-analysis performed by Luo et al.[11] showed there was no correlation between clinical outcomes and cervical sagittal alignment. Our study favored that whether the CL improved or not, it acquired long-term and satisfactory clinical function recovery. Indeed, was it really important to get an improvement of CL? Posterior approaches such as laminoplasty were usually performed to address multi-level compression, but their use was limited to postoperative complications and loss of lordosis because of excessive posterior muscle stripping, impairment of muscle-ligament complex and reduction of muscle adhesion, which was associated with axial pain[26]. While ACDF kept the superiority in minimal incision and invasion, interstitial-space approach and preservation of posterior complex, leading to little kyphosis-derived symptom. Despite restoration of lordosis in a kyphotic cervical spine being a goal of surgery, there was no consensus about the optimal value of CL to achieve[27]. Moreover, it was reported that increased rigidity of adjacent segment and abnormal sagittal balance after ACDF promotes ASD[28]. While in our study, neither in ACP group nor in NIM subgroup, the incidence of ASD was comparable contrasted to another, which administrated ASD might not be directly derived from increased rigidity of adjacent segment or sagittal imbalance and was consistent with the opinion of Zhang et al[24].

In this study, no identified correlation was drawn between clinical outcomes and the change of CL after both procedures. Despite different types of cage and fixation, both procedures decompressed spinal cord directly by removing the anterior pathogenic compression[24]. Although the volume of spinal canal could be effected by CL[7], there was adequate compensated space for spinal cord recruitment after decompression. Then, there was severe dysfunction and long history before ACDF and the patient could acquire instantly complaint relief after surgery instead of what the change of CL brought. Moreover, the change of CL in most cases, although with CL increase or reduction, was in a acceptable range, which might be below the threshold of accelerating alignment-related dysfunction[8]. Therefore, the improvement of CL after SSC or ACP seemed not so essential as reported.

There were some limitations in our study. Firstly, the sample of both groups were little and a larger population could support a higher grade of evidence. Then, global cervical alignment was expressed by CL, which could not ideally describe total shapes of cervical spine such as sigmoid-S-type since it might effect the spinal canal volume [29] and result in a shape-derived compression. Finally, the conclusion was suitable for 3-level ACDF on CSM but might not for other types such as cervical spondylotic radiculopathy, where the nerve root could be effected by the height of intervertebral foramen result from the change of cervical alignment.

4.conclusion

The SSC and ACP system both provide a long-term and effective outcomes in maintaining and correction of CL, OPCL and quality of life with consecutive three-level ACDF on CSM, and make little impact on adjacent segment. ACP system was somewhat superior to SSC in CL improvement. No matter with improvement or reduction of CL, both subgroups acquire satisfied clinical outcomes. There is no identified correlation between clinical outcomes and the change of CL, and the improvement of CL after three-level ACDF seems not so essential.

Declarations

Ethics approval and consent to participate: This study has obtained ethics approval and consent of the ethics committee in our hospital.

Consent for publication: Not applicable

Availability of data and material: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

Funding: National Key R&D Program of China (grant number: 2016YFC0105606).

Authors' contributions: Conceptualization: LHY, LY; Data Curation: LHY, XS, YGJ; Formal Analysis: LY, XS; Investigation: LY, YGJ; Methodology: XSu; LY, ZZQ; Project Administration: LHY; Resources: XS; ZZQ; Software: XS, LY; Validation: LY; Visualization: LHY; Writing & Editing: LHY, XS, LY. All authors read and approved the final manuscript.

Acknowledgements: We acknowledge Houshan Lv who contributed towards the study by making substantial contributions to the design and the acquisition of data.

Abbreviations

anterior cervical discectomy and fusion (ACDF)

cervical spondylotic myelopathy (CSM)

anterior cage-with-plate system (ACP)

polyetheretherketone (PEEK)

self-locked stand-alone cage (SSC)

C2-7 lordosis (CL)

operated-segment cervical lordosis (OPCL)

upper adjacent-segment cervical lordosis (UCL)

lower adjacent-segment cervical lordosis (LCL)

preoperation (POP)

immediate postoperation (IPO)

the final follow-up (FFU)

neck disability index (NDI)

the Japanese Orthopaedic Association (JOA)

recovery rate (RR)

adjacent segment degeneration (ASD)

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Tables

Table 1 Information of demographics and ACDF on SSC group and ACP group

Statistics	SSC group	ACP group	P
Sex (M: F)	21:17	14:12	0.946
Aye (y)	62.9±8.8	63.5±7.7	0.846
BMI(kg/m ²)	24.1±3.5	25.7±3.1	0.196
DM (n)	3	2	0.552
Smoking (n)	7	4	0.687
Follow-up (m)	67.5±5.2(62-75)	69.2±6.6(60-77)	0.441
Operated level			0.252
C3-C6 (n)	7	8	
C4-C7 (n)	31	18	
Operation duration (min)	91.3±16.6	115.4±16.1	<0.001
Blood loss (ml)	67.4±39.6	62.3±32.7	0.867

Footnote: ACDF: anterior cervical discectomy and fusion; SSC:self-locked stand-alone cage; ACP: cage-with-plate system; M: male; F: female; BMI: body mass index; DM: diabetes mellitus

Table 2 Comparisons on CL, OPCL, UCL and LCL between SSC and ACP groups

Parameters	SSC group	ACP group	P
CL at POP (°)	9.1±12.5	3.3±11.7	0.166
CL at IPO (°)	12.8±10.5	8.6±9.8	0.259
CL at FFU (°)	13.1±8.2	11.9±10.5 ^b	0.728
ΔCL [#]	4.0±5.8	8.6±7.9	0.026
OPCL at POP (°)	3.6±9.1	2.9±10.9	0.747
OPCL at IPO (°)	9.6±9.0 ^a	11.9±6.0 ^{aa}	0.414
OPCL at FFU (°)	7.9±7.7	11.3±5.9 ^b	0.263
ΔOPCL [#]	4.1±6.0	10.2±8.8	0.014
UCL at POP (°)	4.6±7.2	3.4±6.7	0.645
UCL at IPO (°)	2.8±4.8	-0.8±3.5	0.037
UCL at FFU (°)	4.8±6.2	1.1±5.1	0.120
ΔUCL [#]	-0.5±5.8	-2.0±5.7	0.471
LCL at POP (°)	4.6±5.9	1.5±6.1	0.178
LCL at IPO (°)	5.2±6.1	0.5±10.7	0.145
LCL at FFU (°)	7.2±6.7	0.7±9.4	0.044
ΔLCL [#]	2.4±5.5	-1.1±5.3	0.083

Footnote: CL: C2-C7 lordosis; OPCL: operated-segment cervical lordosis; UCL: upper adjacent segment cervical lordosis; LCL: lower adjacent segment cervical lordosis; SSC: self-locked stand-alone cage; ACP: cage-with-plate system; POP: preoperation; IPO: immediate postoperation; FFU: final follow-up

^a: significance on parameters between POP and IPO (P<0.05); ^{aa}: significance on parameters between POP and IPO (P<0.01); ^b: significance on parameters between POP and FFU (P<0.05)

[#]: Δ means the change of parameters at FFU compared to POP

Table 3 Comparisons on clinical outcomes between SSC and ACP groups

Parameters	SSC group	ACP group	P
NDI at POP	37.6±2.8	38.5±3.2	0.406
NDI at IPO	19.9±8.6 ^{aa}	18.4±4.1 ^{aa}	0.579
NDI at FFU	12.5±9.9 ^{bb,cc}	12.5±5.9 ^{bb,cc}	0.992
Δ ₁ NDI [#]	17.9±8.5	20.4±4.1	0.364
Δ ₂ NDI [#]	25.3±10.4	26.3±4.5	0.759
JOA at POP	10.5±1.7	10.1±2.1	0.561
JOA at IPO	14.5±1.7 ^{aa}	14.8±0.9 ^{aa}	0.616
JOA at FFU	15.9±2.2 ^{bb}	15.5±1.6 ^{bb,c}	0.565
RR ₁ of JOA (%) [#]	60.3±30.0	68.2±11.1	0.399
RR ₂ of JOA (%) [#]	82.7±36.3	80.6±19.0	0.865

Footnote: SSC: self-locked stand-alone cage; ACP: cage-with-plate system; NDI: the neck disability index; POP: preoperation; IPO: immediate postoperation; FFU: final follow-up; JOA: the Japanese Orthopaedic Association scores

^{aa}: significance on parameters between POP and IPO (P<0.01); ^{bb}: significance on parameters between POP and FFU (P<0.01); ^c: significance on parameters between IPO and FFU (P<0.05); ^c: significance on parameters between IPO and FFU (P<0.01)

[#]: Δ₁ means parameters change at IPO; Δ₂ means parameters change at FFU; RR₁ means recovery rate at IPO; RR₂ means recovery rate at FFU

Table 4 Comparisons on clinical outcomes between IM and NIM subgroups

Parameters	IM subgroup	NIM subgroup	P
NDI at FFU	11.9±6.8	13.7±11.0	0.618
ΔNDI	26.4±6.7	24.6±11.0	0.592
JOA at FFU	15.9±1.5	15.4±2.7	0.575
RR of JOA (%)	84.1±20.6	77.2±43.2	0.578
ASD (n)	13	11	0.286

Footnote:IM: improvement; NIM: no improvement; NDI: the neck disability index; FFU: final follow-up; JOA: the Japanese Orthopaedic Association scores; RR: recovery rate

Table 5 Pearson correlation analysis between clinical outcomes and the change of CL

	r	P
ΔCL and NDI at FFU [#]	-0.164	0.412
ΔCL and ΔNDI [#]	0.162	0.420
ΔCL and JOA at FFU [#]	0.213	0.285
ΔC and RR of JOA [#]	0.215	0.282

Footnote: CL: C2-C7 lordosis; r: correlation coefficient; NDI: the neck disability index; FFU: final follow-up; JOA: the Japanese Orthopaedic Association scores; RR: recovery rate

[#]: Δ means the change of parameters at FFU compared to preoperation

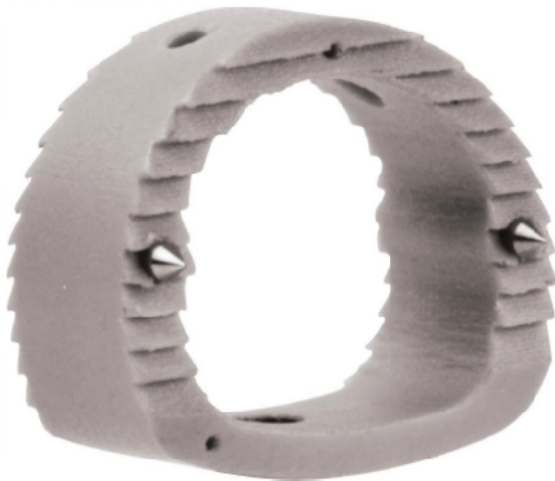
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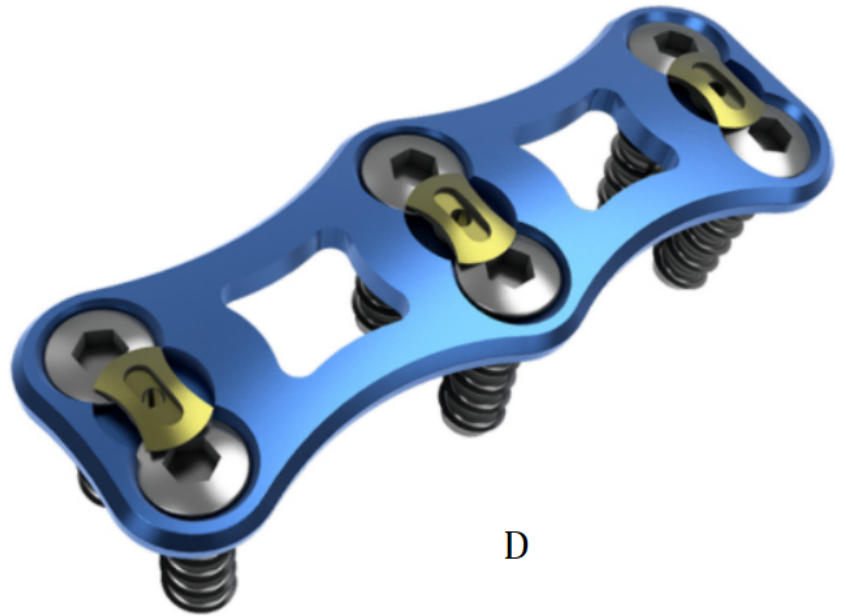
A



B



C



D

Figure 1

Different types of implants in SSC and ACP system. (A): Zero-profile anchored spacer MC+; (B): Zero-profile anchored spacer ROI-C; (C): Solis cage (D): Anterior cervical plate. SSC: self-locked stand-alone cage; ACP: anterior cage-with-plate system.

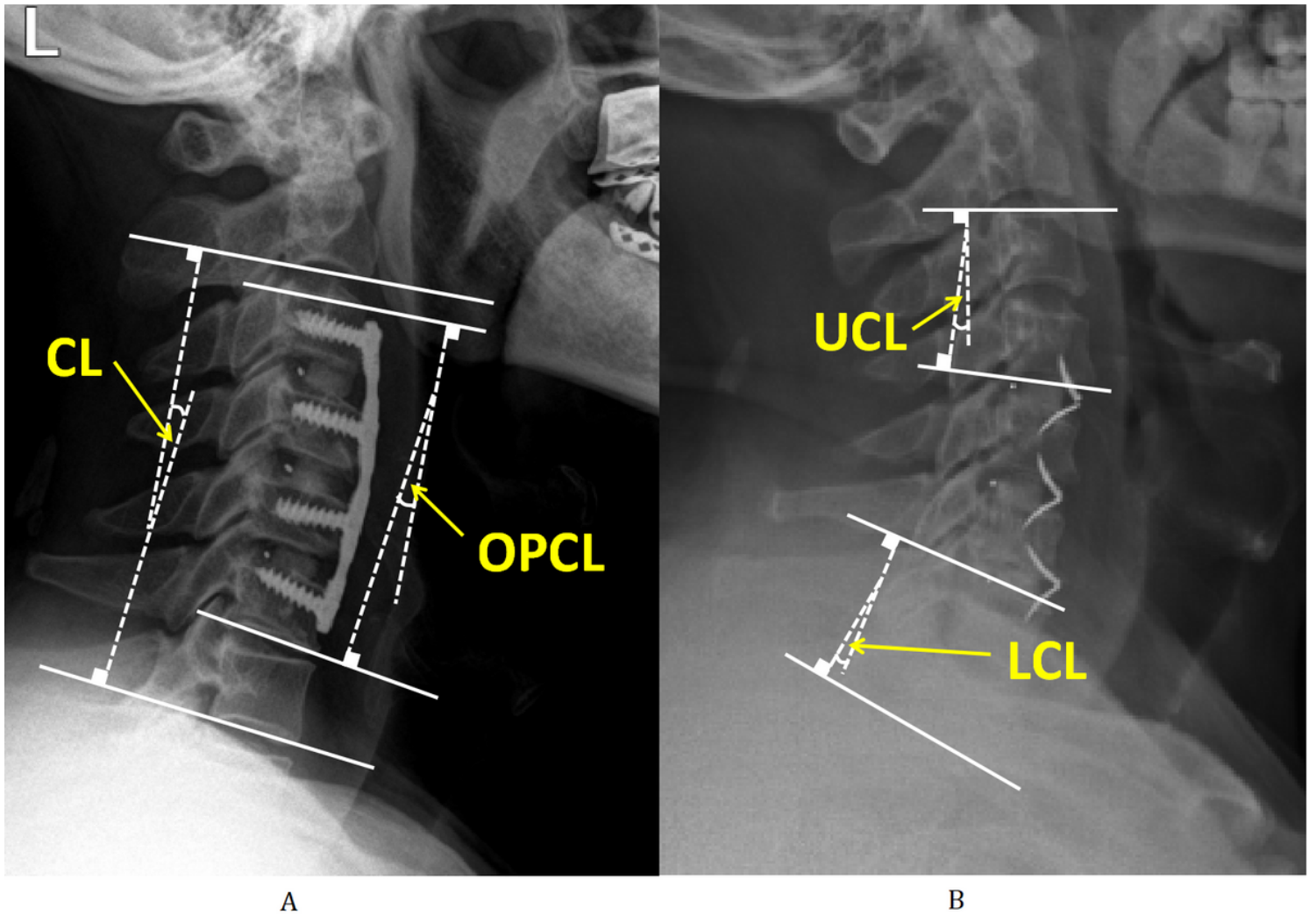


Figure 2

Measurements of cervical alignment on neutral lateral X-ray.(A): The measurements of CL and OPCL;(B): The measurements of UCL and LCL. CL: C2-7 lordosis; OPCL: operated-segment cervical lordosis; UCL: upper adjacent-segment cervical lordosis; LCL: lower adjacent-segment cervical lordosis.



Figure 3

Typical cases referred to CL and clinical outcomes. (A-B): The X-ray at POP and FFU of a 76-year-old male with the largest positive CL. The case from SSC group performed C3-6 with MC+ showed CL was 29.7° with NDI of 9, Δ NDI of 27, JOA of 16 and JOA-RR of 85.7% at FFU. (C-D): The X-ray at POP and FFU of a 64-year-old female with the largest negative CL. The case from ACP group performed C3-6 with Solis cage+plate showed CL was -8.2° with NDI of 6, Δ NDI of 27, JOA of 17 and JOA-RR of 100% at FFU; (E-F): The X-ray at POP and FFU of a 67-year-old female with the largest improvement of CL. The case from ACP group and IM subgroup performed C4-7 with MC+ cage+plate showed Δ CL was 26° with NDI of 15, Δ NDI of 26, JOA of 15 and JOA-RR of 75% at FFU; (G-H): The X-ray at POP and FFU of a 52-year-old male with the largest decrease of CL. The case from SSC group and NIM subgroup performed C4-7 with ROI-C showed Δ CL was -11.3° with NDI of 11, Δ NDI of 31, JOA of 17 and JOA-RR of 100% at FFU. CL: C2-7 lordosis; POP: preoperation; FFU: the final follow-up; SSC: self-locked stand-alone cage; NDI: the neck disability index; JOA: the Japanese Orthopaedic Association; RR: recovery rate; ACP: anterior cage-with-plate system; IM: improvement; NIM: no improvement. Δ means the change of parameters at FFU compared to POP.