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Review Article

Review of anterior cervical diskectomy/fusion (ACDF) using different polyetheretherketone (PEEK) cages

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ABSTRACT

Background: Multiple anterior cervical diskectomy/fusion (ACDF) techniques now use a variety of Polyehteretherketone (PEEK) cages; stand-alone (SA) and zero-profile (ZP) with/without screws, cages filled with demineralized bone matrix/autograft, and cages coated with hydroxyapatite or titanium. We compared the safety/efficacy between different PEEK ACDF cage constructs in 17 studies, and in some cases, additionally contrasted results with "routine" ACDF (i.e. series/historical data performed with combinations of iliac autograft/allograft and plates).

Methods: We focused on the clinical outcomes, fusion rates, postoperative radiographic changes/lordosis/subsidence, and/or reoperation rates for various PEEK ACDF constructs vs. "routine" ACDF.

Results: One to 3 and 4-level PEEK ACDF cages demonstrated high fusion rates, few cage failures, and low reoperation rates. Subsidence for PEEK ACDF cages did not reduce fusion rates or diminish the quality of postoperative outcomes. Further, titanium-coated (T-C) PEEK cages lowered fusion rates in one study (i.e. 44.1% fusions vs. 88.2% for routine PEEK ACDF) while ACDF PEEK cages coated with hydroxyapatite (HA) showed only a "trend" toward enhanced arthrodesis.

Conclusion: One to 3-4 multilevel ACDF PEEK cage constructs demonstrated comparable safety/efficacy when compared with each other, or in select cases, with "routine" ACDF (i.e. using autograft/allograft and plates).

Keywords: Anterior cervical diskectomy fusion (ACDF), Cages, Complications, Fusion rates, Hydroxyapatite Coated (HA), Outcomes, Polyetheretherketone (PEEK), Screws, Stand-Alone (SA), Subsidence, Titanium-Coated (T-C), Zero Profile (ZP)

INTRODUCTION

Multiple anterior cervical diskectomy/fusion (ACDF) Polyetheretherketone (PEEK) cage constructs/techniques are now available. Their various designs include; Stand Alone (SA) or Zero Profile (ZP) cages with/without screws, cages filled with demineralized bone matrix (DBM) and/or autograft, and PEEK cages coated with hydroxyapatite or titanium [Table 1].[1-17] Here, we reviewed 17 papers comparing the relative safety/efficacy of different single to 3 and 4-level PEEK cage ACDF constructs, with select comparisons to "routine" ACDF controls (i.e. typically using iliac autograft or allograft, and plates). Analyses focused on the clinical outcomes, fusion rates,

Table 1: Summary of findings of papers using PEEK cages for ACDF.

Author[REF] journal years	Study design	Variables	Variables	Variables	Outcomes conclusions
Cho *et al.*[4] Neurosurgery 2002	PEEK ACDF 80 Pts 40 Group A: ACDF/ PEEK 40 Group B ACDF Iliac Autograft (IA)	Evaluation Lordosis Ht. Foramina Cross Sect F Fusion/X-rays Neuro Status MR Findings	Peek Cages>Lordosis+2.33 mm (Not IA) >+2.54 Ht Foramina (not IA) Area Foramina>both Groups	Fewer AE Peek (2.5%) vs. IA (17.5%) Fusion Rates 100% PEEK 93.1% IA nearly same Outcomes prolo case better PEEK vs. IA	Better X-ray and MR Visualization Postop Studies with PEEK
Topuz *et al.*[16] Eur Spine J 2009	2-Level Adjacent PEEK ACDF Using DBM+AutoG F/O 3 yrs	Prospective 79 Patients Avg Age 51 DJD 2000–2005 CSM/Rad	Outcomes-Odom's Criteria 69 Exc/Good=87.3% Success 8 Fair/2 Poor	Fusion Based on X-rays 3, 12 (Dynamic), 24, 26 mos Postop	Lordosis same 91.7% postop Fusion Rate (145/158 levels) X-ray-no cage failure or dislodgement No reop
Faldini *et al.*[5] J Orthop Traumatol 2011	ACDF with PEEK Cages 1 Level 25 Pts 2 yr F/O	5 at C45 12 C56 8 C67	Preop NDI 34 13 at 6 mos 10 Latest	Mean Preop VAS 7 Postop 3	Good/exc fusion 10 pts most 100% avg 5 mos PEEK Cage ACDF Safe
Hellbusch *et al.*[8] J Neurosurg Spine 2012	X-ray PEEK Double Lucency Fusion After ACDF/PEEK Titanium Cages+Autograft All 1-Levels	Look for Fusion on 148 X-rays of ACDF with PEEK filled Local Autograft	PEEK Double Lucency Complete Radiolucent Ring Around Titanium Markers	178 levels -356 (2 Sides) 91% Double lucency titanium PEEK cages with full fusion	Double lucency helps confirm PEEK cage fusion
Pereira *et al.*[12] J Clin Neurosci 2013	ACDF+PEEK Cage Fusion 3-4 Levels No Plates	7-4 Levels 23-3 Levels Followed>2 Years (67%)	Sig Improved VAS/JOA ASD Reop ACDF at C34 in 2 pts; 6.7% Avg 62 mos	10% Same level -avg 49 mos-recurrence reop posterior decompression	Conclusion PEEK safe|effective
Park *et al.*[11] J Clin Neurosci 2016	Subsidence 1-Level SA PEEK Cages ACDF-77 Consecutive pts 2005-2012	Subsidence: Decrease Interbody Ht. > 3 mm X-rays 1 yr postop 26/77 (33.8%) Cage Subsidence	Solid Fusion 25/26 (96.2%) in Subsidence Group: Fusion 47/51 (92.2%) Non Subsidence Group	>3 mm Distance Between Anterior Margin Vert. Body/Cage Sig Correlated with Subsidence	Subsidence Not Correlate with Fusion Rate or Clinical Outcomes Cage Location Only Sig. Risk Factor
Gerszten *et al.*[6] Cureus 2016	ZP (A) vs. SA PEEK (B) Cage 3 and 4 Level ACDF Total 110 Levels (No Plates)	A-33 ZP Device T Screw Fixation B-35 SA PEEK -No Screws	A Levels: 27-3 Levels 6-4 Levels B Levels 30-3 Levels 5 – 4 Levels	Group A VAS Pre 6.4 Post 2.5 4 dysphagia Group B VAS Pre 7.1 Postop 2 3 Dysphagia	ZP vs. SA PEEK Cages Both Safe/ Effective 3-4 Level ACDF vs. Plates<<Dysphagia Rates
Shiban *et al.*[13] Acta Neurochir 2016	Outcomes 265 1-3 Level ACDF SA PEEK Cages 2007-2010 1 yr F/O X-rays: Avg. Age 55 139 M/132 CSM135 Rad	1 Level (127) 85% Fused 20% ASD Subside 25% 2-Level (125) 95% fused 29% ASD Subside 27% 3 Level (13) 94% Fused 15% ASD Subside 15%	VAS, HRQL EuroQOL, EQ-5D Non-Fusion 16 Reop ASD 4 Reop Fail Implant	ASD<HRQL Reoperations Required: ASD 16 (6%) And Implant Failure 4 (1.5%) Younger=Better Clinical Outcomes	Conclusion 1-2-3 ACDF with SA PEEK High Fusion Low Reop Rates

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Table 1: (*Continued*).

Author[REF] journal years	Study design	Variables	Variables	Variables	Outcomes conclusions
Spanos *et al.*[15] J Clin Med Res 2018	X-ray+Clinical Outcomes 74 1-2 Level ACDF PEEK Cages F/O 6-12 Mos	Evaluated: Cervical lordosis ROM	Outcomes NDI NRS Sig Reduced NRS and NDI 6 and 12 mos Postop	Cervical lordosis and ROM sig reduced 6, 12 mos postop	Reduced cervical lordosis and sagittal ROM no Sig change disability
Shiban *et al.*[14] Acta neurochir 2018	1-2 Level ACDF SA PEEK+DBM 194 Cases Avg Age 54 91 M	Retrospective CDDD 2010–2013 Minimal F/O 12 Mos 98 1-Level 96 2-Level	Mean VAS Myelop 5.2 Down to 2.6 Rad 5.8 Down to 2.1 Fusion 79% 1 and 82% 2-Level Fusions	Reop ASD 13 7% 1 Level 8% 2 level fusions Implant failure 7% 1 Level 8% 2 Level	No correlation X-ray-clinical Outcomes 1 yr Subsidence, ASDD, and cervical alignment did not change clinical result
Ng *et al.*[10] Asian spine J 2019	SA PEEK Cages 2-Level CSM Mean F/o 59 mos-31 Pts Avg Age 59	Outcomes 2007–2015 JOA score Fusion Subsidence Migration Alignement LSA	C3-C5 45% C4-C6 32% C5-C7 23% Mean JOA Improved 10.2-13.89 At 24 mos 100% Fusion	Subsidence 22.5% No impact on JOA scores or levels fused No cage migration 2 ASD Reop LOP 3 yrs postop	Years later SA PEEK Cages for 2-Level ACDF satisfactory outcomes+fusion rates
Zapolska *et al.*[17] Neurol Neurochir Pol 2019	1-2 Level SA PEEK ACDF Cages-Assess ASD 30 Pts	Preop; 1 yr Postop -NRS NDI-PL Biomech Eval Cobb Angles	1yr F/O ACDF 100% Fusion 97% <Pain<NDI-PL<Mobility	> Superior ASD Motion Non-Sig>ASD Below	1-2 level ACDF vs. PEEK cages High fusion rates<Mobility >QOL
Nakanishi *et al.*[9] J Clin Neurosci 2020	Safety ACDF T-C PEEK SA Cages Multicenter Prospective Study of Subsidence	1-2 Level ACDF CDDD 62 Cages/42 pts	Minimum F/O 6 mos Sig Cage Subsidence 11/62	Subsidence Moderate14.5% Severe 3.2% Incidence Same<65=>65 years old	+/-Subsidence= Improved Outcomes 1-2 Level T-C SA PEEK Cages Safe in Elderly
Ashour *et al.*[1] J Craniovertebr Junction Spine 2020	Eval Safety/Effect SA PEEK for 4-level ACDF Avoid Anterior Plates	Retrospective 2011–2018 66 Pts; 35 M/31 F F/O 24 mos	Mean JOA 13.3 pre 15.9 post Preserved Lordosis	Non significant curvature index ischihara (ICI) 9.9 pre and post 10.5	66 4-level ACDF PEEK cages no plates/ screws Safe/effective
Chin *et al.*[3] Cureus 2021	Gp I-41 HA PEEK Cages 1 Level ACDF Avg. age 58.5 vs.	Group II-47 ACDF No HA Cages-Avg Age 54.3 2 yr Sig. Differences VAS and NDI	Trend to Fusion with HA PEEK as Early as 3–5 mos vs.	Fusion No HA HA 7-8 mos	Sig improved VAS and NDI with HA PEEK No HO with HA PEEK
Balakumar *et al.*[2] Br J Neuorsurg 2021	1 Center RR SA PEEK ACDF Cages (83 pts; 111 levels) vs. ZP CS (79 pts at 111 Levels)	F/O 2-24 mos AE Assessed	AE SA-10 Dysphagia 3 Hoarse, 1 Cage Migration 1 Late Fused 1 Horner's 2 Subsidence	AE in ZP CS 4 Dysphagia 4 Hoarse 1 CSF Leak 1 Recurrent Symptoms	AE No sig differences between SA cages vs. ZP CS -sagittal balance, fusion rate, AE Subsidence

(*Contd...*)

Table 1: (*Continued*).

Author[REF] journal years	Study design	Variables	Variables	Variables	Outcomes conclusions
Godlewski *et al.*[7] Acta Neurochir 2022	85 Fusion Rates ACDF PEEK vs. 59 T-C PEEK Fusion Cages	Scans 12 mos postop 86 pts CT scans (144 disc spaces) 102 X-rays pts (166 Disc Spaces)	Total Fusion 101 (71%) Partial Fusion 43 (29.9%) 0% No Fused	75 Disc Space Fusions PEEK (88.2%) vs. 26 TC-PEEK (44.1%)	Sig. Higher Fusions 12 mos with PEEK vs. Lower TC-PEEK

SA: Stand alone, VAS Visual analog scale, HRQL: Health-related quality of life, EuroQOL quality of life questionnaire (EQ-5D), ACDF: Anterior diskectomy/fusion, M: Males, F: Females, CSM: Cervical spondylotic myelopathy, Rad: Radiculopathy, ASD: Adjacent segment disease, yr: Year, Eval: Evaluation, Preop: Preoperative, Postop: Postoperative, NRS: Numerical rating scale, NDI-PL: Neck disability index questionnaire -polish, Biomech: Biomechanical parameters, Sig: Significantly, Dec.-Decrease, IVH: Intervertebral disc space height, ACD: Anterior diskectomy (without fusion), Multi: Multilevel, F/O: Follow-up, Avg: Average, PEEK: Polyetheretherketone, IA: Iliac autograft, Ht. Foramina: Height foramina, Cross Sect. F: Cross section foramina, MR: Magnetic resonance imaging, AE: Adverse events, T-C Peek: Titanium-coated peek, Pts: Patients, Doc: Documented, ZP: Zero profile devices, T: Titanium, Fix: Fixation, DBM: Demineralized bone matrix, AutoG: Autograft, Exc: Excellent, Pseud: Pseudarthrosis, HA: Hydroxyapatite, HO: Heterotopic ossification, PMMA: Polymethyl methacrylate cervical cage, CDDD: Cervical degenerative disc disease, ROM: Range of motion, FSU: Functional spinal unit, CS: Cage screw construct, Sx: Symptoms, V: Vertebral body, JOA: Japanese orthopedic association score, LSA: Local segmental angle, Ht: Height, Sig: Significant, Reop: Reoperation, LOP: Laminoplasty, RCT: Randomized controlled trial

postoperative radiographic findings (i.e. lordosis, subsidence, disc space height), and/or reoperation rates in these studies.

Methods

Seventeen studies focused on the safety/efficacy between different ACDF PEEK cage constructs with occasional comparisons to "routine" ACDF controls [Table 1].[1-17]

Cho *et al.* Study from 2002 Fusion Rates and Complications for PEEK ACDF vs. Iliac Autograft ACDF

Cho *et al.* (2002) compared the complications, fusion rates, and outcomes for 40 patients undergoing ACDF with PEEK cages vs. 40 having ACDF utilizing iliac crest autograft (IA) [Table 1].[4] PEEK ACDF cages resulted in comparable fusion rates, the same increases in foraminal area, and similar outcomes vs. ACDF/IA. However, PEEK ACDF cages had the added benefits of; increasing the cervical lordosis (i.e. an average of + 2.33 mm), decreasing the complication rate (2.5% vs. 17.5% for ACDF/IA), reducing artifact, and providing better visualization on postoperative MR studies.

Results of 1-Level PEEK ACDF

Several 1-level PEEK ACDF studies showed good/excellent postoperative results with high fusion rates [Table 1].[3,5] Faldini *et al.* (2011) looked at 25 patients undergoing 1-level PEEK ACDF with a 2-year follow-up; there was nearly a 100% fusion rate at 5 postoperative months leading the authors to conclude that single-level PEEK ACDF constructs were safe and effective.[5] Comparing 41 single-level PEEK ACDF with hydroxyapatite (HA) coated cages vs. 47 PEEK ACDF cages without HA, Chin *et al.* (2021) found significant differences in VAS (Visual Analog Scale) and NDI (Neck Disability Index) scores (i.e. improvement) with the addition of HA at 2 postoperative years.[3] There was also a "trend" toward faster fusion with HA PEEK ACDF cages (i.e. as early as 3-5 postoperative months) vs. slower fusion rates (i.e. of 7-8 months) for those performed without HA impregnated into cages.

Results of 1 to 2-Level PEEK ACDF

Multiple 1 to 2-level PEEK ACDF studies also demonstrated high fusion rates and improved outcomes [Table 1].[13-15,17] Of the 1-level (127 patients) and 2-level (125 patients) SA PEEK ACDF performed by Shiban *et al.* (2016), high fusion rates (85% and 95%), comparable frequencies of adjacent segment disease (20% and 29%) and subsidence (25% and 27%), and low reoperations rates were respectively encountered.[13] Outcomes for Shiban *et al.* (2018) 194 patients undergoing single (98 patients) and 2-level (96 patients) SA PEEK ACDF supplemented with demineralized bone matrix (DBM) revealed improvement in postoperative VAS scores, high fusion rates (79% 1-level and 82% 2-level), low reoperation rates for ASD (7% and 8%), and low implant failure rates (7% and 8%).[14] Further, there was no correlation between X-ray findings and clinical status at one postoperative year. When Spanos *et al.* (2018) evaluated clinical and X-ray outcomes for 74 patients undergoing 1-2 level PEEK ACDF, they found significantly reduced postoperative cervical lordosis and sagittal range of motion (ROM) that did not significantly impact disability as determined utilizing the NDI-PS (Neck Disability Index-Polish Rating Scale)and NRS (Numerical Rating Scale). After Zapolsky *et al.* (2019) performed 30 single to 2-level SA PEEK ACDF, they found that patients

demonstrated 100% fusion rates with significant reductions in pain (97%), and significant improvement in the NDI - PL at one postoperative year.[17]

Results of 2-Level PEEK ACDF

Several 2-level PEEK ACDF studies verified high fusion rates and better outcomes with these constructs [Table 1].[10,16] In 2009, Topuz *et al*. supplemented 79 two-level adjacent PEEK ACDF with demineralized bone matrix (DBM) and autograft; outcomes were excellent/good (Odom's Criteria) in 69 patients.[16] Further, 91.7% fused (based on X-rays alone obtained 3-24 mos. postoperatively); there were no cage failures/dislocations, and no reoperations [Table 1]. Additionally, as Ng *et al*. (2019) used SA Peek ACDF Cages for 2-level procedures in 31 patients, they demonstrated a 100% fusion rate, no significant cage migration, and very satisfactory outcomes (i.e. improvement from 10.2 to 13.89 in the mean JOA Score (Japanese Orthopedic Association Score) over an average 24 month follow-up period).[10] Notably, 2 patients who developed ASD required secondary laminoplasties performed 3 years following their index surgery.[10]

Results of 3-4 Level PEEK ACDF

Several other series additionally documented the safety/efficacy of 3 and 4-level PEEK ACDF [Table 1].[1,12,13] Pereira *et al*. (2013) looked at outcomes over 2 postoperative years for 3 (23 patients) and 4-level (7 patients) ACDF PEEK cage fusions performed without anterior plating [Table 1].[12] They observed significant postoperative improvement in VAS and JOA scores for these patients. Notably, 10% of patients exhibited recurrent disease at the index level warranting secondary posterior decompressions. When Shiban *et al*. (2016) evaluated 3-level stand-alone (SA) PEEK ACDF, the fusion rate was 94%, the incidence of adjacent segment disease (ASD) was 15%, and the rate of subsidence was 15%. Of interest, in their latter series that included 1 to 3-level procedures, overall reoperation rates were low (i.e. 16 (6%) for ASD and 4 (1.5%) for implant failures).[13] Analysis by Ashour *et al*. (2020) regarding the safety/efficacy of 66 4-level SA PEEK ACDF performed without plates revealed significant improvement in the mean postoperative JOA scores while adequately preserving the cervical lordosis (i.e. no significant changes in the curvature index).[1]

Results of Zero Profile PEEK Cages vs. Stand Alone PEEK Cages for 3-4 Level ACDF

Zero Profile (ZP) PEEK ACDF, comprised of a radiolucent polyetheretherketone (PEEK) cage with an anterior titanium 4 hole plate for screw placement, were developed to avoid complications of anterior cervical plates, while maintaining stability (i.e. of interbody cages with plates). Two studies confirmed excellent results with ZP PEEK ACDF devices [Table 1].[2,6] In 2016, Gerszten *et al*. (2016) placed 3 to 4-level (i.e. total 110 levels) ZP PEEK ACDF with screws in 33 patients vs. SA PEEK ACDF cages in 35 patients without screws or plates; they found comparable VAS outcomes for both groups, but showed that ZP PEEK cages reduced dysphagia rates.[6] When Balakumar *et al*. (2021) compared the results for 83 SA PEEK ACDF cages (i.e. at 111 levels) vs. 79 ZP PEEK ACDF cage-Screw constructs (i.e. at 111 levels) performed over a 2-24 month follow-up period, they found no significant differences between the two regarding; adverse events/complications, sagittal balance, fusion rates, or incidence of subsidence [Table 1].[2]

Lower Fusion Rates for Titanium-Coated (T-C) PEEK ACDF vs. PEEK ACDF Alone

In 2022, Godlewski *et al*. compared fusion rates for 85 PEEK ACDF cages vs. 59 T-C PEEK ACDF cages.[7] At 12 months postoperatively, CT scans had been performed in 86 patients, and X-rays in 102 patients. These studies demonstrated total fusion in 101 patients and partial fusion in 43 patients; none showed complete fusion failure. Of interest, however, the PEEK ACDF without T-C showed significantly higher 88.2% fusion rates vs. a much lower 44.1% rate for T-C PEEK ACDF.

Subsidence Rates Following Single or Multilevel PEEK ACDF Cage Constructs Varying from Stand-Alone Devices to Titanium-Coated (T-C) PEEK Cages

Several studies documented various postoperative subsidence rates (i.e. defined as a decrease in interbody height of >3 mm on X-rays at 1-year postoperatively) following single to multilevel PEEK ACDF cage procedures [Table 1].[2,9-11,13,14] Park *et al*, (2016) studied subsidence rates following 77 1-level stand-alone PEEK ACDF cage procedures (2005–2012); subsidence occurred in 26 of 77 (33.8%) patients, 25 of whom solidly fused, while another 47 of 51 patients without subsidence fused.[11] They concluded subsidence did not negatively impact fusion rates or outcomes. Subsidence rates in Shiban *et al*. (2016) varied from 25% for 1-level, to 27% for 2-level, and 15% for 3-level SA PEEK ACDF cage procedures (265 cases); reoperations were warranted for ASD (16 patients) or implant failures (4 patients), but none required repeat surgery for subsidence.[13] Later in 2018, Shiban *et al*. found in their 1-2 level SA PEEK ACDF cage series (184 patients) that subsidence did not negatively impact patients' clinical outcomes.[14] Ng *et al*. (2019) noted that for 31 patients undergoing 2-level SA PEEK ACDF, the subsidence rate was 22.5%, but it also did not negatively impact JOA scores or fusion rates.[10] When Nakanishi *et al*. (2020) looked at the safety of performing 62 single to 2-level T-C SA PEEK cage

procedures (i.e. followed for at least 6 months), subsidence occurred in 11 (17.7%) of 62 cases, and was moderate in 14.5%, but severe in 3.2% of cases.[9] Interestingly, the frequency of subsidence was similar for those <65 and >65 years of age (i.e. concluded safe/effective in elderly), and did not negatively impact outcomes. When Balakumar *et al*. (2021) compared SA PEEK ACDF (83 patients) vs. ZP PEEK ACDF cage procedures (79 patients), there were just 2 instances of subsidence in the SA PEEK ACDF group, but none in those receiving ZP devices.[2]

Double Lucency X-ray Sign of Titanium-Coated PEEK ACDF (Plus Autograft) Fusion

Hellbusch *et al*.(2012) described the double lucency sign for confirming fusion based on X-rays performed in 148 patients undergoing 1-level Titanium-Coated (T-C) PEEK ACDF cage fusions filled with autograft [Table 1].[8] This sign, defined as consisting of a "complete radiolucent ring around Titanium markers" was seen in 91% of patients, and added confirmation of fusion.

CONCLUSION

Comparison between multiple types of ACDF PEEK cage constructs and select instances of "routine" ACDF largely demonstrated comparable safety/efficacy for these procedures.

Declaration of patient consent

Patients' consent not required as patients' identities were not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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