North American Spine Society Journal (NASSJ) 21 (2025) 100589

Contents lists available at ScienceDirect

North American Spine Society Journal (NASSJ)

journal homepage: www.elsevier.com/locate/xnsj

Clinical Studies

Complications and reoperations in young versus old patients undergoing cervical disc arthroplasty

Paal K. Nilssen, BA, Karim Shafi, MD, Nakul Narendran, BA, Daniel Farivar, MD, Edward Nomoto, MD, Christopher Mikhail, MD, Todd Lanman, MD, Sang Do Kim, MD*

Department of Orthopaedic Surgery, Cedars-Sinai Medical Center, Los Angeles, CA 90048, United States

ARTICLE INFO

Keywords:
Cervical disc replacement
CDA
Complications
Age
Reoperation
Old
Young

ABSTRACT

Background: Despite the growing popularity of cervical disc arthroplasty (CDA), there remains a lack of literature investigating outcomes in older patients and no consensus exists on an age threshold beyond which CDA is not recommended. This study aimed to compare outcomes between patients younger than 65 and those aged 65 and older undergoing CDA.

Methods: Patients who underwent CDA at a major spine center (January 2009–December 2023), with at least 1 year of follow-up, were included. Two age-based cohorts were analyzed: younger (<65) and older (≥65). Both single and multilevel disc replacements were considered. Primary outcomes included comparing 90-day complications and all-cause reoperation rates in the 2 cohorts. Secondary outcomes included comparisons of patient characteristics, operative data, and length of stay (LOS). Frequencies, chi-squared analysis, and Student's t-test were used to compare cohorts.

Results: A total of 298 CDAs were evaluated among 188 patients. There were 132 patients in the younger cohort (mean age: 48.9±10.2) and 56 in the older cohort (mean age: 69.5±3.8). Cohorts were similar with regards to body mass index, sex, and length of follow up. The overall 90-day complication rate was 23.8%. There was no difference in complication rates (younger: 23.3%, older: 25.0%, p=.60). Older cohort averaged more levels operated (older 1.8±0.6, younger 1.5±0.7, p=.006). The overall reoperation rate was 12.2% (young: 13.5%, older: 8.9%, p=.38). Subsidence was the most common cause of reoperation in both the younger (n=4, 3.0%) and older (n=2, 3.6%) cohorts.

Conclusion: In this series, we found no statistically significant differences in 90-day complication or reoperation rates between younger (<65 years) and older (≥65 years) patients undergoing CDA. Subsidence emerged as the most common complication, occurring at similar rates in both cohorts. While further large-scale, long-term analysis is warranted to determine clinical outcomes of CDA in older patients, this study provides comparable complication and reoperation rates as in the younger population.

Introduction

Degenerative changes in the cervical spine are a natural consequence of aging [1–3]. In patients with cervical radiculopathy or myelopathy, surgical intervention may be warranted, for which anterior cervical discectomy and fusion (ACDF) has largely been considered a mainstay of treatment for single or multilevel disease. Despite a long history of successful clinical outcomes achieved with ACDF, biomechanical studies have suggested that adjacent level kinematics from ACDF might predispose patients to abnormal segmental motion and adjacent segment degeneration (ASD) which may lead to revision surgery [4–7].

To obviate the risk of pseudoarthrosis and to reduce the rate of ASD, cervical disc arthroplasty (CDA) was developed as a motion-preserving alternative, with evidence showing equivalent, if not superior, clinical outcomes when compared to cervical fusion [7–9]. By avoiding fusion and preserving motion, CDA aims to reduce the rate of ASD and subsequent reoperations. However, despite the growing popularity of CDA, there is a substantial lack of literature investigating outcomes in older

FDA device/drug status: Not applicable.

Author disclosures: ***PKN:*** Nothing to disclose. ***KS:*** Nothing to disclose. ***NN:*** Nothing to disclose. ***DF:*** Nothing to disclose. ***EN:*** Nothing to disclose. ***CM:*** Nothing to disclose. ***TL:*** Nothing to disclose. ***SDK:*** Nothing to disclose.

* Corresponding author. Sang Do Kim MD, Department of Orthopaedic Surgery, Cedars-Sinai Medical Center, 444 S San Vicente Blvd Ste 900, Los Angeles, CA 90048, USA

E-mail address: Sang.kim@cshs.org (S.D. Kim).

https://doi.org/10.1016/j.xnsj.2025.100589
Received 17 November 2024; Received in revised form 15 January 2025; Accepted 16 January 2025
Available online 21 January 2025

population who meet the inclusion criteria of cervical disc arthroplasty from Investigational Device Exemption (IDE) studies. To our knowledge, no prior study has suggested a clear cutoff above which complications or reoperations increase.

Large body of evidence across spine literature suggests that advanced patient age is a significant contributor to complications, but IDE studies have no consensus on the upper limit of age [10–13]. The purpose of the present study is to investigate and to compare 90-day complications and reoperations between older and younger patients undergoing CDA.

Methods

Study design and patient selection

A retrospective review of electronic medical records and operative reports was conducted at a single institution to identify all patients who underwent CDA between January 2009 and October 2023. Given that there is no clear cut off of what is defined as younger and older, we decided on the age of 65 years which has been used in other spine studies looking at complications in adult idiopathic scoliosis. Patients were divided into 2 cohorts based on their age at the time of index surgery: patients younger than 65 years old and patients 65 years and older. Both single and multilevel procedures were included. Exclusion criteria were those patients with less than 12 months of follow up available for review.

Primary outcome of interest and secondary outcomes

Primary outcomes included 90-day complications and all-cause reoperations. Complications within 90-days included the incidence of hematoma formation, new neurological deficits, dural tear, dysphagia, vascular injury, dysphonia, and infection. Secondary outcomes included patient demographics, American Society of Anesthesiologists (ASA) classification, operative data, length of hospital stay (days), and mean follow-up time (years). Demographic data included age, sex, body mass index (BMI), and smoking status. Operative data included use of neuromonitoring, mean number of operated levels, implant type, mean operative time (minutes), mean estimated blood loss (mL). Subsidence was defined as a decrease of 3mm or more in functional spinal unit height from which was measured on a postoperative radiograph in comparison to a preoperative radiograph.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics, Version 28.0 (IBM Corp., Armonk, NY, USA). Statistical significance was determined at a p value of $<.05$. Descriptive statistics, such as chi squared analyses and Student's t-tests were used to compare categorical and continuous variables, respectively. Missing data were addressed using multiple imputation. This study was approved by the local institutional review board (IRB).

Results

Patient demographics and operative data

A total of 298 cervical artificial discs among 188 patients met inclusion criteria. There were 132 patients in the younger cohort (mean age 49.9±10.2 years) and 56 patients in the older cohort (mean age 69.5±3.8 years) ($p<.001$). There were 93 single-level cases, 82 two-level cases, and 13 three-level cases (Table 1). The mean follow-up duration was 2.2±1.8 years in the young cohort and 1.7±1.5 years in the old cohort ($p=.07$). There were no between group differences in sex ($p=.83$) and BMI ($p=.06$). The older cohort had slightly higher ASA classification scores ($p=.03$) and underwent more 2-level ADRs (64.3%) than young cohort who underwent more single-level ADRs (58.3%). Intraoperative data showed no differences in the use of neuromonitoring ($p=.11$), length of surgery ($p=.54$), estimated blood loss ($p=.91$), and mean length of hospital stay (0.39) (Table 2). Implant type between groups did not differ ($p=.60$). Prodisc C (41%) and Prestige LP (48.9%) were the most used implant type followed by M6-C (5.3%), Mobi-C (4.3%), and Simplify (0.5%).

Complications

The overall 90-day complication rate was 23.8% (Table 3). There was no difference in 90-day complication rate between groups (Old: 25.0% vs Young: 23.3%, $p=.60$). In the younger cohort there were 5 cases of hematoma formation, 1 dural tear, 1 esophageal injury, 1 vascular injury (vertebral artery injury), 1 infection, 7 instances of prolonged dysphagia (>6 weeks), and 4 instances of prolonged dysphonia (>6 weeks). In the older cohort, there were 4 instances of prolonged dysphagia, 2 instances of prolonged dysphonia, 2 infections, and 1 paraspinal fistula. Seventeen patients experienced a new postoperative neurological deficit; there were 6 deltoid palsies, 1 laryngeal nerve palsy, and 1 unilateral vocal cord paralysis (Table 4). Nine patients experienced new radiculopathy; 6 cases were secondary to residual bony neuroforaminal stenosis.

Secondary surgical interventions

The overall reoperation rate was 12.2% (n=23) (Table 5). There were 18 reoperations in the younger cohort (13.6%) and 5 reoperations (8.9%) in the older cohort ($p=.38$). Of those reoperations, 7/90 (7.8%) were Prodisc C implants and 16/79 (20.3%) were Prestige LP implants. Additionally, 8/93 (8.6%) were 1-level CDAs, 12/82 (14.3%) were 2-level CDAs, and 3/13 (23.1%) were 3-level CDAs. Overall reoperation rate did not differ with regards to female (13/94, 13.8%) and male (10/94, 10.6%) sex ($p=.56$). In the younger cohort, there were 9 female patients who required reoperation and 4 in the older cohort. There was no difference in average ASA score between those with a reoperation (2.31) and those without (2.43) a reoperation ($p=.33$). Lastly, there was no difference in patient BMI between those with a reoperation (26.8) and those without (26.7) ($p=.36$).

Within the younger cohort, subsidence was the most common cause (n=5, 3.8%), followed by excessive implant motion (n=3, 2.3%), evacuation of cervical hematoma (n=3, 2.3%), and continued neck pain (n=2, 1.5%). The causes of reoperation in the older cohort were evenly distributed (n=1, 2.1%) across persistent or new neurological symptoms, pain, subsidence, disc migration, infection, and excessive implant motion. There were no reoperations in the older cohort for implant malposition, hematoma evacuation, or wound exploration. Thirteen of the reoperations were at the index level and 3 involved an adjacent level in the younger cohort, while all 5 occurred at the index level in the older cohort.

Discussion

Despite the increasing utilization of CDA over the past 2 decades, there is a lack of literature evaluating the safety and efficacy of this procedure in older patients [14]. To our knowledge, this is the first study that aims to address this gap by comparing 90-day complications and reoperations among younger and older patients undergoing CDA. We hypothesized that older patients would have a higher incidence of complications and reoperations. Surprisingly, we found no statistically significant difference in either 90-day complications and revisions in patients ≥65 years of age compared to a younger cohort. (25.0% vs 23.3%, $p=.60$; 13.5% vs 8.9%, $p=.38$).

The Food and Drug Administration (FDA) and Investigational Device Exemption (IDE) trials of CDA have similar safety and efficacy when compared to ACDF. These trials did not have a consensus cut off age

Table 1
Patient demographic data.

N (%)	Young (N=132)	Old (N=56)	Total (N=188)	p value
Female	69 (52.3)	25 (44.6)	94 (50.0)	.48
Age	48.9±10.2	69.5±3.8	54.8 (±12.9)	<.001
Body mass index	26.1 (±4.8)	27.5 (±6.3)	26.7 (±5.3)	.06
Smoking status				.65
Current smoker	4 (3.0)	1 (1.8)	5 (2.7)	
Former smoker	44 (33.3)	22 (39.3)	78 (41.5)	
Never smoker	84 (63.6)	33 (58.9)	106 (56.4)	
ASA classification				.03
I	11 (8.3)	0	11 (5.9)	
II	82 (62.1)	27 (48.2)	109 (58.0)	
III	39 (29.6)	29 (51.8)	68 (36.2)	
Follow-up (years)	2.2 (±1.8)	1.7 (±1.5)	2.1 (±1.6)	.07
Total number of operated levels	198	100	298	
Mean number of operated levels	1.5 (±0.7)	1.8 (±0.6)	1.6 (±0.7)	.006
1-level	77 (58.3)	16 (28.6)	93 (49.5)	
2-level	46 (34.9)	36 (64.3)	82 (43.6)	
3-level	9 (6.8)	4 (7.1)	13 (6.9)	
Level distribution				.99
C3-4	20 (10.1)	10 (10.0)	30 (10.1)	
C4-5	41 (20.7)	20 (20.0)	61 (20.5)	
C5-6	74 (37.4)	36 (36.0)	110 (36.9)	
C6-7	61 (30.8)	32 (32.0)	93 (31.2)	
C7-8	2 (1.0)	1 (1.0)	3 (1.0)	
C8-T1	2 (1.0)	1 (1.0)	3 (1.0)	
Implant type				.60
Prodisc C	52 (39.4)	25 (44.6)	77 (41.0)	
Prestige LP	65 (49.2)	27 (48.2)	92 (48.9)	
Simplify	0	1 (1.8)	1 (0.5)	
Mobi-C	7 (5.3)	1 (1.8)	8 (4.3)	
M6-C	8 (6.0)	2 (3.6)	10 (5.3)	

Table 2
Intraoperative and hospital course data.

N (%)	Young (N=132)	Old (N=56)	Total (N=188)	p value
Use of neuromonitoring	74 (56.1)	24 (42.9)	98 (52.1)	.11
Mean operative time (minutes)	155.5 (±84.1)	147.8 (±62.5)	153.2 (±78.0)	.54
Mean estimated blood loss (mL)	83.7 (±119.8)	84.5 (±188.0)	84.2 (±142.6)	.91
Mean length of hospital stay (days)	2.1 (±2.2)	1.80(±1.3)	2.0 (±2.0)	.39

Table 3
90-day complication data.

N (%)	Young (N=132)	Old (N=56)	Total (N=188)	p value
Hematoma	5 (3.8)	0	5 (2.7)	
Dural tear	1 (0.8)	0	1 (0.5)	
Esophageal injury	1 (0.8)	0	1 (0.5)	
Dysphagia	7 (5.3)	4 (7.1)	11 (5.9)	.38
Vascular injury	1 (0.8)	0	1 (0.5)	
Dysphonia/vocal cord injury	4 (3.0)	2 (3.6)	6 (3.2)	.63
Infection	1 (0.8)	2 (3.6)	3 (1.6)	.10

Table 4
90-day neurological complication data.

N (%)	Young (N=132)	Old (N=56)	Total (N=188)	p value
New neurologic deficit	11 (8.3)	6 (10.7)	17 (9.0)	.56
Deltoid palsy	4 (3.0)	2 (3.6)	6 (3.2)	.84
Laryngeal nerve palsy	1 (0.8)	0	1 (0.5)	
Unilateral vocal cord paralysis	1 (0.8)	0	1 (0.5)	
New radicular symptoms	5 (3.8)	4 (7.1)	9 (4.8)	.32

and the mean age of each study was around approximately 45 years old [12,15–18]. Despite the wide range of subject ages, none of the trials investigated age-related differences in detail. With growing popularity of CDA, these surgeries are increasingly offered to older patient population without prior knowledge of their outcomes compared to the younger population cohort studied in these IDE studies.

In this study, we found that older patients undergoing CDA had a similar overall 90-day complication rate as younger patients. The most commonly reported complication in the literature among patients undergoing CDA is dysphagia/dysphonia (range = 1.3%–27.2%) [19–21]. In this study, dysphagia/dysphonia were common, but a majority of the cases resolved within 2 weeks postoperation with 5.8% and 3.2% of pa-

Table 5
Reoperation data.

N (%)	Young N=132	Old N=56	Total (N=188)	p value
Total number of reoperations	18 (13.6)	5 (8.9)	23 (12.2)	.38
Timing				
Early reoperations (<90 days)	6 (4.6)	1 (1.8)	7 (3.7)	.37
Late reoperations (>90 days)	12 (9.1)	4 (7.1)	16 (8.5)	.67
Causes				
Persistent symptoms and/or neurological deficits	3 (2.3)	1 (1.8)	4 (2.1)	.84
Axial neck pain	2 (1.5)	0	2 (1.1)	
Subsidence	4 (3.0)	2 (3.6)	6 (3.2)	.84
Heterotopic ossification	1 (0.8)	0	1 (0.5)	
Infection	0	1 (1.8)	1 (0.5)	
Implant malposition	1 (0.8)	0	1 (0.5)	
Excessive implant motion	3 (2.3)	1 (1.8)	4 (2.1)	.84
Hematoma evacuation	3 (2.3)	0	3 (1.6)	
Wound exploration	1 (0.8)	0	1 (0.5)	

tients experiencing prolonged dysphagia and dysphonia, respectively. Previous studies have identified increased age as a risk factor for postoperative dysphagia [22,23], however, in this study, no difference was observed. Other studies have postulated that dysphagia is an inevitable outcome of anterior cervical procedures and is not a complication [24]. Consequently, our overall rate of complications may be inflated due the inclusion of dysphagia in our complication profile. Other reported complications from this study reflect previously reported numbers in terms of vascular compromise (range: 1.1% [15]–2.4% [25]), dural injury (range: 0.0% [15]–7.1% [26]), and wound infection (range: 1.2% [27]–22.5% [11]).

Neurological complications related to CDAs are uncommon and are thought to be secondary to inadequate nerve root decompression. In the original FDA/IDE trials, neurological-related adverse events were reported to range from 0.4% to 13.4% [28]. However, subsequent follow up studies have reported lower rates of 0.9% to 4.1% [10,29,30]. The rate of neurologic complications in this study, align with previous studies with regards to new radicular symptoms secondary to nerve root impingement, highlighting the importance of evaluating neuroforamina prior to surgery and performing a thorough decompression intraoperatively. With regards to C5 palsy, the present study had an incidence of 3.2%, slightly higher than previously reported values following anterior cervical procedures (0.1%–7.0%) [31]. There remains some debate about the exact mechanism. Possible causes may include iatrogenic injury to the nerve root, spinal cord shifting during decompression, or over-distraction due to device sizing limitations [32,33]. Artificial disc replacements are available in different heights, which can over distract the foramen if not carefully planned.

Our analysis revealed a significant difference in the ASA classification distribution and the mean number of operated levels between the younger and older populations. The variation in ASA classification between groups likely reflects the increased prevalence of comorbidities and overall poorer baseline health in the older population. These findings are consistent with previous literature showing that older patients tend to have higher ASA scores due to factors such as cardiovascular disease, diabetes, and other chronic conditions that may affects surgical risk and recovery [34]. Similarly, the mean number of operated levels was significantly higher in the older group, which may be attributed to the increased degenerative changes commonly seen in the aging spine, requiring more levels of correction compared to their younger counterparts [35]. These differences are important to address as they may influence the overall outcomes and interpretations of our findings. Future studies with more robust sample sizes adjusting for these factors would be beneficial in clarifying the effect on surgical outcomes and reduce potential biases in the interpretation of the data.

The present series had a reoperation rate of 12.2% (n=23 patients), with 5 patients in the older cohort undergoing subsequent surgery and compared to 18 patients in the younger cohort. This value falls within the higher range of reoperation rates reported, though similar to those reported in elderly patients or those with osteoporosis undergoing ACDF [36,37]. Our rates maybe also elevated due to inclusion of revision surgeries and hybrid constructs. With regards to early reoperations, there were 6 cases in the younger cohort and 1 case in the older cohort. Causes of reoperation in the younger cohort were largely approach-related, including evacuation of anterior cervical hematomas as well as irrigation and closure of a ventral spinal fluid leak. Of note, there was 1 case of early subsidence with worsening axial neck pain, requiring removal of the implant and conversion to ACDF (Fig. 1).

Regarding late reoperations, there were 12 in the younger cohort and 4 in the older cohort. Initially, we expected a higher rate of subsidence in the older group due to poorer bone quality, but the subsidence rates were similar between the 2 cohorts (3.0% vs 3.6%). Notably, our subsidence rate is lower than that reported in previous studies, which range from 11% to 23% for single and multilevel procedures [38,39]. Reported risk factors for subsidence include implant design, multilevel procedures, and endplate violation. Additionally, osteopenia and osteoporosis have been identified as independent risk factors for mechanical complications [40]. Unfortunately, due to the retrospective nature of this study, preoperative bone density data were unavailable. While the association may seem intuitive, many surgeons infrequently perform bone health assessments preoperatively [41]. According to several surveys, this could be attributed to several factors, such as logistical challenges, cost-benefit considerations, inadequate insurance coverage, or lack of consensus regarding the implications of low bone density for surgical management [42–44]. While avoiding patients with poor bone quality is crucial for minimizing complications, Blumenthal et al. [45] suggests that routine preoperative DEXA scanning in all CDA candidates may not be necessary. Nonetheless, patients with risk factors for poor bone quality should be evaluated preoperatively. We routinely check for bone density in peri-menopausal and postmenopausal patients or any patients with history of pathologic fractures. Future studies should aim to establish standardized, evidence-based guidelines, incorporating specific bone mineral density thresholds and their implications for treatment. Additionally, due to the variability in how subsidence is defined and reported based on available follow-up, further research is needed to clarify the precise impact of age on this complication.

A major contributor to the success of the operation is appropriate patient selection. Classically, CDA has been more commonly accepted younger patients with soft disc herniations and minimal degenerative cervical spondylosis. However, over the past decade, CDA utilization has expanded, particularly within older patients or those with cervical spondylotic myelopathy [14]. While previous studies have demonstrated a positive correlation between advanced age and increasing morbidity following spine surgery, these results are not universal [46]. Although older patients are more likely to have more medical comorbidi-

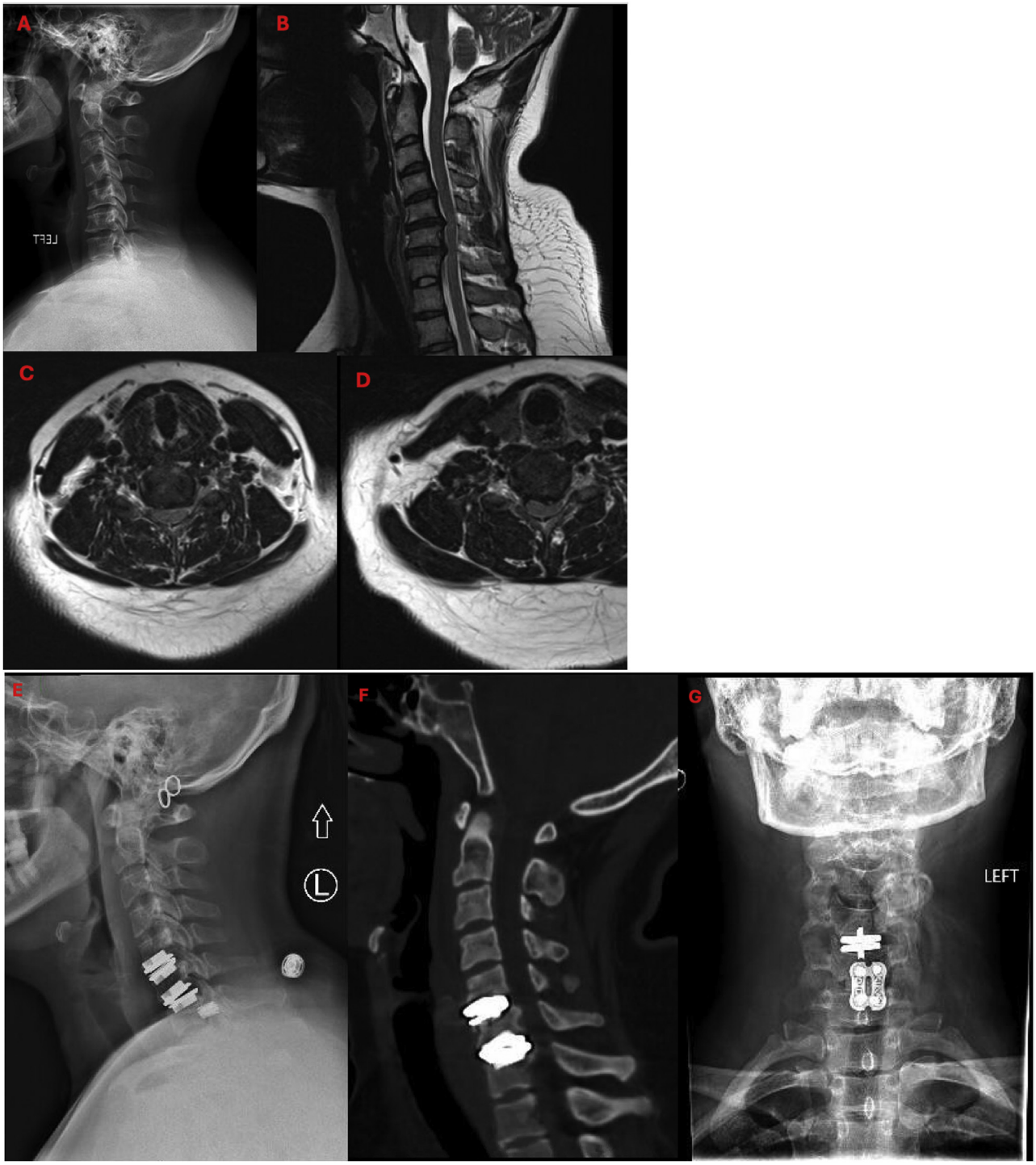

Fig. 1. (A) Lateral radiograph of a 31-year-old female who presented with cervical radiculopathy that had failed extensive conservative treatment. (B) T2-Weighted sagittal MRI demonstrates degenerative changes most severe at C5–C6, C6–C7. Axial MRI cuts of C5–C6 (C) and C6–C7 (D) demonstrate left sided foraminal stenosis. Postoperatively, patient noted worsening axial neck pain, with lateral radiograph demonstrating fixed kyphotic alignment of C6–C7 prosthesis (E). (F) CT scan demonstrating subsidence of implant into C6 endplate. (G) Patient required reoperation with removal of artificial disc device and conversion to anterior cervical discectomy and fusion (ACDF) with allograft and plate fixation.

ties, which may put them at greater risk for complications following surgery. This study demonstrates that the application of CDA in an older population, when performed technically well in appropriate patients, may be a viable and effective option for treatment of degenerative cervical disc disease causing radiculopathy or myelopathy. A recent study by Tsai et al.[47] found that CDA not only alleviated pain in patients with cervical degenerative changes, but also restored sagittal balance in the cervical spine and range of motion.

There are several notable limitations of this study. First, although the demographics and surgical techniques were nearly identical in our study, aside from age, a larger sample size may be necessary to detect subtle differences among age-related factors. Second, age of 65 is some-

what arbitrary cut off. There may be some heterogeneity among cohorts by including patients around 65 in both cohorts. However, excluding these patients from the study would have significantly reduce our sample size and power of the study. Third, we included single and multilevel procedures as well as hybrid procedures. As such, this introduces a significant degree of variability into our study, as the short and long-term effects of combined fusion and motion-sparing devices in a single stage remains poorly understood. However, given that the approach, discectomy, and decompression portions of these procedures are the same as single-implant type procedures, we do not believe that age would be a significant contributor to the clinical success of hybrid constructs.

Conclusions

With an average follow-up time of 2.2 years, this retrospective analysis of a major spine center found that patients aged 65 years and older undergoing CDA had similar 90-day complication and reoperation rates as patients aged less than 65 years. This study demonstrates that the application of CDA in an older population, when performed technically well in appropriate patients, may be a viable and effective option for treatment of degenerative cervical disc disease causing radiculopathy or myelopathy.

Summary sentence

This retrospective analysis of a major spine center found that patients aged 65 years and older undergoing CDA had similar 90-day complication and reoperation rates as patients aged less than 65 years.

Declarations of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No artificial intelligence was used in the writing of this manuscript.

Acknowledgment

None.

References

[1] Gore DR. Roentgenographic findings in the cervical spine in asymptomatic persons: a ten-year follow-up. Spine (Phila Pa 1976). 2001;26(22):2463–6. doi:10.1097/00007632-200111150-00013.
[2] Lehto IJ, Tertti MO, Komu ME, Paajanen HE, Tuominen J, Kormano MJ. Age-related MRI changes at 0.1 T in cervical discs in asymptomatic subjects. Neuroradiology 1994;36(1):49–53. doi:10.1007/BF00599196.
[3] Okada E, Matsumoto M, Ichihara D, et al. Aging of the cervical spine in healthy volunteers: a 10-year longitudinal magnetic resonance imaging study. Spine (Phila Pa 1976) 2009;34(7):706–12. doi:10.1097/BRS.0b013e31819c2003.
[4] Hilibrand AS, Robbins M. Adjacent segment degeneration and adjacent segment disease: the consequences of spinal fusion? Spine J 2004;4(6 Suppl) 190S–194S. doi:10.1016/j.spinee.2004.07.007.
[5] Eck JC, Humphreys SC, Lim TH, et al. Biomechanical study on the effect of cervical spine fusion on adjacent-level intradiscal pressure and segmental motion. Spine (Phila Pa 1976) 2002;27(22):2431–4. doi:10.1097/00007632-200211150-00003.
[6] Park DH, Ramakrishnan P, Cho TH, et al. Effect of lower two-level anterior cervical fusion on the superior adjacent level. J Neurosurg Spine 2007;7(3):336–40. doi:10.3171/SPI-07/09/336.
[7] Wang Q, Tu Z, Hu P, et al. Long-term results comparing cervical disc arthroplasty to anterior cervical discectomy and fusion: a systematic review and meta-analysis of randomized controlled trials. Orthop Surg 2019;12(1):16–30. doi:10.1111/os.12585.
[8] Moatz B, Tortolani PJ. Cervical disc arthroplasty: pros and cons. Surg Neurol Int 2012;3(Suppl 3):S216–24. doi:10.4103/2152-7806.98582.
[9] Gao F, Mao T, Sun W, et al. An updated meta-analysis comparing artificial cervical disc arthroplasty (CDA) versus anterior cervical discectomy and fusion (ACDF) for the treatment of cervical degenerative disc disease (CDDD). Spine (Phila Pa 1976) 2015;40(23):1816–23. doi:10.1097/BRS.0000000000001138.
[10] Heller JG, Sasso RC, Papadopoulos SM, et al. Comparison of BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion: clinical and radiographic results of a randomized, controlled, clinical trial. Spine (Phila Pa 1976) 2009;34(2):101–7. doi:10.1097/BRS.0b013e31818ee263.
[11] Burkus JK, Traynelis VC, Haid RW, Mummaneni PV. Clinical and radiographic analysis of an artificial cervical disc: 7-year follow-up from the Prestige prospective randomized controlled clinical trial: clinical article. J Neurosurg: Spine 2014;21(4):516–28. doi:10.3171/2014.6.SPINE13996.
[12] Davis RJ, Kim KD, Hisey MS, et al. Cervical total disc replacement with the Mobi-C cervical artificial disc compared with anterior discectomy and fusion for treatment of 2-level symptomatic degenerative disc disease: a prospective, randomized, controlled multicenter clinical trial: clinical article. J Neurosurg: Spine 2013;19(5):532–45. doi:10.3171/2013.6.SPINE12527.
[13] Upadhyaya CD, Wu JC, Trost G, et al. Analysis of the three United States food and drug administration investigational device exemption cervical arthroplasty trials: clinical article. J Neurosurg: Spine 2012;16(3):216–28. doi:10.3171/2011.6.SPINE10623.
[14] Shafi K, Du JY, Blackburn CW, et al. Trends in indications and contraindications for cervical disk arthroplasty from 2009 to 2019. Clin Spine Surg 2024;37(7):E283–9. doi:10.1097/BSD.0000000000001589.
[15] Hisey MS, Bae HW, Davis R, et al. Multi-center, prospective, randomized, controlled investigational device exemption clinical trial comparing Mobi-C cervical artificial disc to anterior discectomy and fusion in the treatment of symptomatic degenerative disc disease in the cervical spine. Int J Spine Surg 2014;8:7. doi:10.14444/1007.
[16] Murrey D, Janssen M, Delamarter R, et al. Results of the prospective, randomized, controlled multicenter food and drug administration investigational device exemption study of the ProDisc-C total disc replacement versus anterior discectomy and fusion for the treatment of 1-level symptomatic cervical disc disease. Spine J 2009;9(4):275–86. doi:10.1016/j.spinee.2008.05.006.
[17] Coric D, Nunley PD, Guyer RD, et al. Prospective, randomized, multicenter study of cervical arthroplasty: 269 patients from the Kineflex|C artificial disc investigational device exemption study with a minimum 2-year follow-up: clinical article. J Neurosurg Spine 2011;15(4):348–58. doi:10.3171/2011.5.SPINE10769.
[18] Phillips FM, Lee JYB, Geisler FH, et al. A prospective, randomized, controlled clinical investigation comparing PCM cervical disc arthroplasty with anterior cervical discectomy and fusion. 2-year results from the US FDA IDE clinical trial. Spine (Phila Pa 1976) 2013;38(15):E907–18. doi:10.1097/BRS.0b013e318296232f.
[19] Zhang X, Zhang X, Chen C, et al. Randomized, controlled, multicenter, clinical trial comparing BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion in China. Spine (Phila Pa 1976) 2012;37(6):433–8. doi:10.1097/BRS.0b013e31822699fa.
[20] Lanman TH, Burkus JK, Dryer RG, Gornet MF, McConnell J, Hodges SD. Long-term clinical and radiographic outcomes of the prestige LP artificial cervical disc replacement at 2 levels: results from a prospective randomized controlled clinical trial. J Neurosurg Spine 2017;27(1):7–19. doi:10.3171/2016.11.SPINE16746.
[21] Xu JC, Goel C, Shriver MF, et al. Adverse events following cervical disc arthroplasty: a systematic review. Global Spine J 2018;8(2):178–89. doi:10.1177/2192568217720681.
[22] Wang T, Ma L, Yang DL, et al. Factors predicting dysphagia after anterior cervical surgery: a multicenter retrospective study for 2 years of follow-up. Medicine (Baltimore) 2017;96(34):e7916. doi:10.1097/MD.0000000000007916.
[23] Wu B, Song F, Zhu S. Reasons of dysphagia after operation of anterior cervical decompression and fusion. Clin Spine Surg 2017;30(5):E554–9. doi:10.1097/BSD.0000000000000180.
[24] Shriver MF, Lewis DJ, Kshettry VR, Rosenbaum BP, Benzel EC, Mroz TE. Dysphagia rates after anterior cervical diskectomy and fusion: a systematic review and meta-analysis. Global Spine J 2017;7(1):95–103. doi:10.1055/s-0036-1583944.
[25] Gornet MF, Burkus JK, Shaffrey ME, Argires PJ, Nian H, Harrell FE. Cervical disc arthroplasty with PRESTIGE LP disc versus anterior cervical discectomy and fusion: a prospective, multicenter investigational device exemption study. J Neurosurg Spine 2015;23(5):558–73. doi:10.3171/2015.1.SPINE14589.
[26] Qizhi S, Lei S, Peijia L, et al. A comparison of zero-profile devices and artificial cervical disks in patients with 2 noncontiguous levels of cervical spondylosis. Clin Spine Surg 2016;29(2):E61–6. doi:10.1097/BSD.0000000000000096.
[27] Skeppholm M, Lindgren L, Henriques T, Vavruch L, Löfgren H, Olerud C. The discover artificial disc replacement versus fusion in cervical radiculopathy–a randomized controlled outcome trial with 2-year follow-up. Spine J 2015;15(6):1284–94. doi:10.1016/j.spinee.2015.02.039.
[28] Anderson PA, Nassr A, Currier BL, et al. Evaluation of adverse events in total disc replacement: a meta-analysis of FDA summary of safety and effectiveness data. Global Spine J 2017;7(1 Suppl) 76S–83S. doi:10.1177/2192568216688195.
[29] Pickett GE, Sekhon LHS, Sears WR, Duggal N. Complications with cervical arthroplasty. J Neurosurg Spine 2006;4(2):98–105. doi:10.3171/spi.2006.4.2.98.
[30] Nandyala SV, Marquez-Lara A, Fineberg SJ, Singh K. Comparison of revision surgeries for one- to two-level cervical TDR and ACDF from 2002 to 2011. Spine J 2014;14(12):2841–6. doi:10.1016/j.spinee.2014.03.037.
[31] Bydon M, Macki M, Kaloostian P, et al. Incidence and prognostic factors of C5 palsy: a clinical study of 1001 cases and review of the literature. Neurosurgery 2014;74(6):595. doi:10.1227/NEU.0000000000000322.
[32] Pan FM, Wang SJ, Ma B, Wu DS. C5 nerve root palsy after posterior cervical spine surgery: a review of the literature. J Orthop Surg (Hong Kong) 2017;25(1):2309499016684502. doi:10.1177/2309499016684502.
[33] Guyer RD, Coric D, Nunley PD, Ohnmeiss DD. Cervical total disk replacement: available implant size matters. Clin Spine Surg 2022;35(4):166–9. doi:10.1097/BSD.0000000000001314.
[34] Somani S, Capua JD, Kim JS, et al. ASA classification as a risk stratification tool in adult spinal deformity surgery: a study of 5805 patients. Global Spine J 2017;7(8):719–26. doi:10.1177/2192568217700106.

[35] Brinjikji W, Luetmer PH, Comstock B, et al. Systematic literature review of imaging features of spinal degeneration in asymptomatic populations. AJNR Am J Neuroradiol 2015;36(4):811–16. doi:10.3174/ajnr.A4173.

[36] Aj K, Ar G, Py J, et al. Comparison of postoperative outcomes in patients with and without osteoporosis undergoing single-level anterior cervical discectomy and fusion. North Am Spine Soc J 2022;12:170–4. doi:10.1016/j.xnsj.2022.100174.

[37] Ca L, As L, Ml L, Py C, Pl L, Cc N. The surgical outcome of multilevel anterior cervical discectomy and fusion in myelopathic elderly and younger patients. Scientific reports 2022;12(1):8243–8. doi:10.1038/s41598-022-08243-8.

[38] Berg A, Killen MC, Khan S, Reddy G, Friesem T. Subsidence in single level cervical disc arthroplasty. Global Spine J 2015;5(1_suppl):s-0035-1554496. doi:10.1055/s-0035-1554496.

[39] Cy L, Kk T, Hk T, et al. Risk factors for cervical disc arthroplasty subsidence with bryan disc-a retrospective observational analysis. J Clin Med 2024;13(6):1589. doi:10.3390/jcm13061589.

[40] He J. Cervical disc arthroplasty for patients with osteopenia: a matched cohort study. Spine J 2024;24:S11. doi:10.1016/j.spinee.2024.06.465.

[41] Filley A, Baldwin A, Ben-Natan AR, et al. The influence of osteoporosis on mechanical complications in lumbar fusion surgery: a systematic review. N Am Spine Soc J 2024;18:100327. doi:10.1016/j.xnsj.2024.100327.

[42] Dipaola CP, Bible JE, Biswas D, Dipaola M, Grauer JN, Rechtine GR. Survey of spine surgeons on attitudes regarding osteoporosis and osteomalacia screening and treatment for fractures, fusion surgery, and pseudoarthrosis. Spine J 2009;9(7):537–44. doi:10.1016/j.spinee.2009.02.005.

[43] Díaz-Romero R, Henríquez MS, Melián KA, Balhen-Martin C. Practice patterns of spine surgeons regarding osteoporosis: an international survey. Int J Spine Surg 2021;15(2):376–85. doi:10.14444/8049.

[44] Pantoja S, Molina M. Surgeon management of osteoporosis in instrumented spine surgery: AOSPINE Latin America survey. Global Spine J 2019;9(2):169–72. doi:10.1177/2192568218785369.

[45] Blumenthal SL, Guyer RD, Zigler JE. Ohnmeiss DD. Is osteoporosis screening routiney needed to evaluate cervical total disc replacement patients? Spine J 2019;19(9):S53–4. doi:10.1016/j.spinee.2019.05.124.

[46] K.N Paal, N Nakul, C Ida, et al., Risk factors for reoperation following single-level cervical disc arthroplasty as utilized in a representative sample of united states clinical practice: a retrospective pearl diver study, Global Spine J., 21925682241230965, doi:10.1177/21925682241230965.

[47] Tsai MC, Liu YF, Lin WH, Lee MC. Restoration of range of motion in the cervical spine through single-segment artificial disc replacement using the Baguera®C prosthesis. J Clin Med 2024;13(7):2048. doi:10.3390/jcm13072048.