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Article

From Fusion to Motion Preservation: A Nationwide Propensity-Matched Analysis of 97,999 Patients Undergoing Cervical Disc Arthroplasty vs. ACDF

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Abstract

Introduction: Cervical disc diseases (CDD) are a significant cause of disability and diminished quality of life globally, with prevalence increasing with age. Two common surgical interventions for symptomatic CDD patients who do not respond to conservative treatments are Anterior Cervical Discectomy and Fusion (ACDF) and Cervical Disc Arthroplasty (CDA). While ACDF is more established and has a more extended history of use, CDA has been gaining popularity due to its motion-preserving benefits and comparable, if not superior, long-term outcomes. This study aims to compare these two procedures using a comprehensive dataset of 97,999 patients, focusing on patient demographics, complications, costs, length of hospital stay, and mortality rates to contribute valuable insights that can inform clinical practice and healthcare policy. **Methods:** In this study, data was sourced from the Nationwide Inpatient Sample (NIS) database, covering the period from January 1st, 2016, to December 31st, 2019. The dataset comprised 97,999 patients, with 85,584 undergoing ACDF and 11,415 CDA. Patients were identified using ICD-10 codes, with exclusions for non-elective admissions and surgeries performed prior to admission. Statistical analyses, including crosstabs and t-tests, were conducted, with a significance level of $p < 0.05$. Propensity score matching was utilized to control selection bias, resulting in a refined cohort of 11,415 matched pairs. Comorbidities and clinical outcomes were analyzed using the NIS dataset, including mortality, length of stay, complications, and hospitalization costs. **Results:** The study observed a significant increase in the utilization of CDA surgeries compared to ACDF from 2016 to 2019. ACDF patients were older (55.6 vs. 47.2 years, $P < 0.001$) and more likely to have Medicare coverage (33.9% vs. 10.7%, $P < 0.001$). Comorbidities such as hypertension, dyslipidemia, and diabetes mellitus were more prevalent in ACDF patients ($P < 0.001$). Propensity score matching balanced both groups, confirming comparable demographic and comorbidity profiles, with no significant differences in major conditions like hypertension ($P = 0.59$) and dyslipidemia ($P = 0.93$). Hospitalization outcomes revealed a slightly longer length of stay for ACDF (1.39 vs. 1.32 days, $P < 0.001$), while CDA incurred higher mean charges (\$82,431 vs. \$58,472, $P < 0.001$). Postoperatively, ACDF patients experienced more dysphagia (4.90% vs. 3.60%, $P < 0.001$), venous thromboembolism (0.13% vs. 0.04%, $P = 0.03$), and sepsis (0.04% vs. 0.00%, $P = 0.03$). Cervical spinal cord injury and urinary tract infections were more frequent in the CDA group ($P = 0.04$ and $P = 0.02$, respectively). **Conclusions:** This study highlights a growing trend in favor of CDA, particularly among younger patients and those with private insurance. The advantages of motion preservation, reduced adjacent-segment disease, shorter hospital stays, and lower complication rates make CDA an increasingly viable alternative to traditional ACDF, despite its higher initial costs. These findings align with recent literature, further supporting the adoption of CDA in appropriate patient populations.

Keywords: cervical disc arthroplasty; anterior cervical discectomy and fusion; national inpatient sample; big data; NIS

1. Introduction

Cervical disc diseases (CDD) are a leading cause of disabilities and decreased quality of life [1–3] worldwide, with prevalence increasing with age [4–6]. The related pathologies are varied and highly common in the population [7–11]. Two widespread surgical interventions for symptomatic CDD patients who have failed or are not suitable for conservative treatment are ACDF and the newer, motion-preserving, Cervical Disc Arthroplasty (CDA). The ACDF is currently the most commonly performed procedure due to its extended history of use and a larger body of clinical evidence supporting its effectiveness. However, the popularity of CDA has been rising in recent years, and like ACDF, it can be used for both single-level and multi-level diseases.

Three major drawbacks of ACDFs for single-level disease post-surgery are limited neck mobility, the potential for adjacent segment disease, and longer recovery time. These drawbacks can be addressed with the more expensive CDA procedure [12], which has shown long-term results that are not inferior and even superior to those of ACDF [13–18]. Previous studies have attempted to characterize the patient population more likely to undergo the CDA procedure over ACDF for single-level disc disease and compare the inpatient outcomes [12]. These studies show shorter lengths of stay with CDA and highlight that younger patients, patients with private insurance, and patients with higher median household incomes are more likely to undergo this procedure [19–22].

Although previous studies have utilized the NIS database to compare CDA and ACDF, these investigations were conducted over a decade ago, employed the now outdated ICD-9 coding system, and did not account for advancements in CDA technology. In contrast, our study incorporates the updated ICD-10 coding system, includes a significantly more extensive and robust patient cohort, and reflects technological improvements in CDA, providing a more accurate and contemporary comparison. Our study utilizes a comprehensive dataset of 97,999 patients to compare ACDF with CDA. The primary objective is to contribute to the ongoing discourse regarding the efficacy of CDA by elucidating its practical implications, including patient demographics, complications, costs, length of hospital stay, and mortality rates. This investigation aims to provide valuable insights that can guide policymakers and ultimately enhance patient-centered care.

2. Methods

2.1. Data Source

This investigation employed data from the National Inpatient Sample (NIS), a nationally representative database developed by the Agency for Healthcare Research and Quality (AHRQ) as part of the Healthcare Cost and Utilization Project (HCUP). The NIS is the largest publicly accessible, all-payer inpatient healthcare dataset in the United States, systematically sampling approximately 20% of all hospital discharges from HCUP-affiliated institutions. This sampling framework encompasses roughly 7 million unweighted admissions annually and, when adjusted using the discharge-level sampling weights provided by HCUP, allows for the generation of robust national estimates and comprehensive epidemiological assessments.

For the present study, data spanning January 1, 2016, through December 31, 2021, were analyzed, representing the most recent and complete period available at the time of analysis. Within the NIS, each discharge record—referred to as a “case”—is assigned a statistical weight, with each weighted record corresponding to approximately five actual inpatient encounters nationwide. This methodology enables precise extrapolation to the national inpatient population, thereby enhancing both the external validity and statistical rigor of the study’s findings.

2.2. Cohort Definition and Selection Criteria

The National Inpatient Sample (NIS) database was queried for the period 2016–2021 to identify adult patients (aged ≥18 years) who underwent single-level anterior cervical discectomy and fusion (ACDF) or cervical disc arthroplasty (CDA). Procedural identification was performed using International Classification of Diseases, Tenth Revision (ICD-10) procedure codes specific to these operations, as detailed in the Appendix. The final cohort comprised 97,999 patients, including 85,584 who underwent ACDF and 11,415 who underwent CDA.

Patients with non-elective admissions or those who had undergone surgery prior to the index hospitalization were excluded. In addition, cases with incomplete or inconsistent records—such as missing procedural codes, demographic variables, or other critical data—were removed to preserve the accuracy and reliability of statistical analyses. This exclusion strategy minimized the potential for bias arising from incomplete datasets and ensured methodological rigor.

2.3. Outcome Variables (End Points)

Procedural identification was based on International Classification of Diseases, Tenth Revision, Procedure Coding System (ICD-10-PCS) codes specific to single-level ACDF and CDA, as detailed in the Table 1. Comorbidities were identified through review of patient-specific ICD-10-CM diagnosis codes.

Table 1. ICD-10 and Procedure Codes Used for Case Selection and Variable Definition.

Category	ICD 10 CODES
Cervical Disc Arthroplasty (CDA)	0RR30JZ, 0RR20JZ
Anterior Cervical Discectomy and Fusion (ACDF)	0RG10A0, 0RG10A1, 0RG10A4, 0RG10J0, 0RG10J1, 0RG10J4
Heart Failure	I5021, I5031, I5033, I5041, I5043
Acute Kidney Injury	N170, N171, N172, N178, N179
Acute Coronary Artery Disease	I2101, I2102, I2109, I211, I2119, I2111, I212, I2129, I213, I214, I219
Stroke	I60, I61, I62, I63, I650, I688, O873, O2250, O2251, O2252
Pulmonary Edema	J810, J811, I501
Hypertension	I10(start with)
Blood Loss Anemia	D62 (start with)
Pneumonia	J189, J159, J22
Pulmonary Embolism	I2602, I2609, I2692, I2699
DVT	I82401, I82402, I82403, I82409, I82411, I82412, I82413, I82419, I82421, I82422, I82423, I82429
Dyslipidemia	E78(start with)
Obstructive Sleep Apnea	G473
Chronic Anemia	D64(start with)
Alcohol Abuse History	F10
Osteoporosis	M81, M82
Mental Disorders	F (start with)
Parkinson Disease	G20 (start with)
Type 2 Diabetes Mellitus	E11 (start with)
Chronic Kidney Disease	N18 (start with)
Congestive Heart Failure	I500, I501, I509
Chronic Lung Disease	J44 (start with)
History of Myocardial Infarction	I252
Peripheral Vascular Disease	I73 (start with)
History of Cerebrovascular Accident (CVA)	Z8673, I69 (start with)
Dementia	F03 (start with)

Peptic Ulcer Disease	K25-K28
Hemiplegia	G81
Neoplasms	C (start with)
Neoplasms of Lymphoid and Hematopoietic Tissue	C81-C96

Primary outcomes included in-hospital mortality, length of stay, total hospitalization costs, and perioperative complication rates. Complications were identified using ICD-10 codes and encompassed dysphagia, postoperative anemia due to blood loss, cervical spinal cord injury, urinary tract infection, acute renal failure, pneumonia, blood transfusion requirement, venous thromboembolism, pulmonary edema, ileus, feeding tube placement, dural tear, sepsis, pulmonary embolism, and mortality. These definitions were applied consistently across both groups to ensure methodological uniformity and comparability of results.

2.4. Statistical Analysis

All statistical analyses were conducted using SPSS version 26 (IBM Corp., Armonk, NY, USA) and MATLAB 2024 (MathWorks, Natick, MA, USA). Categorical variables were compared using Pearson’s χ^2 test, and continuous variables were evaluated using independent-sample t-tests. A two-tailed p-value < 0.05 was considered statistically significant.

To minimize selection bias and control for confounding inherent in observational studies, propensity score matching (PSM) was employed. This method facilitated the creation of statistically comparable cohorts of patients undergoing anterior cervical discectomy and fusion (ACDF) or cervical disc arthroplasty (CDA) by matching individuals on key demographic, hospital-related, and clinical characteristics. PSM enhances the validity of causal inferences by approximating the balance achieved in randomized controlled trials, thereby improving the robustness and reliability of comparative analyses.

Propensity scores were estimated using a multivariable logistic regression model incorporating 34 covariates spanning three domains: (1) Hospital characteristics – hospital size, location (urban vs. rural), teaching status, geographic region, and total annual discharges. (2) Demographic and socioeconomic factors – patient location (urban vs. rural classification), median household income quartile, race, age, and primary payer status (Medicare, Medicaid, private insurance, self-pay, or other). (3) Preoperative comorbidities – 24 conditions including hypertension, dyslipidemia, obstructive sleep apnea, chronic anemia, alcohol abuse, osteoporosis, neurodegenerative disorders (Parkinson’s disease, Alzheimer’s disease, and dementia), chronic kidney disease, congestive heart failure, chronic lung disease, diabetes mellitus, inflammatory bowel disease, liver disease, obesity, fibromyalgia, thyroid disorders, prior myocardial infarction, peripheral vascular disease, prior cerebrovascular accident, any neoplasm, neoplasms of lymphoid and hematopoietic tissue, and any other recorded preoperative health condition.

Matching was performed using MATLAB, yielding two final cohorts of 11,415 patients each with comparable baseline characteristics. Matching criteria included hospital size, patient location (urban–rural classification), median household income quartile, hospital region, comorbidity profile, and total number of hospital discharges within the NIS dataset.

2.5. Ethical Consideration

This study received exempt status from the Institutional Review Board (IRB) owing to the fully de-identified nature of the National Inpatient Sample (NIS) dataset, in accordance with ethical standards for research involving human subjects. Artificial intelligence (AI) tools were employed exclusively for linguistic refinement, including improvements in clarity, grammatical precision, and stylistic coherence. These tools were not used for data analysis, statistical computation, or content generation, thereby ensuring the preservation of the study’s scientific integrity and methodological rigor.

3. Results

Over the past few years, cervical disc arthroplasty (CDA) has been used more often compared to anterior cervical discectomy and fusion (ACDF), as shown in Figure 1. From 2016 to 2019, the share of CDA among all CDA and ACDF procedures steadily increased, with the trend reaching statistical significance ($p = 0.001$). This rise reflects a growing preference for CDA in suitable patients, likely influenced by advances in technology, supportive clinical evidence, and increasing surgeon experience with the procedure.

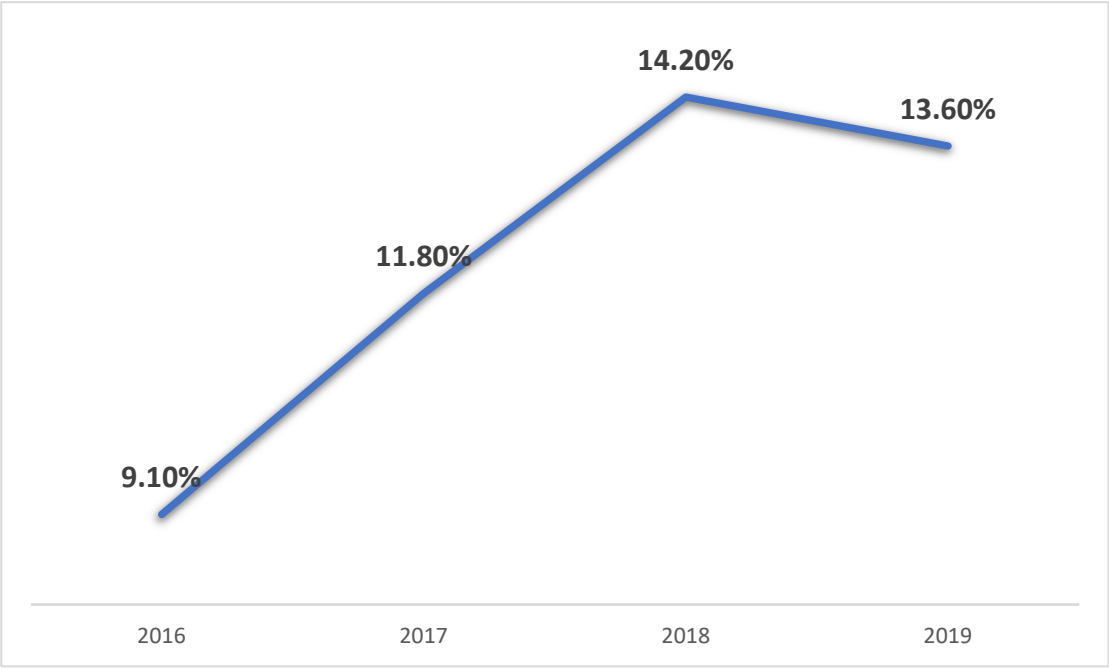


Figure 1. Annual Proportion of Cervical Disc Replacement Surgeries Relative to Total Disc Arthroplasty and ACDF Procedures (2016–2019).

Table 2 compares 85,584 patients who underwent anterior cervical discectomy and fusion (ACDF) with 11,415 patients who underwent cervical disc arthroplasty (CDA), detailing procedure distribution, demographic characteristics, and primary expected payer categories. Patients undergoing ACDF were, on average, significantly older than those undergoing CDA (55.6 vs. 47.2 years, $p < 0.001$). The proportion of female patients was similar between the groups (51.7% for ACDF vs. 52.5% for CDA, $p = 0.108$). Differences in primary payer status closely reflected the age disparity between cohorts. Medicare was the primary expected payer for 33.9% of ACDF patients compared with only 10.7% of CDA patients ($p < 0.001$), consistent with the older age profile of the ACDF group. Conversely, private insurance coverage was more prevalent among CDA patients (64.9%) than ACDF patients (44.5%) ($p < 0.001$), reflecting the younger, working-age demographic more commonly undergoing disc arthroplasty.

Table 2. Demographic and Payer Characteristics of Patients Undergoing ACDF and CDA.

Parameter	ACDF	CDA	Significance
Total Surgeries (%)	85,584	11,415	-
Average Age (y)	55.6	47.2	P<0.001
Female (%)	51.7	52.5	P=0.108
Primary expected payer - Medicare (%)	33.9	10.7	P<0.001
Primary expected payer - Medicaid (%)	10.7	9.7	

Primary expected payer - private including HMO (%)	44.5	64.9	
Primary expected payer - self-pay (%)	1.2	1.3	
Primary expected payer - no charge (%)	0.1	0	
Primary expected payer - other (%)	9.6	13.3	

Table 3 presents a comparative analysis of preoperative comorbidities between patients undergoing anterior cervical discectomy and fusion (ACDF) and those undergoing cervical disc arthroplasty (CDA). The table details the prevalence of each condition and the statistical significance of differences between cohorts. Overall, ACDF patients exhibited a higher burden of comorbidities compared with CDA patients. Notably, the prevalence of hypertension (43.7% vs. 25.1%), dyslipidemia (30.0% vs. 17.3%), and diabetes mellitus (19.5% vs. 9.6%) was significantly greater in the ACDF group ($p < 0.001$ for all). Similarly, chronic lung disease (8.0% vs. 3.2%) and chronic kidney disease (3.8% vs. 1.1%) were more common among ACDF patients, with both differences reaching high statistical significance ($p < 0.001$). These patterns are consistent with the older mean age of the ACDF cohort and suggest that patients selected for CDA are generally younger and have fewer chronic health conditions, potentially reflecting stricter surgical candidacy criteria for arthroplasty compared with fusion.

Table 3. Prevalence of Comorbidities Among Patients Undergoing ACDF and CDA.

Parameter	ACDF (n=85,584)	CDA (n=11,415)	Significance
Hypertension (%)	43.7	25.1	P<0.001
Dyslipidemia (%)	30	17.3	P<0.001
Obstructive Sleep Apnea (%)	9.5	6.9	P<0.001
Chronic Anemia (%)	2.3	1.8	P<0.001
Alcohol Abuse (%)	1.2	0.8	P<0.001
Osteoporosis (%)	2.3	0.9	P<0.001
Parkinson Disease (%)	0.5	0.1	P<0.001
Alzheimer Disease (%)	0.1	0	P=0.698
Chronic Kidney Disease (%)	3.8	1.1	P<0.001
Congestive Heart Failure (%)	0.9	0.1	P<0.001
Chronic Lung Disease (%)	8	3.2	P<0.001
Diabetes Mellitus (%)	19.5	9.6	P<0.001
IBD (%)	0.5	0.3	P<0.001
Liver Disease (%)	1.1	0.7	P<0.001
Obesity (%)	18.5	15.6	P<0.001
Fibromyalgia (%)	3.8	3	P<0.001
Disorders of Thyroid (%)	11.9	9.4	P<0.001
History of Myocardial Infarction (%)	2.9	0.7	P<0.001
Peripheral Vascular Disease (%)	1.3	0.6	P<0.001
History of Cerebrovascular Accident (%)	3.9	1.3	P<0.001
Dementia (%)	0.2	0.2	P<0.001
Neoplasms (%)	0.8	0.3	P<0.001
Neoplasms of Lymphoid and Hematopoietic Tissue (%)	0.3	0.1	P<0.001

To address potential selection bias and baseline differences in preoperative comorbidity profiles, a propensity score–matched (PSM) analysis was performed. This statistical technique balances observed covariates by pairing patients with comparable probabilities of undergoing either anterior cervical discectomy and fusion (ACDF) or cervical disc arthroplasty (CDA), thereby minimizing

confounding and enhancing the validity of comparative analyses. By emulating the balance achieved through random assignment, PSM improves the reliability of conclusions drawn from observational data.

Following matching, the final analysis included 11,415 patients in each cohort, ensuring a balanced distribution of demographic and clinical characteristics. As shown in Table 4, no statistically significant differences were observed between groups across the evaluated parameters, confirming the effectiveness of the matching process.

Post-matching comparisons demonstrated that the cohorts were similar in mean age (47.3 years for ACDF vs. 47.2 years for CDA, $p = 0.36$) and sex distribution (52.1% female for ACDF vs. 52.5% female for CDA, $p = 0.62$). Primary expected payer status was also comparable, with private insurance—including health maintenance organizations (HMOs)—being the most common coverage type (64.5% for ACDF vs. 64.9% for CDA, $p = 0.41$). Likewise, the prevalence of common comorbidities such as hypertension (24.7% vs. 25.1%, $p = 0.59$) and dyslipidemia (17.2% vs. 17.3%, $p = 0.93$) showed no significant differences. Similar parity was observed across a range of additional comorbidities, underscoring that the matched cohorts were well-balanced and suitable for valid outcome comparisons.

Table 4. Comparison of Demographic and Clinical Characteristics in Propensity Score-Matched Cohorts Undergoing ACDF and CDA.

Parameter	ACDF (n=11,415)	CDA (n=11,415)	Significance
Average Age (y)	47.3	47.2	P=0.36
Female (%)	52.1	52.5	P=0.62
Primary expected payer - Medicare (%)	11.6	11.3	P=0.41
Primary expected payer - Medicaid (%)	9.7	9.7	
Primary expected payer - private including HMO (%)	64.5	64.9	
Primary expected payer - self-pay (%)	1.5	1.3	
Primary expected payer - no charge (%)	0	0	
Primary expected payer - other (%)	12.7	12.7	
Hypertension (%)	24.7	25.1	P=0.59
Dyslipidemia (%)	17.2	17.3	P=0.93
Obstructive Sleep Apnea (%)	6.4	6.9	P=0.05
Chronic Anemia (%)	1.6	1.8	P=0.43
Alcohol Abuse (%)	0.7	0.8	P=0.33
Osteoporosis (%)	0.9	0.9	P=0.52
Parkinson Disease (%)	0	0.1	P=0.20
Alzheimer Disease (%)	0	0	P=1
Chronic Kidney Disease (%)	1	1.1	P=0.51
Congestive Heart Failure (%)	0.1	0	P=0.06
Chronic Lung Disease (%)	2.9	3.2	P=0.09
Diabetes Mellitus (%)	8.9	9.6	P=0.05
Inflammatory Bowel Disease (%)	0.4	0.3	P=0.23
Liver Disease (%)	0.5	0.7	P=0.19
Obesity (%)	16.4	15.6	P=0.09
Fibromyalgia (%)	2.7	3	P=0.11
History of Myocardial Infarction (%)	0.6	0.6	P=0.18
Peripheral Vascular Disease (%)	0.6	0.6	P=0.35
History of Cerebrovascular Accident (%)	1.3	1.3	P=0.42
Neoplasms (%)	0.4	0.3	P=0.09

Neoplasms of Lymphoid and Hematopoietic Tissue (%)	0.1	0.1	P=1
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Table 5 summarizes hospitalization outcomes for anterior cervical discectomy and fusion (ACDF) and cervical disc arthroplasty (CDA) following propensity score matching. Both procedures were associated with short postoperative hospital stays; however, CDA demonstrated a statistically significant yet clinically modest reduction in length of stay compared with ACDF (1.32 vs. 1.39 days, $p < 0.001$). This difference may reflect procedural factors such as less invasive exposure, more rapid postoperative mobilization, or differences in perioperative management protocols favoring CDA. Despite the shorter hospitalization duration, CDA was associated with substantially higher total hospital charges (\$82,431 vs. \$58,472, $p < 0.001$). This cost disparity likely reflects increased expenditures related to surgical instrumentation, implant technology, and potentially higher reimbursement rates for arthroplasty procedures. These findings underscore the need to balance clinical advantages with economic considerations when selecting the optimal surgical strategy for cervical degenerative pathology.

Table 5. Comparison of Hospitalization Outcomes in Propensity Score-Matched Cohorts Undergoing ACDF and CDA.

	ACDF (n=11,415)	CDA (n=11,415)	Significance
Length of stay mean in days	1.39 (Std. deviation 1.52)	1.32 (Std. deviation 1.27)	P<0.001
Total charges mean in \$	58,472 (Std. deviation 41703)	82,431 (Std. deviation 53105)	P<0.001

Table 6 compares postoperative complication rates between patients undergoing anterior cervical discectomy and fusion (ACDF) and those receiving cervical disc arthroplasty (CDA) after propensity score matching. Dysphagia occurred more frequently in the ACDF cohort (4.90% vs. 3.60%, $p < 0.001$), potentially reflecting greater esophageal retraction inherent to the fusion technique. In contrast, cervical spinal cord injury, although rare, was observed slightly more often in the CDA group (0.30% vs. 0.17%, $p = 0.04$), which may be related to the technical precision required for prosthesis placement. Urinary tract infections were also more prevalent among CDA patients (0.39% vs. 0.22%, $p = 0.02$), possibly due to variations in perioperative management or urinary catheter utilization. ACDF patients demonstrated higher rates of perioperative blood transfusion (0.13% vs. 0.00%, $p = 0.01$) and venous thromboembolism (0.13% vs. 0.04%, $p = 0.03$), findings that may be attributable to greater intraoperative blood loss and longer postoperative immobilization. Additional complications—such as sepsis (0.04% vs. 0.00%, $p = 0.03$), pulmonary embolism (0.04% vs. 0.00%, $p = 0.03$), and feeding tube placement (0.08% vs. 0.00%, $p = 0.01$)—were also more common in the ACDF group, potentially reflecting the increased physiological stress and recovery demands associated with fusion procedures.

Table 6. Postoperative Outcomes in Patients Undergoing ACDF and CDA After Propensity Score Matching.

Parameter	ACDF (n=11,415)	CDA (n=11,415)	Significance	Odds Ratio	Odds Ratio 95% Confidence
Dysphagia (%)	4.90%	3.60%	P<0.001	0.724	0.63 - 0.82
Blood Loss Anemia (%)	1.00%	0.80%	P=0.17	0.825	0.62 - 1.08
Cervical spinal cord injury (%)	0.17%	0.30%	P=0.04	1.752	1.01 - 3.03
UTI (%)	0.22%	0.39%	P=0.02	1.803	1.1 - 2.94

Acute Renal Failure (%)	0.21%	0.26%	P=0.50	1.201	0.7 - 2.04
Pneumonia (%)	0.17%	0.17%	P=1.00	1.000	0.53 - 1.86
Blood transfusion (%)	0.13%	0.00%	P=0.01	0.500	0.17 - 1.46
Venous Thromboembolism (%)	0.13%	0.04%	P=0.03	0.308	0.12 - 0.75
Pulmonary Edema (%)	0.04%	0.04%	P=1.00	1.000	0.28 - 3.45
Ileus (%)	0.08%	0.17%	P=0.07	2.002	0.93 - 4.27
Feeding Tube (%)	0.08%	0.00%	P=0.01	0.5	0.17 - 1.46
Dural tear (%)	0.04%	0.04%	P=1.00	1.000	0.28 - 3.45
Sepsis (%)	0.04%	0.00%	P=0.03	0.500	0.49 - 0.5
Pulmonary Embolism (%)	0.04%	0.00%	P=0.03	0.500	0.49 - 0.5
Mortality (%)	0.00%	0.00%	P=1.00	-	

4. Discussion

Anterior cervical discectomy and fusion (ACDF) is a well-established surgical intervention for patients with severe or refractory cervical spine pathology who have not achieved symptomatic relief through conservative management [23]. While ACDF reliably decompresses the spinal cord and restores intervertebral disc height, the procedure eliminates motion at the fused segment, potentially increasing biomechanical stress on adjacent levels and predisposing to adjacent-segment disease (ASD). Cervical disc arthroplasty (CDA) was developed as a motion-preserving alternative designed to maintain cervical spine biomechanics, reduce stress transfer to adjacent segments, and thereby mitigate the risk of ASD [24,25]. Despite promising biomechanical and clinical rationale, the question of whether CDA offers superior long-term outcomes compared with ACDF remains the subject of ongoing debate [26].

This study leveraged a large, propensity score–matched cohort from the National Inpatient Sample (NIS) to evaluate the epidemiological trends and complication profiles of anterior cervical discectomy and fusion (ACDF) versus cervical disc arthroplasty (CDA). Our findings demonstrate a marked increase in CDA utilization over the past decade, consistent with previously published reports. One study [27] observed an increase in CDA procedures from 4.0% to 14.2% between 2010 and 2018, followed by a plateau from 2018 to 2021. Similarly, Singh BS et al. [28] documented a 25.25% rise in ACDF procedures from 2011 to 2014 and an extraordinary 654.24% increase in CDA procedures from 2011 to 2019, with subsequent stabilization in the rates of both interventions. The growing adoption of CDA over ACDF is likely influenced by earlier evidence suggesting superior postoperative functional mobility with arthroplasty, potentially mitigating biomechanical stress on adjacent segments and lowering the incidence of adjacent-segment degeneration [29,30].

In our cohort, patients undergoing cervical disc arthroplasty (CDA) were generally younger and demonstrated fewer comorbidities. CDA is frequently selected for younger individuals with preserved baseline segmental motion and without advanced degenerative changes of the cervical spine, as it offers the potential for greater postoperative mobility and segmental flexibility compared with anterior cervical discectomy and fusion (ACDF) [12]. The procedure’s success relies on the structural integrity of adjacent facet joints and spinal ligaments to maintain stability, rendering it less suitable for patients with poor bone quality, advanced spondylosis, or multi-level disc pathology. Older patients, who are more likely to present with comorbidities such as diabetes mellitus, hypertension, and dyslipidemia, often derive greater benefit from fusion procedures, which provide definitive stabilization of diseased segments [31,32]. These relative indications and contraindications help explain the higher prevalence of ACDF among older individuals with myelopathy and advanced disc degeneration in our study population.

Overall, cervical disc arthroplasty (CDA) demonstrated complication rates comparable to or lower than anterior cervical discectomy and fusion (ACDF), with overall incidences of 5.81% and

7.29%, respectively. ACDF was associated with a higher prevalence of dysphagia (4.90% vs. 3.60%) and a greater need for perioperative blood transfusion (0.13% vs. 0.00%). Conversely, CDA patients experienced slightly higher rates of cervical spinal cord injury (0.30% vs. 0.17%) and urinary tract infections. The existing literature presents mixed findings: several studies have reported fewer adverse events following CDA [33,34], whereas others have noted either no difference or higher complication rates compared with ACDF [35,36]. Given the similarities in surgical approach, both procedures demonstrated comparable rates of approach-related complications.

A recent systematic review and meta-analysis found that CDA was associated with a significantly lower incidence of secondary surgeries and adverse events compared with ACDF, without significant differences in neurological success [37]. Similarly, another study reported no statistically significant differences in the incidence of spinal cord injury or other major complications between the two techniques [38].

Although the present analysis identified statistically significant differences in certain complication rates between CDA and ACDF, the absolute rates were low for both procedures. These findings suggest that while statistical differences exist, their clinical impact may be limited. Future research should aim to determine whether these differences translate into meaningful variations in long-term patient outcomes, healthcare utilization, and quality of life.

In this study, a significantly greater proportion of cervical disc arthroplasty (CDA) patients (64.9%) were covered by private insurance compared with anterior cervical discectomy and fusion (ACDF) patients (44.5%). Similar trends have been reported in previous analyses. For example, a study utilizing the National Inpatient Sample (NIS) from 2006 to 2013 found that 66.2% of CDA patients had private insurance versus 55.4% of ACDF patients [19]. This disparity likely reflects differences in patient age and eligibility, as younger individuals—who are more likely to have private insurance—are also more likely to meet selection criteria for CDA. In contrast, older patients, particularly those covered by Medicare, may be less frequently considered for arthroplasty due to the presence of advanced degenerative changes or other contraindications. Additionally, variation in insurance coverage policies, including reimbursement rates and authorization practices, may contribute to the observed differences in payer distribution.

In terms of resource utilization, CDA patients in our cohort had a modestly shorter mean length of stay compared with ACDF patients (1.32 vs. 1.39 days) yet incurred substantially higher total hospital charges (\$82,431 vs. \$58,472). These findings are consistent with prior studies [19,39] that also demonstrated reduced length of stay for CDA relative to ACDF, while highlighting the potential impact of device costs, surgical instrumentation, and reimbursement structures on total expenditures.

The higher costs associated with cervical disc arthroplasty (CDA) compared with anterior cervical discectomy and fusion (ACDF) are primarily attributable to the increased expense of implants and surgical instrumentation required for arthroplasty. CDA implants, incorporating motion-preserving technology, are generally more costly than the devices used in ACDF [40,41]. A study published in *World Neurosurgery* reported that the mean supply cost for CDA was approximately \$9,532, compared with \$4,173 for ACDF, with the majority of this discrepancy attributable to the higher price of disc replacement implants [40]. Beyond implant costs, total intraoperative expenses are also greater for CDA; the same study found mean intraoperative costs of \$12,026 for CDA versus \$6,776 for ACDF. This difference reflects not only the increased cost of implants but also the additional operative time and resources required for arthroplasty [40].

Differences in hospital reimbursement policies further contribute to the economic disparity between CDA and ACDF. Reimbursement for CDA is often influenced by private insurance coverage, with some payers limiting approval due to the higher upfront cost and ongoing uncertainty regarding long-term benefits. These reimbursement structures can influence surgical decision-making and patient access to CDA, particularly for individuals with limited insurance coverage or financial constraints.

Economic trends further highlight the growing financial burden associated with CDA. Between 2009 and 2019, the mean total hospital charges for elective CDA increased by 73%, while the mean

total cost for index hospital admissions rose by 26% [41]. Notably, this cost escalation has not been matched by a proportional rise in reimbursements, resulting in higher out-of-pocket expenses for patients and increased financial strain on healthcare systems. These findings underscore the importance of considering the long-term economic implications of CDA relative to ACDF when evaluating its broader adoption in clinical practice.

The shorter length of stay (LOS) observed in cervical disc arthroplasty (CDA) patients may reflect more standardized perioperative care protocols and implant-specific surgical workflows. In contrast, the higher costs associated with CDA are likely attributable to the advanced technology, specialized implants, and longer operative times required for these procedures. In resource-limited settings, such elevated costs can place substantial strain on healthcare budgets, potentially restricting the availability of CDA. Consequently, anterior cervical discectomy and fusion (ACDF) is often favored in such environments, as it demonstrates greater cost-effectiveness across various willingness-to-pay thresholds [42]. The financial burden associated with CDA may also disproportionately limit access for patients from lower socioeconomic backgrounds or those without comprehensive insurance coverage [12]. Future studies should investigate the long-term cost-effectiveness of CDA and ACDF, incorporating revision rates, patient-reported outcomes, indirect costs, and broader measures of healthcare utilization.

Accurate determination of indications and patient eligibility is essential when selecting between CDA and ACDF. Inappropriate selection for CDA can compromise surgical outcomes. For example, if the posterior longitudinal ligament is divided during the removal of posterior osteophytes, segmental fusion is generally preferred over disc replacement to avoid iatrogenic instability [43]. This underscores the importance of adhering to established surgical principles and tailoring procedural choice to individual anatomical and pathological characteristics.

CDA is most commonly indicated for patients with single- or two-level cervical disc disease between the C3 and C7 levels. Regulatory approval for CDA is based on clinical trials demonstrating non-inferiority to ACDF, with evidence indicating that, in appropriately selected patients, CDA can provide comparable or superior clinical and functional outcomes while preserving segmental motion [44,45]. Proper patient selection is critical, with absolute contraindications including severe osteoporosis, active infection, and significant cervical instability due to the heightened risk of implant failure and poor postoperative outcomes. Relative contraindications—such as segmental kyphosis or prior cervical spine surgery—require individualized assessment, as emerging evidence suggests that CDA may remain a viable option in select patients with outcomes comparable to standard candidates [46,47]. While preoperative segmental mobility has historically been regarded as a key criterion for CDA candidacy, recent studies suggest that even patients with reduced baseline mobility can achieve meaningful postoperative improvements in pain relief and functional status, challenging the traditional reliance on mobility as a strict determinant [48].

Collectively, these findings highlight the necessity of a nuanced, evidence-based approach to surgical decision-making. Patient-specific planning, careful evaluation of anatomical and biomechanical factors, and ongoing research into long-term cost-effectiveness, functional outcomes, and quality of life are essential to optimizing treatment strategies for cervical degenerative disease.

This study acknowledges several limitations inherent to its methodological approach, which is based on the use of a broad set of ICD-10 procedure and diagnosis codes applied to a large administrative dataset. While this strategy enables a macro-level assessment of national trends and facilitates the analysis of a substantial sample size—approximately 98,000 single-level CDA and ACDF cases—it does not permit granular, patient-level clinical detail. This reflects an inherent trade-off between the depth of individual patient information and the statistical power afforded by large-scale, population-based analyses. Additionally, the cost estimates reported in the National Inpatient Sample (NIS) are derived from hospital-specific cost-to-charge ratios, which may overestimate actual procedural expenses. However, these ratios undergo internal validation by the Agency for Healthcare Research and Quality, supporting their use in comparative economic analyses.

5. Conclusions

In conclusion, this study demonstrates a clear and sustained increase in the utilization of cervical disc arthroplasty (CDA), driven by younger patient demographics, higher rates of private insurance coverage, and the procedural advantages of motion preservation and reduced risk of adjacent-segment disease. Although CDA is associated with higher initial costs, its shorter hospital stays and lower complication rates make it an attractive option for appropriately selected patients. These findings align with current literature and support the growing adoption of CDA as a viable alternative to traditional anterior cervical discectomy and fusion (ACDF).

List of Abbreviations (A-Z)

ACDF: Anterior Cervical Discectomy and Fusion

CDA: Cervical Disc Arthroplasty

HCUP: Healthcare Cost and Utilization Project

ICD-10: International Classification of Diseases, 10th Revision

NIS: Nationwide Inpatient Sample

SPSS: Statistical Package for the Social Sciences

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