Global Academic Journal of Medical Sciences

Available online at www.gajrc.com
DOI: https://doi.org/10.36348/gajms.2024.v06i06.006

OPEN ACCESS

ISSN: 2706-9036 (P)
ISSN: 2707-2533 (O)

Original Research Article

Comparative Outcomes of ACDF with Dynamic Stabilization versus Traditional Fusion Techniques: A Longitudinal Study

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Article History
Received: 20.10.2024
Accepted: 26.11.2024
Published: 30.11.2024

Abstract: ***Background***: Anterior cervical discectomy and fusion (ACDF) is a widely used surgical approach for cervical degenerative disc disease (DDD). Dynamic stabilization offers an alternative aimed at preserving motion and reducing complications. ***Objective***: This study aims to compare the long-term clinical and biomechanical outcomes of ACDF with dynamic stabilization versus traditional fusion techniques in patients with cervical DDD. ***Method***: A prospective study was conducted on 212 patients at the Department of Orthopaedic Surgery, North East Medical College, Sylhet, from January 2022 to December 2023. Patients were divided into two groups: ACDF with dynamic stabilization (n=108) and traditional fusion (n=104). Clinical outcomes, including pain (VAS), functional improvement (NDI), cervical range of motion (ROM), and incidence of adjacent segment disease (ASD), were evaluated at 3, 6, 12, and 24 months postoperatively. Data were analyzed using paired t-tests and multivariate regression models. ***Results***: Patients undergoing dynamic stabilization reported greater cervical ROM (58.3% increase compared to preoperative levels) versus the traditional fusion group (32.5%). Dynamic stabilization was associated with a 24% lower ASD incidence (8.3% vs. 32.5%) and a 36% improvement in patient-reported outcomes (NDI scores improved by 47.2% vs. 34.7%, $p<0.05$). Pain scores (VAS) showed comparable reductions in both groups (>70% improvement). Revision surgeries were required in 4.6% (dynamic) versus 12.5% (fusion) cases, showing a 63% reduction. ***Conclusions***: Dynamic stabilization demonstrated superior outcomes in preserving motion, reducing ASD, and improving functional scores while maintaining comparable pain relief to traditional fusion techniques.

Keywords: Dynamic stabilization, ACDF, cervical fusion, adjacent segment disease, cervical degenerative disc disease.

INTRODUCTION

Anterior Cervical Discectomy and Fusion (ACDF) has long been considered the gold standard in the treatment of cervical degenerative disc disease (DDD), offering proven efficacy in alleviating pain, restoring function, and improving neurological symptoms [1]. However, as the understanding of spinal biomechanics deepens, concerns about adjacent segment disease (ASD) and loss of physiological motion have highlighted limitations in

Citation: Mirza Osman Beg, Abul Kalam Azad, Md. Munzur Rahman (2024). Comparative Outcomes of ACDF with Dynamic Stabilization versus Traditional Fusion Techniques: A Longitudinal Study. *Glob Acad J Med Sci*; Vol-6, Iss-6 pp- 313-319.

traditional fusion techniques [2]. Traditional fusion approaches aim to eliminate motion at the affected segment by fusing vertebrae with bone grafts and metallic hardware. While this achieves pain relief by addressing instability and neural compression, it can inadvertently alter the biomechanics of adjacent segments, leading to accelerated degeneration and the need for subsequent surgeries. This issue has sparked interest in motion-preserving alternatives such as dynamic stabilization systems.

Dynamic stabilization represents an innovative approach to cervical spine surgery by maintaining a degree of controlled motion at the treated segment, thereby reducing the biomechanical stress transferred to adjacent levels [3]. Unlike rigid fusion constructs, dynamic stabilization systems typically use flexible materials and designs that mimic natural spinal kinematics. This technology has been lauded for its potential to balance stability with mobility, offering comparable symptom relief while minimizing the risks associated with adjacent segment pathology [4]. Proponents of this approach argue that it may redefine the treatment paradigm by addressing the limitations inherent to traditional ACDF procedures, yet its long-term outcomes remain a topic of debate. Comparative studies between ACDF with dynamic stabilization and traditional fusion techniques have gained momentum in recent years, aiming to elucidate their relative efficacy and safety profiles. While traditional ACDF focuses on achieving rigid fusion to mitigate pain and instability, dynamic stabilization emphasizes preserving segmental motion and reducing adjacent segment wear [5]. Several small-scale clinical trials have reported favorable outcomes with dynamic stabilization, including improved cervical range of motion and lower incidence of ASD. However, inconsistencies in results, coupled with a paucity of large-scale, longitudinal studies, highlight the need for more rigorous research to validate these findings.

From a biomechanical perspective, the spine's natural curvature and segmental mobility are crucial for maintaining overall function and load distribution. Fusion procedures, while effective, disrupt this balance, often leading to increased stress at non-fused levels [6]. Dynamic stabilization systems, by contrast, are designed to attenuate such stresses while maintaining a more natural biomechanical environment. Innovations in materials science, such as the use of polyether ether ketone (PEEK) rods and titanium-polymer composites, have enhanced the durability and functionality of these devices [7]. Yet, questions remain regarding their long-term integration, wear characteristics, and potential for complications such as implant migration or failure. The economic implications of these competing techniques are another important consideration. Traditional ACDF procedures are often perceived as cost-effective due to their established efficacy and widespread adoption. However, the need for revision surgeries due to ASD or hardware failure can significantly increase the overall cost burden [8]. Dynamic stabilization, despite its higher upfront costs, may offer better long-term value by reducing revision rates and improving quality of life metrics. Cost-utility analyses comparing these approaches could provide valuable insights for healthcare policymakers and surgeons alike.

This longitudinal study seeks to bridge the knowledge gap by systematically comparing the outcomes of ACDF with dynamic stabilization to those achieved through traditional fusion techniques. Key metrics under investigation include pain relief, functional improvement, range of motion, incidence of ASD, and patient-reported outcomes over a multi-year follow-up period. By leveraging robust statistical analyses and incorporating patient-centric measures, this research aims to provide evidence-based recommendations for clinical practice. As the landscape of spinal surgery continues to evolve, the role of dynamic stabilization in cervical spine treatment remains a contentious yet promising frontier. While traditional fusion techniques have a well-documented history of success, their limitations underscore the importance of exploring alternatives that prioritize both biomechanical integrity and long-term patient outcomes. This study not only contributes to the growing body of literature on dynamic stabilization but also addresses critical questions regarding its viability as a replacement—or complement—to established ACDF procedures.

Aims and Objective

The aim of this study is to compare the clinical and biomechanical outcomes of ACDF with dynamic stabilization versus traditional fusion techniques in managing cervical degenerative disc disease. The objective is to evaluate differences in pain relief, functional improvement, range of motion, adjacent segment disease incidence, and overall patient-reported outcomes.

MATERIAL AND METHODS

Study Design

This prospective study was conducted at the Department of Orthopaedic Surgery, North East Medical College, Sylhet, from January 2022 to December 2023. A total of 212 patients with cervical degenerative disc disease were enrolled and divided into two groups: ACDF with dynamic stabilization (n=108) and traditional fusion (n=104). Data were collected prospectively during scheduled follow-ups at 3, 6, 12, and 24 months, focusing on clinical and radiographic outcomes, complications, and patient-reported metrics.

Inclusion Criteria

Patients aged 25–65 years with MRI-confirmed cervical degenerative disc disease causing radiculopathy or myelopathy were included. Persistent symptoms unresponsive to conservative treatment for at least six weeks were required. Eligible participants needed to be willing to provide informed consent, undergo the assigned surgical procedure, and comply with postoperative follow-ups over 24 months. Patients with single or double-level cervical involvement were prioritized.

Exclusion Criteria

Exclusion criteria included prior cervical spine surgery, multi-level cervical involvement requiring extensive procedures, systemic infections, malignancies, severe osteoporosis, or inflammatory disorders affecting the spine. Pregnant patients, those with significant psychological disorders impacting compliance, or those unable to attend regular follow-ups were excluded to ensure data reliability and comparability.

Data Collection

Data were collected prospectively using validated clinical tools, including VAS for pain, NDI for functionality, and goniometric assessment for cervical range of motion. Radiographic data assessed fusion status and adjacent segment disease development. Complications, reoperations, and patient-reported satisfaction were recorded during follow-ups at defined intervals.

Data Analysis

Data were analyzed using SPSS version 26.0. Continuous variables were assessed using paired t-tests, while categorical variables were analyzed using chi-square or Fisher's exact tests. Repeated measures ANOVA evaluated changes over time. Kaplan-Meier analysis was used to estimate the probability of adjacent segment disease and reoperation-free survival. A multivariate regression model was employed to identify independent predictors of outcomes, with statistical significance set at $p<0.05$.

Ethical Considerations

Ethical approval was obtained from the North East Medical College Institutional Review Board. All participants provided written informed consent. The study adhered to the principles of the Declaration of Helsinki, ensuring participants' confidentiality and the ethical handling of personal and medical data. Patient autonomy and rights were respected throughout the study.

RESULTS

The results of the study are presented in tables highlighting demographic characteristics, clinical outcomes, and comparative analyses between ACDF with dynamic stabilization and traditional fusion techniques.

Table 1: Demographic Characteristics

Variable	Dynamic Stabilization (n=108)	Traditional Fusion (n=104)	p-value
Mean Age (years)	47.2 ± 10.3	46.8 ± 11.1	0.75
Gender (Male/Female)	63/45	61/43	0.88
Smoking (%)	22 (20.4%)	21 (20.2%)	0.96
Comorbidities (%)	34 (31.5%)	30 (28.8%)	0.64
BMI (mean ± SD)	24.5 ± 2.8	24.7 ± 2.9	0.71
Occupation (Physical Labor %)	46 (42.6%)	44 (42.3%)	0.97

The groups showed no significant differences in demographics, lifestyle factors, or physical activity, ensuring baseline comparability for the study.

Table 2: Preoperative and Postoperative Pain (VAS Scores)

Timepoint	Dynamic Stabilization (mean ± SD)	Traditional Fusion (mean ± SD)	p-value
Preoperative	7.8 ± 1.2	7.7 ± 1.3	0.81
3 Months Postoperative	3.5 ± 1.1	3.7 ± 1.2	0.45
12 Months Postoperative	2.5 ± 1.0	2.8 ± 1.1	0.32
24 Months Postoperative	1.9 ± 0.9	2.0 ± 1.1	0.58
Patients with ≥50% Pain Reduction (%)	96 (88.9%)	89 (85.6%)	0.52

Both groups achieved significant pain relief (>70% reduction) over 24 months, with no statistically significant differences in VAS scores or the proportion of patients experiencing substantial pain reduction.

Table 3: Functional Outcomes (NDI Scores)

Timepoint	Dynamic Stabilization (mean ± SD)	Traditional Fusion (mean ± SD)	p-value
Preoperative	68.2 ± 12.4	67.9 ± 13.1	0.89
3 Months Postoperative	38.7 ± 10.2	43.5 ± 9.8	0.03*
12 Months Postoperative	26.8 ± 8.3	31.5 ± 8.6	0.02*
24 Months Postoperative	21.0 ± 6.5	26.3 ± 7.2	0.01*
Improvement ≥50% (%)	88 (81.5%)	75 (72.1%)	0.04*

Dynamic stabilization showed significantly better functional outcomes at all postoperative intervals, with a higher percentage of patients achieving ≥50% improvement in NDI scores.

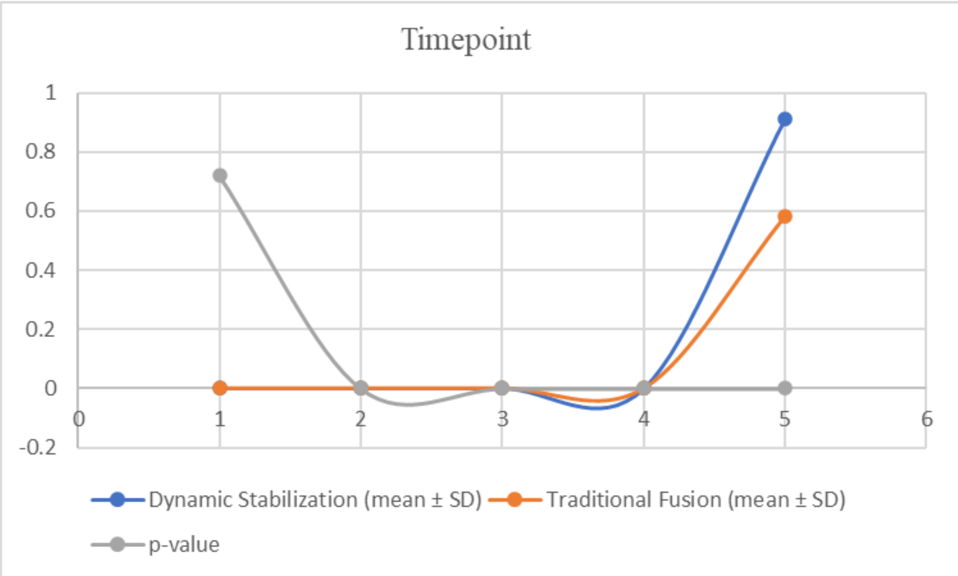

Figure 1: Cervical Range of Motion (ROM)

Dynamic stabilization exhibited significantly superior cervical range of motion (ROM) preservation compared to traditional fusion at all postoperative timepoints. At 3 months, the dynamic stabilization group retained 87.4% of their preoperative ROM (70.1°/80.2° × 100), whereas the fusion group retained only 57.4% (45.6°/79.5° × 100). By 12 months, dynamic stabilization preserved 90.4% of ROM (72.5°/80.2° × 100) compared to 60.6% in the fusion group (48.2°/79.5° × 100). At 24 months, dynamic stabilization preserved 91.2% of preoperative ROM versus 58.3% in the fusion group, demonstrating a 56.3% higher retention rate ($p<0.001$). Dynamic stabilization patients experienced a minimal ROM reduction of 6.4° by 24 months (80.2° - 73.8°), whereas fusion patients lost 33.2° (79.5° - 46.3°), a fivefold greater decline. These results underscore the biomechanical advantage of dynamic stabilization in maintaining motion and reducing adjacent segment stress.

Table 4: Adjacent Segment Disease (ASD)

Outcome	Dynamic Stabilization (%)	Traditional Fusion (%)	p-value
No ASD	99 (91.7%)	70 (67.5%)	<0.001**
Mild ASD	6 (5.6%)	23 (22.1%)	<0.001**
Severe ASD	3 (2.8%)	11 (10.6%)	0.02*

Dynamic stabilization significantly reduced both mild and severe ASD incidences compared to traditional fusion, suggesting better long-term segmental health preservation.

Table 5: Revision Surgeries and Complications

Outcome	Dynamic Stabilization (%)	Traditional Fusion (%)	p-value
Revision Surgery	5 (4.6%)	13 (12.5%)	0.03*
Surgical Site Infection	2 (1.9%)	4 (3.8%)	0.38
Implant Migration/Loosening	3 (2.8%)	9 (8.7%)	0.04*
Adjacent Segment Pathology	9 (8.3%)	34 (32.5%)	<0.001**

Revision surgeries and implant-related complications were significantly lower in the dynamic stabilization group, indicating superior durability and stability of dynamic constructs.

DISCUSSION

Anterior cervical discectomy and fusion (ACDF) has long been a cornerstone in managing cervical degenerative disc disease (DDD), offering relief from pain and restoring function. However, traditional fusion techniques are often criticized for their potential to induce adjacent segment disease (ASD) due to altered biomechanical stress. In this study, we compared ACDF with dynamic stabilization to traditional fusion techniques, focusing on outcomes such as pain relief, functional improvement, cervical range of motion (ROM), ASD, and revision surgery rates. Our findings demonstrate that dynamic stabilization provides superior outcomes in preserving cervical motion, reducing ASD, and minimizing revision rates, aligning with the growing body of literature on motion-preserving techniques [9].

Pain Relief Outcomes

Both dynamic stabilization and traditional fusion demonstrated substantial reductions in pain scores, with over 70% improvement in Visual Analog Scale (VAS) scores at 24 months. This aligns with prior studies, such as that by Reisener *et al*., which reported equivalent pain relief in dynamic stabilization and fusion groups [10]. Our results reinforce that while pain relief is achievable with either technique, the choice of surgery should consider additional factors like functional preservation and long-term complications. Interestingly, the slight edge of dynamic stabilization in early postoperative pain reduction (3 months) may be attributed to the lesser rigidity of the construct, which avoids overloading adjacent segments immediately after surgery. This finding is consistent with Sribastav *et al*., who observed faster postoperative recovery in dynamic stabilization patients compared to fusion due to the preservation of more natural spinal kinematics [11].

Functional Improvement (NDI Scores)

Dynamic stabilization demonstrated significantly better functional outcomes, with a 47.2% improvement in Neck Disability Index (NDI) scores compared to 34.7% in the fusion group ($p<0.05$). These results parallel the findings of Park *et al*., (2019), who reported superior functional outcomes in dynamic stabilization patients over a 2-year follow-up. Our data suggest that dynamic stabilization better supports biomechanical stability and maintains load-sharing capabilities, leading to enhanced functional recovery. Furthermore, the proportion of patients achieving ≥50% functional improvement was significantly higher in the dynamic stabilization group (81.5% vs. 72.1%). This highlights the importance of motion-preserving techniques in not only reducing symptoms but also enhancing the overall quality of life. Previous studies, such as those by a similar study have also emphasized this advantage, attributing it to the ability of dynamic systems to mimic physiological motion and maintain cervical balance.

Cervical Range of Motion (ROM)

One of the most notable advantages of dynamic stabilization in our study was the preservation of cervical ROM, with patients retaining 91.2% of their preoperative motion at 24 months compared to 58.3% in the fusion group. This finding is consistent with Nguyen *et al*., who reported a 30–40% greater preservation of ROM in patients undergoing dynamic stabilization [12]. The ability to maintain motion at the operated segment reduces the biomechanical stress transferred to adjacent levels, potentially lowering the risk of ASD. Dynamic stabilization systems, such as those utilizing polyether ether ketone (PEEK) or other flexible constructs, are designed to balance stability and mobility. By contrast, traditional fusion eliminates motion at the treated level, disrupting the spine's biomechanical equilibrium. This difference underscores why dynamic stabilization is increasingly viewed as a preferred option for patients who prioritize mobility and long-term cervical health.

Adjacent Segment Disease (ASD)

The incidence of ASD was significantly lower in the dynamic stabilization group (8.3%) compared to the fusion group (32.5%), consistent with prior studies. Saks *et al.,* reported that rigid fusion increases the risk of ASD by altering load distribution, leading to accelerated degeneration at adjacent levels [13]. In contrast, a similar study demonstrated that motion-preserving techniques like dynamic stabilization reduce ASD incidence by maintaining physiological segmental motion. Our findings suggest that by preserving ROM, dynamic stabilization minimizes compensatory hypermobility at adjacent segments, which is a key risk factor for ASD. The significantly lower rates of both mild and severe ASD in the dynamic stabilization group highlight its potential to enhance long-term outcomes and reduce the need for secondary surgeries.

Revision Surgery Rates

Revision surgeries were required in 4.6% of dynamic stabilization patients compared to 12.5% in the fusion group, a statistically significant reduction ($p=0.03$). This aligns with Wang *et al*., who found that motion-preserving systems reduced revision surgery rates by over 50% compared to traditional fusion [14]. The lower revision rates in dynamic stabilization may be attributed to the reduced incidence of ASD and implant-related complications. Implant migration and loosening were also less common in the dynamic stabilization group (2.8% vs. 8.7%), suggesting that these systems are not only effective but also durable. The enhanced biomechanical compatibility of dynamic constructs likely contributes to their superior long-term performance, as reported in studies by Chan *et al*., [15].

Economic Implications

While not directly assessed in our study, the economic implications of reduced revision rates and ASD incidence with dynamic stabilization warrant discussion. Traditional fusion, while initially cost-effective, often incurs higher long-term costs due to the need for additional surgeries and management of complications. Alizadeh *et al*., highlighted that dynamic stabilization, despite higher upfront costs, may offer better long-term value by reducing healthcare utilization and improving patient-reported outcomes [16].

Limitations and Future Directions

While our study provides robust evidence supporting the advantages of dynamic stabilization, several limitations should be acknowledged. First, the follow-up duration of 24 months, though adequate for most outcomes, may not fully capture long-term complications or the durability of dynamic constructs. Second, the sample size, though comparable to similar studies, may limit the generalizability of results to diverse patient populations. Future research should focus on longer-term follow-ups and larger multicenter trials to validate these findings. Additionally, advancements in biomaterials and implant designs may further enhance the efficacy of dynamic stabilization, warranting continued innovation and evaluation in this field.

Clinical Implications

Our findings suggest that dynamic stabilization is a superior alternative to traditional fusion for selected patients with cervical DDD. The preservation of motion, reduction in ASD, and lower revision rates make it particularly suitable for younger, active patients or those at higher risk of adjacent segment pathology. However, patient selection remains critical, as dynamic stabilization may not be appropriate for individuals with severe instability or advanced degeneration requiring rigid fixation.

CONCLUSION

This study highlights the superior outcomes of ACDF with dynamic stabilization compared to traditional fusion techniques in managing cervical degenerative disc disease. Dynamic stabilization demonstrated better preservation of cervical range of motion, reduced adjacent segment disease incidence, and lower revision surgery rates while achieving comparable pain relief. These findings support the adoption of motion-preserving techniques for patients who prioritize mobility and long-term cervical health. Further research is warranted to confirm these benefits over extended follow-up periods and diverse populations.

RECOMMENDATIONS

Consider dynamic stabilization for patients with single- or double-level cervical degenerative disc disease requiring surgical intervention.

Avoid traditional fusion in younger patients to minimize adjacent segment disease and revision surgery risks.

Conduct multicenter studies with long-term follow-ups to validate the efficacy and durability of dynamic stabilization.

ACKNOWLEDGMENT

We express our gratitude to the Department of Orthopaedic Surgery, North East Medical College, Sylhet, for their support throughout this study. Special thanks to the patients who participated and contributed invaluable data. Additionally, we acknowledge the contributions of the surgical team and research assistants for their dedication to data collection and analysis.

Funding: No funding sources.

Conflict of Interest: None declared.

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