Anterior Cervical Discectomy and Fusion (ACDF): A Review of Surgical Approaches for Cervical Spine Disorders

Abstract

Anterior cervical discectomy and fusion (ACDF) is one of the most widely performed surgical procedures for managing cervical spine pathologies, including cervical radiculopathy, myelopathy, and traumatic or degenerative disc disease. This review aims to provide a comprehensive overview of the historical evolution, surgical techniques, graft materials, instrumentation options, clinical outcomes, and complication profiles of ACDF, with emphasis on the comparative analysis of alternative anterior and posterior approaches. Literature from PubMed, Scopus, and Google Scholar between 1950 and 2025 was reviewed. Evidence suggests that ACDF provides high rates of symptom resolution and fusion success, though risk of complications such as dysphagia, adjacent segment disease, and pseudarthrosis persists. Advancements in minimally invasive techniques and biomaterials continue to refine surgical outcomes.

Keywords: anterior cervical discectomy and fusion, ACDF, cervical spine surgery, surgical approaches, cervical spondylosis, cervical myelopathy

1. INTRODUCTION

Cervical spine disorders are a significant cause of chronic pain, neurological deficits, and disability worldwide. They include degenerative disc disease, cervical spondylosis, herniated discs, traumatic instability, tumors, and inflammatory lesions. Cervical radiculopathy affects about 83 per 100,000 people annually, while cervical myelopathy is the most common cause of spinal cord dysfunction in older adults.[1] These conditions have substantial socioeconomic consequences due to long-term treatment and reduced productivity. Anterior cervical discectomy and fusion (ACDF) is considered the gold standard surgical treatment for radiculopathy and myelopathy when conservative measures fail. The anterior approach enables direct decompression of neural structures and stabilization via interbody fusion, relieving symptoms and preventing further neurological decline. [2]

ACDF was first described in the late 1950s by Smith and Robinson, and independently by Cloward. Smith and Robinson used an oblique anterior approach with an iliac crest autograft, while Cloward employed a dowel graft technique for stability. Both achieved excellent results, laying the foundation for modern cervical spine surgery. Over the decades, ACDF has evolved with significant refinements in technique, graft selection, and fixation methods. [3] The shift from iliac crest autografts to PEEK, titanium, and carbon fiber cages reduced donor site morbidity while maintaining fusion rates. The introduction of anterior plating in the 1980s improved stability, fusion success, and multi-level procedure outcomes. [4]

Recent advancements include minimally invasive and endoscopic ACDF, aiming to reduce tissue trauma, perioperative complications, and postoperative dysphagia. Despite its success, ACDF has recognized risks, including dysphagia, recurrent laryngeal nerve palsy, pseudarthrosis, and adjacent segment degeneration—especially in multi-level surgeries. [5] Growing interest in motion-preserving alternatives, such as cervical disc arthroplasty, has prompted reevaluation of ACDF's long-term biomechanical effects. This review examines current evidence on ACDF, comparing traditional and minimally invasive techniques, discussing graft and fixation options, evaluating complications, and offering guidance for optimal patient selection and outcomes. [6]

2. Historical Background

Anterior cervical discectomy and fusion (ACDF) originated in the mid-20th century as a transformative approach to cervical spine surgery. In **1955**, Smith and Robinson introduced an anterior approach for cervical decompression, utilizing a **horseshoe-shaped autologous iliac crest graft** to restore disc height and maintain stability. Their method provided direct access to the pathological disc and addressed both central and foraminal compression in a single exposure. Almost simultaneously, **Ralph Cloward** described a **dowel graft technique**, inserting a cylindrical autograft harvested from the iliac crest into the prepared disc space. His emphasis on **direct visualization and thorough disc removal** improved decompression quality and spinal alignment. [7]

Subsequent refinements included the **Bailey-Badgley slot graft**, which offered enhanced load-sharing, and the **Simmons-Bhalla keystone graft**, designed to resist graft migration and subsidence. These innovations sought to improve fusion stability and reduce complications. A major milestone came in the **1980s** with the introduction of **anterior cervical plating**. Rigid internal fixation provided immediate stability, improved fusion rates, reduced graft-related complications, and enabled earlier patient mobilization—particularly important in multilevel procedures. Modern ACDF techniques integrate these foundational principles with advanced biomaterials, cage systems, and minimally invasive methods, reflecting over six decades of continuous refinement aimed at optimizing patient outcomes. [8]

3. Indications for ACDF

Anterior cervical discectomy and fusion (ACDF) is primarily indicated for cervical spine pathologies that cause neural compression and segmental instability, particularly when conservative management has failed or when there is progressive neurological decline. The main clinical scenarios include:

1. **Degenerative Disc Disease with Radiculopathy or Myelopathy**

   Chronic degeneration of the cervical intervertebral discs can lead to loss of disc height, osteophyte formation, and hypertrophy of the uncovertebral and facet joints. These changes may compress nerve roots (radiculopathy) or the spinal cord (myelopathy), resulting in pain, sensory loss, motor weakness, and gait disturbances. ACDF is indicated when symptoms are persistent and significantly impact function despite adequate non-operative therapy.
2. **Cervical Spondylotic Myelopathy (CSM)**

   CSM is the most common cause of spinal cord dysfunction in adults over the age of 55. It results from progressive degenerative narrowing of the cervical spinal canal, often at multiple levels. ACDF is particularly suited for cases with ventral cord compression, as it allows for direct removal of osteophytes and disc material while restoring cervical lordosis. [9]

3. **Cervical Disc Herniation Refractory to Non-Surgical Treatment**

   Acute or subacute disc herniations that cause severe radicular pain, weakness, or myelopathy and do not respond to analgesics, physiotherapy, or epidural steroid injections may require ACDF. The anterior approach provides direct access to the herniated material, enabling complete decompression of the affected nerve root and spinal cord.

4. **Traumatic Injuries with Instability**

   High-energy trauma, such as motor vehicle accidents or falls, can cause fractures, ligamentous injury, or dislocation in the cervical spine. In cases where there is anterior column compromise or disc disruption with instability, ACDF can achieve decompression, realignment, and stabilization in a single-stage procedure. [10]

5. **Neoplastic Lesions Requiring Decompression and Stabilization**

   Primary or metastatic tumors involving the cervical vertebral bodies or intervertebral discs can cause neural compression and spinal instability. ACDF enables removal of the pathological tissue from an anterior approach, followed by reconstruction and stabilization to maintain spinal integrity.

6. **Infective Pathologies After Debridement**

   Infections such as cervical spondylodiscitis or vertebral osteomyelitis may necessitate surgical debridement when there is neurological compromise, instability, or failure of medical therapy. ACDF allows removal of infected tissue, decompression of neural elements, and stabilization with appropriate grafting, often combined with postoperative antimicrobial therapy. [11]

4. Surgical Approaches and Techniques

4.1 Traditional Open ACDF

The **traditional open anterior cervical discectomy and fusion (ACDF)** remains the gold standard for treating symptomatic cervical degenerative disc disease, radiculopathy, and myelopathy. The procedure begins with a **transverse or oblique skin incision** along a natural skin crease in the anterior neck. Blunt dissection is performed through the platysma and along anatomical planes to reach the **prevertebral space**, taking care to protect the carotid sheath laterally and the trachea–esophagus medially. Under direct visualization, the affected **intervertebral disc** is removed, osteophytes are excised, and the **endplates are prepared** to optimize graft incorporation. Interbody fusion is achieved using autograft, allograft, or synthetic cages, often supplemented with **anterior cervical plating** to enhance stability, promote fusion, and reduce the risk of graft dislodgement. This approach allows excellent visualization of the surgical field and precise decompression of neural structures. [12]

4.2 Minimally Invasive and Endoscopic ACDF

Minimally invasive (MI) and endoscopic ACDF techniques have been developed to minimize surgical morbidity while maintaining the efficacy of decompression and fusion. These approaches use smaller skin incisions and **tubular or expandable retractors**, often combined with endoscopic visualization, to reduce **soft tissue trauma**, postoperative neck pain, and blood loss. Advantages include shorter hospital stays, faster return to work, and improved cosmetic outcomes. However, they require **specialized instruments, high-definition optics, and advanced technical skills**, leading to a steeper learning curve. Furthermore, the reduced exposure may limit their applicability in cases with severe deformity, extensive osteophyte formation, or multi-level disease. [13]

4.3 Multilevel ACDF

Multilevel ACDF—typically involving two or more contiguous levels—is indicated in patients with **multi-segment cervical spondylosis, myelopathy, or trauma** where decompression at multiple sites is required. While it can provide excellent neurological recovery, it carries **higher complication rates** compared to single-level procedures. These include increased **dysphagia**, higher risk of **pseudarthrosis** due to the greater number of fusion interfaces, and a greater likelihood of **adjacent segment degeneration (ASD)** because of altered cervical biomechanics. Surgical planning often involves careful graft selection, consideration of supplemental posterior fixation in high-risk cases, and meticulous attention to alignment to minimize long-term complications. Despite these risks, successful multilevel fusion can yield substantial symptom relief and functional improvement, especially when combined with meticulous postoperative rehabilitation. [14]

5. Graft Materials and Instrumentation

5.1 Autograft (Iliac Crest)

Autologous iliac crest bone graft has historically been considered the **gold standard** for ACDF due to its **osteogenic, osteoinductive, and osteoconductive properties**, leading to consistently **high fusion rates exceeding 95%** in single-level procedures. The structural integrity of the tricortical graft helps maintain disc height and cervical alignment. However, harvesting autograft introduces **donor site morbidity**, which may include **persistent pain, infection, hematoma, sensory disturbances, or gait difficulties**. This drawback has driven the search for alternatives that avoid a secondary surgical site. [15]

5.2 Allograft

Cadaveric allograft bone eliminates the need for graft harvesting, thereby avoiding donor site pain and shortening operative time. It is readily available in various shapes and sizes, and pre-shaped allografts facilitate surgical handling. However, **fusion rates with allografts tend to be slower** due to the absence of living osteogenic cells and the need for creeping substitution. While modern sterilization and preservation techniques have reduced the risk of **disease transmission**, they may also compromise mechanical strength and biological activity. Allografts are often supplemented with **anterior plating** to enhance stability during the prolonged incorporation phase. [16]

5.3 Interbody Cages (PEEK, Titanium)

Polyetheretherketone (PEEK) cages and **titanium cages** have gained popularity as graft substitutes in ACDF. These devices **maintain disc height and cervical lordosis**, reducing the risk of postoperative segmental collapse.

- **PEEK cages** are radiolucent, allowing clear postoperative imaging to assess fusion, and have an elastic modulus similar to bone, which reduces stress shielding.
- **Titanium cages** provide excellent structural strength and are often coated with porous or hydroxyapatite layers to enhance osseointegration.
  Both cage types can be filled with autograft, allograft chips, or synthetic bone substitutes, functioning as fusion conduits while preserving intervertebral spacing. [17]

5.4 Anterior Cervical Plates

Anterior cervical plating systems are commonly used to provide **rigid segmental fixation**, particularly in **multilevel ACDF** or in patients at high risk of graft migration and pseudarthrosis. Plates help maintain sagittal alignment, resist flexion–extension forces, and enhance the likelihood of successful fusion. Modern low-profile and dynamic plate designs aim to reduce the risk of **adjacent level ossification** and postoperative dysphagia. Their use is especially beneficial in complex reconstructions or when immediate postoperative stability is critical for early mobilization. [18]

6. Clinical Outcomes

Multiple prospective and retrospective studies have demonstrated that anterior cervical discectomy and fusion (ACDF) achieves excellent clinical outcomes in appropriately selected patients. In the majority of series, more than 90% of patients experience significant relief from radicular pain, improvement in sensory deficits, and recovery of motor function within the early postoperative period. These improvements are typically sustained over the long term, translating into marked enhancements in functional status, quality of life, and return to work.

Radiographic evidence indicates fusion rates exceeding 95% for single-level ACDF when modern fixation techniques, such as anterior cervical plating and structural interbody grafts, are employed. Successful fusion is strongly associated with symptom resolution, spinal stability, and reduced reoperation rates. In multilevel ACDF, fusion rates remain high but may be slightly lower, with a corresponding increase in the risk of pseudarthrosis. [19]

Longitudinal follow-up studies show that patient-reported outcomes—including Neck Disability Index (NDI), Visual Analogue Scale (VAS) scores for pain, and SF-36 measures—demonstrate sustained benefit for 5 to 10 years after surgery. However, a subset of patients exhibit gradual symptom recurrence or functional decline over time, most commonly attributed to adjacent segment disease (ASD), which is thought to arise from altered biomechanics following fusion. Despite this, overall satisfaction rates remain high, and the majority of patients maintain significant improvement compared to their preoperative status.

7. Complications

Complication	Approximate Incidence
Dysphagia	5–20% (often transient)
Pseudarthrosis	2–10% (higher in multilevel)
Adjacent segment degeneration	8–25% over 10 years
Hardware failure	2–3%
Recurrent laryngeal nerve palsy	1–3%
Infection	1–2%
Esophageal injury	0.2–0.5%
Vertebral artery injury	0.1–0.5%

Table 1: Indicates the complication and the approximate incidence [20]

Comparison with Alternative Approaches

Posterior Cervical Foraminotomy (PCF):

Posterior cervical foraminotomy is a motion-preserving procedure primarily indicated for **single-level cervical radiculopathy** caused by foraminal stenosis or lateral disc herniation. Multiple randomized controlled trials have shown that PCF provides **comparable symptomatic relief** to ACDF in properly selected patients, while avoiding the need for fusion and its associated risks such as pseudarthrosis and adjacent segment degeneration. The procedure preserves the native disc and cervical alignment, allowing maintenance of segmental motion. However, it does not address **central canal stenosis or ventral compressive pathology**, and there is a higher chance of recurrent symptoms if central degeneration progresses. [21]

Cervical Corpectomy:

Cervical corpectomy involves removal of one or more vertebral bodies along with the intervening discs to decompress the spinal cord in cases of **multi-level compression**, ossification of the posterior longitudinal ligament (OPLL), or vertebral body pathology such as tumors or fractures. While this approach allows **direct decompression of central canal pathology** extending behind the vertebral body, it is technically more demanding than ACDF and is associated with **greater intraoperative blood loss, longer operative times, and higher rates of graft subsidence and pseudarthrosis**, particularly in multilevel constructs. Compared to multilevel ACDF, corpectomy may provide more complete decompression but at the expense of increased surgical morbidity. [22]

Cervical Disc Arthroplasty (CDA):

Cervical disc arthroplasty is designed to **preserve motion at the operated level** while providing neural decompression, thereby potentially reducing the incidence of **adjacent segment degeneration** seen after fusion procedures. Current evidence suggests CDA offers similar or slightly superior functional outcomes compared to ACDF in **younger patients with single-level disease** who have minimal spondylosis and preserved segmental motion preoperatively. Contraindications include advanced degenerative changes, facet arthropathy, and significant instability. Long-term studies suggest that CDA may delay or prevent degeneration at adjacent levels, but cost, implant longevity, and revision strategies remain considerations in patient selection.

9. Future Directions

Advancements in ACDF technology are increasingly focused on improving fusion rates, minimizing complications, and enhancing patient recovery. **Biomechanically optimized cervical cages with porous titanium** are being developed to promote osseointegration while preserving optimal load-sharing properties. **Stand-alone cage-plate systems** aim to provide sufficient stability without the need for separate anterior plates, potentially reducing postoperative dysphagia. The use of **stem cell–enhanced bone graft substitutes** holds promise for accelerating bone healing and achieving earlier fusion, particularly in high-risk or multilevel cases. Furthermore, **fully endoscopic anterior approaches** are under investigation as a means to minimize soft tissue disruption, reduce perioperative morbidity, and facilitate faster return to function, potentially redefining the surgical standard for cervical degenerative disease.

10. Conclusion

ACDF remains a cornerstone in the management of cervical spine disorders, offering high rates of neurological improvement and spinal stability. Proper patient selection, meticulous surgical technique, and appropriate choice of graft and instrumentation are key to optimizing outcomes. The evolution of minimally invasive techniques and motion-preserving alternatives may redefine surgical paradigms in the coming decades.

REFERENCES

1. Awawdeh, F., Abdul Salam, A., & Soti, V. (2024). Efficacy of Anterior Cervical Discectomy and Fusion Versus Cervical Disc Arthroplasty in the Treatment of Cervical Degenerative Disc Disease, Radiculopathy, and Myelopathy: A Systematic Review. *Cureus*. https://doi.org/10.7759/cureus.74418
2. Joaquim, A. F., Sielatycki, J. A., & Riew, K. D. (2019). *Anterior surgical options for cervical spondylotic myelopathy*. *2*(1), 33. https://doi.org/10.4103/ISJ.ISJ_39_18
3. Tumialán, L. M. (2019). *Anterior Cervical Discectomy and Fusion* (pp. 249–270). Springer, Cham. https://doi.org/10.1007/978-3-319-97952-6_22
4. Zahid, A., & Mohammed, R. (2023). A retrospective comparison of cage-alone versus cage-plate constructs used in anterior cervical discectomy and fusion. *Orthopaedic Proceedings*, *105-B*(SUPP_4), 9. https://doi.org/10.1302/1358-992x.2023.4.009
5. Robertson, S. C., & Ashley, M. (2023). *Complications of Anterior Cervical Discectomy and Fusion* (pp. 169–178). Springer Science+Business Media. https://doi.org/10.1007/978-3-030-12887-6_20
6. Epstein, N. E. (2019). A Review of Complication Rates for Anterior Cervical Diskectomy and Fusion (ACDF). *Surgical Neurology International*, *10*, 100. https://doi.org/10.25259/SNI-191-2019
7. Adams, C., Sweiss, F., Feinberg, M., & Sherman, J. H. (2020). *Anterior Cervical Discectomy and Fusion* (pp. 1–8). Springer, Cham. https://doi.org/10.1007/978-3-030-20847-9_1
8. Battistelli, M., Polli, F. M., D'Alessandris, Q. G., D'Ercole, M., Izzo, A., Rapisarda, A., & Montano, N. (2023). An Overview of Recent Advances in Anterior Cervical Decompression and Fusion Surgery. *Surgical Technology International*, *43*. https://doi.org/10.52198/23.sti.43.ns1732
9. Fakhoury, J., & Dowling, T. J. (2021). *Cervical Degenerative Disc Disease*. https://www.ncbi.nlm.nih.gov/books/NBK560772/
10. Girolami, M., Ghermandi, R., Gasbarrini, A., Akman, Y. E., & Boriani, S. (2017). *Cervical Spine Instrumentation* (pp. 69–86). Springer, Cham. https://doi.org/10.1007/978-3-319-42737-9_6
11. Malone, H., & Kaiser, M. G. (2019). *Multilevel ACDF Versus Corpectomy* (pp. 287–307). Springer, Cham. https://doi.org/10.1007/978-3-319-97952-6_24
12. Wu, Z.-P., Wei, Z., & Song, X.-L. (2024). Comparison of efficacy between endoscope-assisted anterior cervical discectomy and fusion (ACDF) and open ACDF in the treatment of single-segment cervical spondylotic myelopathy. *Journal of Orthopaedic Surgery and Research*, *19*. https://doi.org/10.1186/s13018-023-04514-w
13. *Anterior Cervical Discectomy and Interbody Fusion by Endoscopic Approach* (pp. 83–86). (2023). https://doi.org/10.1007/978-981-19-7761-9_7
14. Jack, M. M., Lundy, P., Reeves, A., & Arnold, P. M. (2021). Four-level Anterior Cervical Discectomy and Fusions: Results Following Multilevel Cervical Fusion With a Minimum 1-Year Follow-up. *Clinical Spine Surgery*, *34*(4). https://doi.org/10.1097/BSD.0000000000001116
15. Ur-Rehman, R., Khan, M. N., Nasir, A., & Ur-Rahman, A. (2019). *Surgical Outcome of Anterior Cervical Discectomy and Fusion (ACDF) with Autologous Bone Graft from Iliac Bone and Miniplate Application Over It*. *23*(3), 217–220. https://doi.org/10.36552/PJNS.V23I3.362
16. Lopez, G. D., Hijji, F. Y., Narain, A. S., Yom, K. H., & Singh, K. (2017). Iliac Crest Bone Graft: A Minimally Invasive Harvesting Technique. *Clinical Spine Surgery*, *30*(10), 439–441. https://doi.org/10.1097/BSD.0000000000000556

17. Review of anterior cervical diskectomy/fusion (ACDF) using different polyetheretherketone (PEEK) cages. (2022). *Surgical Neurology International*, *13*, 556. https://doi.org/10.25259/sni_992_2022
18. Altorfer, F. C. S., Laux, C. J., Graf, D. N., Götschi, T., Abel, F., Farshad, M., & Spirig, J. M. (2024). Titanium-Coated Polyetheretherketone Cages Vs Full Titanium Cages for Stand-Alone 1- or 2-Level Anterior Cervical Discectomy and Fusion: A Comparative Study. *The International Journal of Spine Surgery*, *18*(3), 287–294. https://doi.org/10.14444/8610
19. Hameed, H. H., & Hammood, E. K. (2020). Anterior Cervical Discectomy with Fusion in Patients with Degenerative Cervical Disc Disease. *Dwight's Journal of Music*, *19*(1), 50–59. https://doi.org/10.26505/DJM.19015260216
20. Grin, A. A., Kasatkin, D. S., & Shtadler, V. D. (2020). *Dysphonia, dysphagia, and injury of recurrent laryngeal nerve with anterior cervical spinal fusion*. *22*(2), 98–104. https://doi.org/10.17650/1683-3295-2020-22-2-98-104
21. Ghobrial, G. M., & Levi, A. D. (2018). *Posterior Cervical Foraminotomy* (pp. 203–211). Springer, Cham. https://doi.org/10.1007/978-3-319-71943-6_17
22. Mehren, C., & Wanke-Jellinek, L. (2019). Posterior foraminotomy for lateral cervical disc herniation. *European Spine Journal*, *28*(1), 1–2. https://doi.org/10.1007/S00586-018-05863-5
23. Clark, D. M., Yow, B. G., Piscoya, A. S., Roach, W. B., & Wagner, S. C. (2021). Cervical Disc Arthroplasty is an Acceptable Treatment Option for Adjacent Segment Degeneration After Fusion. *Clinical Spine Surgery*, *34*(4), 119–120. https://doi.org/10.1097/BSD.0000000000000951
24.