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Techniques for anterior cervical decompression for radiculopathy

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Object. The objective of this systematic review was to use evidence-based medicine to identify the best techniques for anterior cervical nerve root decompression.

Methods. The National Library of Medicine and Cochrane Database were queried using MeSH headings and keywords relevant to techniques for the surgical management of cervical radiculopathy. The guidelines group assembled an evidentiary table summarizing the quality of evidence (Classes I–III). The group formulated recommendations that contained the degree of strength based on the Scottish Intercollegiate Guidelines network. Validation was done through peer-review by the Joint Guidelines Committee of the American Association of Neurological Surgeons/Congress of Neurological Surgeons.

Results. Both anterior cervical discectomy (ACD) and anterior cervical discectomy with fusion (ACDF) are equivalent treatment strategies for 1-level disease with regard to functional outcome (Class II). Anterior cervical discectomy with fusion may achieve a more rapid reduction of neck and arm pain compared to ACD with a reduced risk of kyphosis, although functional outcomes may be similar. Anterior cervical discectomy with fusion is not a lasting means of increasing foraminal or disc height compared to ACD. Anterior cervical plating (ACDF with instrumentation) improves arm pain (but not other clinical parameters) better than ACDF in the treatment of 2-level disease (Class II). With respect to 1-level disease, plating may reduce the risk of pseudarthrosis and graft problems (Class III) but does not necessarily improve clinical outcome alone (Class II). Cervical arthroplasty is recommended as an alternative to ACDF in selected patients for control of neck and arm pain (Class II).

Conclusions. Anterior cervical discectomy, ACDF, and arthroplasty are effective techniques for addressing surgical cervical radiculopathy. *(DOI: 10.3171/2009.2.SPINE08721)*

Key Words • cervical spine • fusion • fixation • instrumentation • practice guidelines • radiculopathy

Recommendations

Indications: 1-Level Cervical Disc Degeneration. Both ACD and ACDF are recommended as equivalent treatment strategies for 1-level cervical disc degeneration with respect to clinical outcome measures such as VAS pain score, Odom's criteria, the McGill Pain Questionnaire, SF-36, and arm pain (quality of evidence, Class II, strength of recommendation, C). There is conflicting Class II evidence as to whether ACDF relieves overall neck pain associated with 1-level cervical disc degeneration better than ACD.

Methods: ACDF Compared to ACD. Both ACD and ACDF are recommended as equivalent treatment strategies for 1-level cervical disc degeneration with respect to clinical outcome measures such as VAS pain scores, Odom's criteria, the McGill Pain Questionnaire, SF-36, and arm pain (quality of evidence, Class I; strength of recommendation, C). There is conflicting Class II evidence as to whether ACDF relieves overall neck pain

Abbreviations used in this paper: ACD = anterior cervical discectomy; ACDF = anterior cervical discectomy with fusion; ACDFI = anterior cervical discectomy and fusion with instrumentation; LOS = length of stay; NDI = Neck Disability Index; NS = not significant; RCT = randomized controlled trial; RSA = radiostereometric analysis; SF-36 = 36-Item Short Form Health Survery; VAS = visual analog scale.

associated with 1-level cervical disc degeneration better than ACD. Anterior cervical discectomy with fusion is recommended over ACD for a more rapid reduction of neck and arm pain (quality of evidence, Class III; strength of recommendation, D), although functional outcomes may be similar. Anterior cervical discectomy with fusion is also recommended over ACD as a means to reduce the risk of kyphosis and increase fusion rate (quality of evidence, Class II; strength of recommendation, C). Anterior cervical discectomy with fusion is not recommended as a lasting means of increasing foraminal or disc height compared to ACD (quality of evidence, Class II; strength of recommendation, C).

Indications: 2-Level Cervical Disc Degeneration. Anterior cervical plating (ACDFI) is recommended over ACDF to improve arm pain in the treatment of 2-level cervical disc degeneration (quality of evidence, Class II; strength of recommendation, C). Plating does not improve other clinical outcome parameters with respect to 2-level disease.

Indications: 1-Level Cervical Disc Degeneration. With respect to 1-level cervical disc degeneration, the addition of a cervical plate is recommended if the goal is to reduce the risk of pseudarthrosis and graft problems (quality of evidence, Class III; strength of recommendation, D) and to maintain lordosis (quality of evidence, Class II; strength of recommendation, C) but not necessarily to improve clinical outcome alone (quality of evidence, Class II; strength of recommendation, B). Cervical arthroplasty is recommended as an alternative to ACDF in selected patients for control of neck and arm pain (quality of evidence, Class II; strength of recommendation, B).

Methods: Plating Compared to No Plating. Anterior cervical discectomy and fusion with instrumentation is recommended over ACDF to improve arm pain in the treatment of 2-level cervical disc degeneration (quality of evidence, Class II; strength of recommendation, C). Plating does not improve other clinical outcome parameters with respect to 2-level disease. With respect to 1-level cervical disc degeneration, the addition of a cervical plate is recommended if the goal is to reduce the risk of pseudarthrosis and graft problems (quality of evidence, Class III; strength of recommendation, D) and to maintain lordosis (quality of evidence, Class II; strength of recommendation, C) but not necessarily to improve clinical outcome alone (quality of evidence, Class II; strength of recommendation, B).

Methods: Cervical Arthroplasty. Cervical arthroplasty is recommended as an alternative to ACDF in selected patients for control of neck and arm pain (quality of evidence, Class II; strength of recommendation, B).

Timing. There is insufficient evidence to make a recommendation on timing.

Rationale

Anterior cervical surgery to address radiculopathy has several variations. Described approaches include ACD, ACDF, and ACDFI. The surgeon may achieve interbody fusion (or arthrodesis) using a variety of techniques such as autograft, allograft, or the use of an interbody cage. These are addressed in a separate chapter. More recently, instrumentation (or fixation) techniques have expanded to include choices such as static or dynamic plating, and the operative armamentarium continues to enlarge.

The purpose of this chapter was to undertake an evidence-based review of techniques for anterior surgery in the treatment of radiculopathy. As Angevine and colleagues[2] noted, the rate of hospitalization for operative and nonoperative treatment of cervical disc disease did not increase during the 1990s. However, the proportion of hospitalizations involving cervical fusion did increase, indicating a paradigm shift toward inclusion of arthrodesis. Although instrumentation was not specifically analyzed in the study by Angevine et al.,[2] plating does appear to be popular even for short-segment constructions. More recently, cervical arthroplasty has been developed as an alternative to fusion. Specifically to be addressed are comparisons between ACD and ACDF, ACDF and ACDFI, dynamic versus static plates, and ACDF versus arthroplasty.

Search Criteria

We searched the National Library of Medicine (Pubmed) and the Cochrane Database for the period from 1966 through 2007 using keywords and associated MeSH subject headings. A search of "anterior cervical discectomy" yielded 436 references. "Anterior cervical diskectomy" plus "fusion" yielded 367 references. "Anterior cervical diskectomy" plus "fixation" yielded 92 references while "anterior cervical diskectomy" plus "plating" yielded 125 references. Adding to the above terms was the term "outcome," which yielded a total of 607 references. Adding "technique" yielded 386 references. Finally, using "anterior" and "cervical" with either "fusion" or "outcome" yielded 1073 references. After combining the databases and eliminating duplicate references, 2155 articles remained. We reviewed titles and abstracts with attention to titles addressing trials comparing different techniques; 1 Cochrane database review addressed the subject as well.[14] Outcomes of interest, both short and long term, included LOS, operative time, blood loss, improvement in arm and neck pain, and functional improvement.

We selected articles if they included a clinical comparison of 2 or more treatment options and excluded articles that contained information on only a single technique. We gave preference to RCTs, systematic reviews, or studies containing prospective data. We compiled evidentiary tables (Tables 1–3) based on the resulting 30 studies that met inclusion criteria. Ten studies and 1 systematic review examined ACD compared with ACDF (Table 1). Sixteen studies and 2 systematic reviews addressed ACDFI (plating) versus ACDF without plating (Table 2). The authors of 4 studies examined dynamic plating versus static plating (Table 3).

For arthroplasty, the search protocol was similar to above. Search terms included "arthroplasty" and "spine"

TABLE 1: Evidentiary summary of studies comparing ACD to ACDF

Authors & Year	Description	Results	Class	Conclusions
Jacobs et al., 2004	Systematic review of techniques including ACD vs ACDF, plate vs no plate fixation, & allograft vs autograft. The authors detailed 6 studies that met criteria. These studies involved 430 patients (ACD 212, ACDF 218). In general, they found that methodological quality was low & the studies did not provide adequate homogeneous comparison groups.	Conflicting evidence noted on the relative effectiveness of ACD vs ACDF. Authors observed moderate evidence that LOS & operative times were shorter w/ ACD. There was also moderate evidence that pain relief after 6 wks was higher w/ ACDF, but that return-to-work was higher for ACD in the same postop time period.	III	ACD & ACDF fairly equivalent outcome, although pain relief may be better w/ ACDF. Systematic review only as good as underlying studies, most of which had low-quality methodology.
Abd-Al-rahman et al., 1999	90 patients w/ 1- or 2-level cervical disc disease who underwent surgery w/ ICBG (ACDF in 50) & w/o (ACD in 40) graft using Smith-Robinson. Evaluated w/ Odom's criteria, VAS, & radiographic evaluation of bone trabeculae. Mean FU 15 mos.	Odom's criteria & VAS equivalent w/ successful outcome in 84% in both groups. Kyphosis evident in 55% of ACD group & 28% of ACDF group ($p = 0.02$).	III	ACD equivalent to ACDF in functional outcome. Kyphosis more preponderant ACD. Class III because allocation not concealed & randomization technique unclear. Outcome assessors not necessarily blinded.
Barlocher et al., 2002	125 cervical monoradiculopathies randomized to ACD (n = 33), ACDF (n = 30), fusion w/ PMMA (n = 26), or TTC (n = 36). Outcome at 3, 6, & 12 mos using Odom's, VAS, & exam.	Outcome showed similar Odom's & VAS scores & work incapacity in ACD & ACDF groups over time periods. Fusion rate was similar (93%) on dynamic radiographs & CT. Kyphosis 24.2% (ACD) vs 3.3% (ACDF).	III	ACD equivalent to ACDF for functional outcome. Kyphosis more preponderant but statistics not given. Class III randomization not detailed, allocation not concealed, clinical outcome assessor not blinded.
Dowd & Wirth, 1999	84 consecutive patients w/ monoradiculopathy randomized to ACD (n = 44) or ACDF (n = 40). Cloward technique used for graft. Clinical evaluation at 5 & 10 wks & by phone.	Operative time 29 minutes more for ACDF ($p < 0.001$); more complications at 1 day in ACDF (n = 10) than ACD (n = 4; $p < 0.05$). Pain relief better at 1 day w/ less narcotic usage & short LOS in ACD ($p < 0.01$); this resolved at 5 & 10 wks. Radiographic FU in 31 patients only. Fusion rate: ACDF 30/31 vs ACD 22/31 ($p < 0.01$).	III	ACD had shorter operative time & fewer immediate complications than ACDF although no neurological difference & no difference after 5 wks. Fusion greater in ACDF. Class III due to extremely short clinical FU & fusion assessment in only ~75%. Uncertain whether patients or assessors were blinded & whether allocation concealed.
Lunsford et al., 1980	295 patients w/ cervical radiculopathy underwent ACD (n = 135) or ACDF (n = 108). Odom's criteria used to assess outcome.	Overall outcome good or better in 67% w/o clinical difference between ACD & ACDF ($p = 0.314$). LOS was shorter for ACD w/ disproportionately more in ACD group discharged in < 4 days ($p < 0.0004$). The complication rate was lower for ACD (13 vs 23%; $p < 0.03$).	III	ACD & ACDF produce generally good outcomes w/o difference.
Murphy et al., 1994	19 patients who underwent ACD (n = 12) or ACDF (n = 7) examined w/ plain, oblique radiographs using digitization software to examine foraminal dimensions. Clinical outcome assessed w/ Odom's at 6 mos.	24 foramina examined in each group. After ACDF, foramina area (cm^2) increased significantly ($p = 0.0005$). After ACD, it decreased ($p = 0.0005$). Magnitude of change was no different though ($p > 0.8$). Clinical difference not significant ACDF (100% good or better vs ACD 84% good or better).	III	ACD & ACDF clinically insignificant. Although foramina area increases w/ ACDF it does not correlate w/ clinical outcome. Class III: unclear if randomized or blinded.

(continued)

TABLE 1: Evidentiary summary of studies comparing ACD to ACDF* *(continued)*

Authors & Year	Description	Results	Class	Conclusions
Oktenoglu et al., 2007	20 patients w/ cervical radiculopathy underwent ACD (n = 11) or ACDF (n = 9) randomized by coin flip. ACDF done using structural allograft & semirigid plate. Outcome assessed using VAS at 1 day & 12 mos postoperatively by blinded observer. Intervertebral height measured using digitizing software.	VAS arm pain improved from 8.2 to 3.3 (ACD) & 8.0 to 3.1 (ACDF) at 12 mos. This was not significant between groups but was significant from pre- to postoperative within group. Neck VAS score improved from 3.2 to 2.8 (NS) for ACD, & 3.1 to 2.0 ($p < 0.01$) for ACDF at 12 mos. ACD disc height not significantly changed at 1 day postop, but 2 mm decreased at 12 mos ($p = 0.003$); ACDF disc height increased 1.1 mm at 1 day, but decreased 1 mm at 12 mos ($p < 0.03$). Foraminal height decreased at 12 mos in ACDF (1 mm; $p < 0.004$) & 1.2 mm at 12 mos in ACD ($p < 0.007$).	II	ACD & ACDF clinically similar w/ respect to arm pain but neck pain may be greater w/ ACD. Foraminal height not preserved at 1 yr. Class II: randomization done by coin flip, uncertain whether concealed. Outcome blinded.
Savolainen et al., 1998	91 w/ cervical monoradiculopathy who underwent ACD, ACDF (Smith-Robinson), ACDF w/ plate fixation. Outcome at 2 mos, 6 mos, & 4 yrs. Outcomes (Odom's) at 4 yrs were questionnaire w/ 88 replies. Late (>2 yrs) radiographs in 71 but none dynamic.	Fusion in all ACDFs & 90% of ACD. Slight kyphosis in 55% ACD, 60% Smith-Robinson, 47% Caspar at 6 mos (p = NS). Late kyphosis 62, 44, 41% respectively (p = NS). Outcomes were good or better in 67, 70, 77% at 6 mos (p = NS) & 76, 82, 73% at 4 yrs (p = NS).	III	ACD & ACDF & ACDF w/ plate fixation all have similar outcomes. Complication rates were similar. Class III. Randomization technique not described & uncertain whether allocation concealed. Outcome observer independent but not necessarily blinded.
Thorell et al., 1998	525 patients underwent ACD (n = 290) or ACDF (n = 235) w/ >2-yr FU. FU by questionnaire regarding clinical symptoms & subjective outcome.	262 (49.9%) respondents. LOS was 3.2 days for ACD & 4.7 days for ACDF (no statistics). Mean FU was 8.1 yrs. 56.8% ACD had pain vs 42.1% ACDF ($p < 0.05$). No difference regarding numbness, leg weakness, or work status ($p > 0.05$). Arm weakness less w/ ACDF ($p < 0.05$). For first time surgeries, normal functional status no different but pain less w/ ACDF ($p < 0.05$).	III	ACDF yields less pain but similar functional status. Class III due to retrospective study & only 49% respondents.
Watters & Levinthal, 1994	126 patients underwent ACD (n = 62) or ACDF (n = 64) over 7-yr period. ACD & ACDF (Smith-Robinson) done by 2 surgeons each doing same procedure. Outcome by independent observer by phone interview regarding pain. Mean duration FU 75 mos.	Mean operative time was 77 vs 46 min for ACD ($p < 0.01$). Blood loss 94 vs 22 ml for ACD ($p < 0.01$). LOS 3.7 vs 2.5 days ($p < 0.01$). Long-term pain control similar: neck 2.7 vs 2.3; arm 1.4 vs 1.4 (p = NS). ACDF neck pain resolved 27 vs 70 days ($p < 0.001$) while arm pain 8 to 22 days ($p < 0.01$). Return-to-work 10–12 wks (p = NS).	III	ACD had shorter LOS & operative time. Long-term outcomes similar. However, time to resolution of pain shorter w/ ACDF. More complications w/ ACDF (16/64 vs 4/62). Class III due to retrospective nature (1 surgeon did 1 technique while other surgeon did the other).
White & Fitzgerald, 2005	148 patients underwent cervical discectomy over 1 or 2 levels (Smith-Robinson). Analysis of postop radiographs undertaken w/ respect to angulation. Also, evaluation of complications.	Full radiographs only available in 91 patients. However, changes in kyphosis & angulation most impressive when disc heights were >4 mm. Largest complications occurred if disc < 4 mm grafted or >4 mm not grafted including C-5 palsy & graft failure.	III	Grafting restores lordosis; however, settling is trivial in disc heights <4 mm. Retrospective nature of study downgrades it. This was scored Class III (instead of II) due to complete films in 91 patients only.

(continued)

TABLE 1: Evidentiary summary of studies comparing ACD to ACDF* *(continued)*

Authors & Year	Description	Results	Class	Conclusions
Wirth et al., 2000	72 patients w/ cervical monoradiculopathy. Posterior foraminotomy (n = 22), ACD (n = 25), ACDF (n = 25) using Cloward. Outcome measures were subjective pain improvement & return-to-work; fusion assessed on radiography.	Operative time shorter for ACD (98 min) vs ACDF (120 min). Analgesic requirements were not significantly different & hospital LOS was the same. Postop weakness & numbness was similar as well (4–8%, p = NS). Costs no different. Pain relief similar in all & near 100%.	III	Grafting offers similar, but not superior, outcome w/ similar costs. Operative time slightly longer & LOS similar. Class III due to uncertainty regarding blinding of patients, blinding of outcome assessors, & allocation concealment.
Xie & Hurlbert, 2007	45 patients w/ monoradicular disease randomized to ACD, ACDF, ACDFI w/ fixation (n = 15 each group). Outcomes assessed serially over 2 yrs using McGill and SF-36.	Clinically pain improvement in all from preop ($p < 0.05$). Neck pain absent or better than 83, 80, 73% respectively. Arm pain absent in 92, 93, 100%, respectively. No difference between groups on McGill Pain Scores & SF-36. All improved from preoperative. Return-to-work >80% in all. At 1 yr, fusion 8, 93, 100%; at 2 yrs, 67, 93, 100% ($p < 0.02$). Segmental kyphosis was 17% for ACD & 75% at 3 mos which persisted for 2 yrs ($p = 0.0007$). No kyphosis w/ ACDF or ACDFI.	II	Clinical outcome not related to technique. ACD alone likely to have more kyphosis but significance uncertain. The study power calculations were acceptable but only 80% of FU in ACD group after 3 mos. No Bonferroni correction for multiple group comparisons.

* The criteria for scoring each manuscript into a class were described in the *Methodology* chapter. Abbreviations: FU = follow-up; ICBG = iliac crest bone graft; PMMA = polymethyl-methacrylate; TTC = threaded titanium cage.

and "cervical vertebra," which yielded 88 references, and "arthroplasty" and "spine," which yielded 280 references. After reviewing abstracts and titles, we examined 10 studies that reported outcomes of arthroplasty compared to preoperative function or ACDF (Table 4).

Scientific Foundation

Anterior Cervical Discectomy Versus ACDF

Jacobs and colleagues[14] undertook a systematic review of techniques for anterior cervical surgery using the standardized techniques detailed by van Tulder et al.[35] Aspects of this review focused on ACD versus ACDF for qualitative and quantitative clinical outcomes. The authors examined 6 studies that met their inclusion criteria. These studies involved 430 patients, in whom ACD was performed in 212, and ACDF in 218. In general, the authors found that the methodological quality was low and that the studies did not provide adequate homogeneous comparison groups. They noted conflicting evidence on the relative effectiveness of ACD versus ACDF. The authors defined "moderate evidence" as consistent findings among multiple low quality RCTs and/or a single high quality RCT. Using this definition, the authors reported moderate evidence that LOS and operative time are shorter after ACD. There was also moderate evidence that pain relief after 6 weeks was higher after ACDF, but that return-to-work was higher after ACD after the same time period.[14]

Oktenoglu et al.[22] and Xie and Hurlbert[40] both reported Class II studies comparing ACD to ACDF. The Oktenoglu et al.[22] study randomized 20 patients by coin flip: 11 patients were assigned to ACD and 9 to ACDF. Outcomes were assessed using the VAS at 1 day and 12 months after surgery by a blinded observer. The study assessed intervertebral height using digitizing software. The VAS score for arm pain at 12 months improved in both groups by 4.9 (p = NS between groups but significant within subgroup). Neck pain at 12 months improved a total of 0.4 in the patients who had undergone ACD, but only 1.1 in the ACDF group ($p < 0.01$). After ACD, disc height was unchanged on Day 1 postoperatively but was decreased by 2 mm at 12 months after surgery ($p = 0.003$). After ACDF, disc height had increased 1.1 mm on Day 1 but decreased 1.0 mm at 12 months ($p < 0.03$). Foraminal height decreased in both groups at 12 months by ~ 1 mm ($p < 0.01$). This study was graded Class II because of the small sample size, unclear randomization technique, and uncertainty regarding concealment of allocation.[22]

The Xie and Hurlbert[40] study randomized 45 patients to ACD, ACDF, or ACDFI (15 patients each). The authors assessed outcome using McGill Pain Questionnaire scores and the SF-36. Clinically, pain improved from the preoperative level in all groups ($p < 0.05$). Neck pain was absent or better in > 80% of patients in the ACD and ACDF groups, whereas arm pain improved in > 90% (p = NS). The McGill, SF-36 scores, and return-to-work were not different between the groups, either. Fusion was 8% in the ACD group and 93% in ACDF group at 1 year, whereas it was 67 and 93%, respectively, after 2 years.

Segmental kyphosis developed in 75% of patients who underwent ACD at 3 months and persisted for 2 years ($p = 0.0007$ compared to ACDF). This study was graded Class II because the randomization technique was not delineated, and only 80% follow-up occurred in the ACD group after 3 months. It was not clear whether the authors undertook a multiple comparison correction (Bonferonni) in the statistical analysis.[40]

Lunsford et al.[16] reported on a series of 295 patients with cervical degenerative radiculopathy, of whom 135 underwent ACD and 108 received ACDF. Follow-up data were available in 253 patients over varying durations. Outcome was assessed using Odom's criteria. Results between the techniques were similar with respect to good or better outcome (in 66% ACD vs 69% ACDF; $p = 0.314$). Complication rates were 13% for the ACD group versus 23% for the ACDF group ($p < 0.03$). The LOS was shorter in patients who underwent ACD ($p < 0.0004$), with proportionally more patients with shorter hospitalizations (LOS < 4 days). The relevance of this LOS data from the 1970s to modern practice is questionable. This study was scored Class III due to selection bias. It was not evident which patients were eligible for ACD versus ACDF. In addition, outcome assessment was subjective and not blinded.

Abd-Alrahman and colleagues[1] reported on 90 patients who underwent either 1- or 2-level ACD (40 patients) or ACDF (50 patients). The authors used the Smith-Robinson technique with iliac crest autograft for ACDF. They assessed outcomes qualitatively using Odom's criteria, and quantitatively using the VAS. Radiographic fusion and kyphosis were assessed on plain radiographs. The mean follow-up period was at 15 months. Functional outcome using VAS and Odom's was superb in both groups (> 84% success on Odom's). Kyphosis was significantly increased in 55% of the ACD group compared to only 28% of the ACDF group ($p < 0.02$). This study was graded as Class III because it was uncertain if or how patients were randomized and whether allocation was concealed.

Barlocher et al.[3] reported on 125 patients with monoradiculopathy who underwent surgery. This study was primarily focused on examining methyl-methacrylate as an interbody device. However, 33 patients who underwent ACD and 30 who underwent ACDF were also subgroups. The authors assessed outcomes at 3, 6, and 12 months using Odom's criteria and the VAS, which yielded similar results in both modalities. Surprisingly, the fusion rate was similar (93%) on dynamic films. However, the ACD group developed > 3° of kyphosis in 24.2% versus 3.3% in the ACDF group (subgroup statistics not done). This study was graded as Class III because the randomization process was not detailed, allocation concealment was not certain, and outcome assessment was not blinded.

Savolainen et al.[31] reported on 91 patients with cervical monoradiculopathy who underwent ACD, ACDF (with Smith-Robinson), or ACDFI. The authors assessed outcomes at 2 and 6 months and conducted a phone interview at 4 years using a uniform questionnaire. Late (> 2 years) radiographs were obtained in 71 patients. The authors reported fusion in all patients who underwent ACDF and ACDFI and in 90% of the ACD group. They observed slight kyphosis in 55% of patients who underwent ACD, in 60% of those who underwent ACDF, and in 47% of the ACDFI group at 6 months (p = NS). Late kyphosis was higher in the ACD group (62%) than in the ACDF or ACDFI groups (44 and 41%, respectively; p = NS). Outcomes were good or excellent using Odom's criteria at 6 months (67, 70, and 77% in the ACD, ACDF, and ACDFI groups, respectively; p = NS) and at 4 years (76, 82, and 73%, respectively; p = NS). This study was graded Class III because the randomization technique was not described and allocation concealment was uncertain. Although the outcome observer was "independent," it was uncertain whether the person was blinded.[31]

Dowd and Wirth[9] described 2 studies comparing ACD and ACDF.[9,39] One study had 84 patients, 44 of whom underwent ACD and 40 ACDF, whereas the other study involved 72 patients (25 with ACD, 25 with ACDF, and 22 with posterior foraminotomy).[39] In both studies, operative time was significantly shorter for ACD. The authors reported conflicting results for other parameters. In the larger study, early pain relief was better, narcotic usage was shorter, and LOS was shorter after ACD than ACDF. The increase in LOS and narcotic usage after ACDF was probably due to the use of iliac crest autograft.[9] However, over the 5–10-week postoperative period, pain and neurological function were similar between the groups. Fusion was compared in the larger study and was significantly better ($p < 0.01$) for the ACDF group.[9] Both studies were graded as Class III because of flaws based on uncertain randomization methods, uncertain allocation concealment, and unblinded outcome assessment.[9,39]

Watters and Levinthal[37] reported similar findings in 126 patients (62 who underwent ACD and 64 who underwent ACDF) over a 7-year period. The mean operative time and blood loss were significantly less in the ACD group ($p < 0.01$). However, neck and arm pain scores on a scale of 1–10 were similar at long-term follow-up (75 months). However, neck and arm pain resolved faster after ACDF than ACD (neck, 27 vs 70 days, $p < 0.001$; arm, 8 vs 22 days, $p < 0.01$). Thorell and colleagues[33] surveyed 525 patients, of whom 290 underwent ACD and 235 underwent ACDF. Resolution of pain appeared to be more common after ACDF, with pain in 42.1% after ACDF and in 56.8% after ACD. Functional outcomes with the exception of self-reported arm weakness were similar. These studies were graded Class III because potential selection bias was introduced based on lack of randomization, surgeon assignment to the study group, and poor follow-up (only 49.9% of patients responded to the questionnaire further selection bias).[33]

Murphy and colleagues[20] (12 patients with ACD and 7 with ACDF) and White et al.[38] (reported 148 patients, only 91 with full studies) undertook radiological studies comparing ACD to ACDF. Murphy et al.[20] imaged the foramina in their patients and calculated the pre- and postoperative area, observing that it decreased after ACD but increased after ACDF ($p = 0.0005$ for each group). The magnitude of the change between the groups was not significant ($p > 0.8$). Outcome was excellent in both ACD and ACDF groups (Odom's criteria, 84 vs 100%;

TABLE 2: Evidentiary summary of studies comparing fusion with fixation to fusion without fixation*

Authors & Year	Description	Results	Class	Conclusions
Jacobs et al., 2004	Systematic review of techniques including ACDF vs ACDFI among other techniques. The authors detailed 2 studies that met criteria. 2 other studies dealt only w/ interbody cages. These 2 studies involved 107 patients (ACDF, n = 52; ACDFI, n = 55). In general, they found that methodological quality was low & that the studies did not provide adequate homogeneous comparison groups.	Qualitatively, authors noted limited evidence only that showed equivalency between outcomes w/ & w/o plate fixation. For 2-level surgery, conflicting evidence existed on whether plating improved arm pain. No evidence existed that either technique was better for other outcomes. Quantitatively, they felt that there was moderate evidence that plating improved arm pain after 2-level ACDF.	III	ACDF & ACDFI have similar outcomes w/ respect to 1 level. For 2-level surgery, ACDFI may improve quantitative arm pain better but no other functional improvement observed.
Resnick & Trost, 2007	Systematic review w/o heterogeneity testing of randomized trials that examined the role of fixation in the setting of ACDF.	Clinical benefits of surgery applied to both ACDF & ACDFI. No clear substantial benefit arose w/ adding fixation. Heterogeneity not tested.	III	Taken as a whole, the medical literature does not provide substantial evidence that ventral plate fixation adds to improved clinical outcomes in patients undergoing 1-level ACDF. Class III since it examined primarily Class III studies.
Bolesta et al., 2002	40 patients who underwent 1- or 2-level ACDF w/ autograft (Smith-Robinson) chosen over 7-yr period. ACDF (n = 17, 16 w/ 1-level); ACDFI (n = 23, 4 w/ 1-level). No randomization—surgeon decided on plating.	Clinical outcomes using Odom's after 24 mos were similar between nonplated 1-level & plated 2-level. Similar rates of nonunion as well 5/16 vs 4/19.	III	Plate fixation seems to help w/ 2-level surgery but there was no clear control group. Class III due to selection bias since surgeon decided on plating. Outcome assessment not blinded.
Caspar et al., 1998	356 patients w/ 1- or 2-level disc surgery (ACDF n = 210; ACDFI n = 146). Fusion by standard Smith-Robinson.	Reop for pseudarthrosis in 12 ACDF patients. In ACDFI group, reop for pseudarthrosis in 1 and hardware failure in 2. Overall reop rate 0.7% in ACDFI group & 4.8% in ACDF ($p < 0.04$). Decrease in reop rates for 1-level was 5.1, 5.7, & 6.2% over 3-years. Decrease in reop rates for 2-level was 5.0, 12.8, 11.2% over 3 yrs.	III	Cervical plating reduces pseudarthrosis & need for reop. Distribution of cases based on surgeon preference w/ variable FU; decision for reop was not based on clear parameters.
Connolly et al., 1996	43 patients w/ cervical disc disease (ACDF, n = 18; ACDFI, n = 25). 1-level fusion in 6/25 ACDFI & 2-level in 15/25. 1-level in 8/18 & 2-level in 10/8.	Odom's for outcome success in 72% of ACDFI & 83% of ACDF (no statistics). Fusion rate was not improved w/ plate fixation for 1-level ($p > 0.05$); although fusion greater for 2-level, not significant ($p > 0.05$). Finally, plating reduces overall graft complication rate for multilevel only.	III	Plate fixation does not improve fusion rates or clinical outcome. Class III due to no randomization & different subgroup populations consistent w/ selection bias.
Grob et al., 2001	50 patients w/ 1- or 2-level disease stratified to ACDF (n = 26) & ACDFI (n = 24). Monosegment disease in 54% ACDF & 62% ACDFI.	Patients w/o fixation had similar levels of function on VAS, sensory, motor & had similar narcotic requirements. Patients had similar fusion rates 34/35 & 34/37 w/o fixation. However, graft issues were 5/37 in no plate group.	III	ACDF w/ fixation does not improve function or fusion but may reduce chance of graft issues. Class III because there was no randomization or blinded observer.
Kaiser et al., 2002	251 patients who underwent ACDFI retrospectively reviewed & compared w/ historical cohort of ACDF. Assessment of fusion rate.	ACDFI fusion rates were 96% 1-level & 90% 2-level. ACDF fusion rates were 91% 1-level, 72% 2-level. Overall fusion, 94% ACDFI & 88% ACDF ($p < 0.03$). Significant differences observed. Complication rates 1.3% for ACDFI & 6% ACDF due to graft ($p < 0.001$).	III	Plating increases fusion rates. Class III due to historical cohorts & unblinded outcome observer.

(continued)

TABLE 2: Evidentiary summary of studies comparing fusion with fixation to fusion without fixation* ***(continued)***

Authors & Year	Description	Results	Class	Conclusions
McLaughlin et al., 1997	64 patients who underwent ACDF (n = 25) or ACDFI (n = 39). Clinical outcomes assessed w/ Odom's criteria & return to activities including work.	Odom's criteria good or better in 23/25 & 36/39. Return-to-work & driving ($p < 0.05$) faster w/ plate; return-to-light activity not faster.	III	No change in long-term functional outcome but short-term return-to-work may make plate fixation cost effective. Class III since ACDF done in first 2 yrs & ACDFI done in last 2 yrs.
Mobbs et al., 2007	242 patients who underwent surgery w/ ACDF (n = 130) or ACDFI (n = 112). 1-level (n = 95), 2-level (n = 140). Radiographs & Odom's criteria for outcome.	Comparing excellent clinical outcomes showed no differences ACDF 72% vs ACDFI 78% ($p = 0.31$). However, plating reduced the number of poor outcomes (1% to 7%, $p < 0.05$). Also, complication rate was 1.8% w/ plating versus 10% w/o ($p < 0.05$). Fusion rates 99% vs 93%.	III	Excellent outcomes similar but the number of poor outcomes increased w/o plating. Fusion rate better. Class III since statistics & criteria for fusion were not detailed.
Nabhan et al., 2007	37 patients w/ single level ACDF w/ PEEK cage or PEEK cage (n = 19) w/ plate (ACDFI, n = 18). Randomization by sealed envelopes. Radiographic outcome using radiostereometric analysis. VAS for clinical outcome at 6, 12, & 24 mos.	VAS improvement neck 4.3, arm 6.1 w/ cage & 4.4, 5.8 w/o. Comparison between groups was not significant ($p > 0.05$). RSA did not show any difference between cage & cage w/ fixation group at any point over 2 yrs.	II	Addition of a plate did not change clinical outcome nor did it change the progression of fusion. Class II since no comparison of subgroups after randomization for homogeneity.
Samartzis et al., 2004	69 patients underwent cervical fusion (ACDF 38 & ACDFI 31). Outcomes w/ CSOQ & radiographs including dynamic views at 18 mos average.	Fusion in 66/69 w/ 100% in ACDF & 90.3% in ACDFI. Good or better outcome in 91.3% in ACDF & 90.3% in ACDFI. Blood loss significantly greater in ACDFI ($p < 0.05$).	III	ACDFI has higher blood loss w/ no improvement in fusion or outcome. Class III due to patient selection of Tx arm.
Savolainen et al., 1998	91 w/ cervical monoradiculopathy who underwent ACD, ACDF (Smith-Robinson), ACDFI. Outcome at 2 mos, 6 mos, 4 yrs. Outcomes (Odom's) at 4 yrs were questionnaire w/ 88 replies. Late (>2 yrs) radiographs in 71 but none dynamic.	Fusion in all ACDFs & 90% of ACD. Slight kyphosis in 55% ACD, 60% Smith-Robinson, 47% Caspar at 6 mos (p = NS). Late kyphosis 62, 44, 41% respectively (p = NS). Outcomes were good or better in 67, 70, 77% at 6 mos (p = NS) & 76, 82, 73% at 4 yrs (p = NS).	III	ACD & ACDF & ACDFI all have similar outcomes. Complication rates were similar. Class III since randomization technique not described & uncertain if allocation concealed. Outcome observer independent but not necessarily blinded.
Troyanovich et al., 2002	47 patients who underwent ACDFI (n = 26) vs ACDF (n = 21). Assessed by independent observer for lordosis over period of 12 mos.	After ACDF, 4.2° of lordosis while ACDFI group gain 0.9° (p = NS). At local surgical segment, lordosis lost by 2.5° after ACDF & increased 5.7° after ACDFI ($p < 0.05$).	III	Plating may preserve local lordosis but no overall lordosis. Class III due to possible selection bias. Although they used an independent observer, it was unclear how cases were selected or chosen for plate fixation.
Wang et al., 1999	80 patients who underwent single-level ACDF (n = 36) or ACDFI (n = 44). Odom's criteria for outcome along w/ dynamic radiographs.	Pseudarthrosis in 2/44 ACDFI & 3/36 ACDF ($p > 0.05$); graft collapse ACDFI 0.75 mm & 1.5 mm for ACDF ($p < 0.03$); kyphotic change at fused segment was 1.2° for ACDFI & 1.9° for ACDF ($p > 0.07$). Good outcome or better 91% ACDFI & 88% ACDF.	III	Clinical outcomes & rate of pseudarthrosis similar; plate reduces graft collapse. Class III due to selection bias. Cases first done as ACDF followed by ACDFI. Also, outcome was done by operating surgeon.

(continued)

p = NS).[20] White et al.[38] examined radiographs for fusion, kyphosis, and graft failure. Development of kyphosis was minimal when disc height was < 4 mm. When disc height was > 4 mm, development of kyphosis was greater in the ACD group. There were 15 complications, but 12 (80%) occurred when a disc > 4 mm was not grafted or a disc < 4 mm was grafted. The Murphy et al. study was considered Class III because the randomization process was not described, and it was uncertain whether outcome assessors were blinded. The White et al. study was graded Class III because of the limited number of complete radiographs (91/148, 62%) available for inclusion, resulting in potential reporting bias.

TABLE 2: Evidentiary summary of studies comparing fusion with fixation to fusion without fixation* *(continued)*

Authors & Year	Description	Results	Class	Conclusions
Xie & Hurlbert, 2007	45 patients w/ monoradicular disease randomized to ACD, ACDF, ACDFI w/ fixation (n = 15 each group). Outcomes assessed serially over 2 yrs using McGill pain scores & the SF-36. Alignment was assessed using plain radiographs.	Clinically pain improvement in all from preop ($p < 0.05$). Neck pain absent or better than 83, 80, 73%, respectively. Arm pain absent in 92, 93, 100% respectively. No difference between groups on McGill Pain Scores & SF-36. All improved from preop. Return-to-work > 80% in all. At 1 yr postop, fusion 8, 93, 100%; at 2 yrs, 67, 93, 100% ($p < 0.02$) Segmental kyphosis was 17% for ACD & 75% at 3 mos, which persisted for 2 yrs ($p = 0.0007$). No kyphosis w/ ACDF or ACDFI.	II	Clinical outcome not related to technique. ACDF & ACDFI have similar rates of fusion & functional outcome & kyphosis. The study power calculations were acceptable but only 80% of FU in ACD group after 3 mos. No Bonferroni correction for multiple group comparisons & randomization technique not listed; so graded Class II.
Zoëga et al., 1998	27 patients w/ 1-level disc disease randomized to ACDFI (n = 15) & ACDF (n = 12) w/ sealed envelopes. Outcome using radiography w/ tantalum markers over 2 yrs. Reliability tested for this method. VAS used for clinical outcome.	No difference in arm or neck pain at 2 yrs. Kyphosis developed in ACDF group at 1 yr ($p < 0.04$) but $p = 0.06$ at 2 yrs. Kyphosis was 5° for ACDF group but 1° of lordosis ACDFI.	II	Plate fixation does not improve clinical outcome but may reduce kyphosis over 2 yrs. Class II due to uncertainty regarding allocation concealment & power. Objective outcome measures.
Zoëga et al., 2000	46 patients w/ 1-level disc disease randomized to ACDFI (n = 24) & ACDF (n = 22) w/ sealed envelopes. Outcome assessed w/ Million Index, Oswestry Index, Zung Depression Scale, & VAS. Blinded observer & test-retest reliability undertaken.	General improvement seen in all scores. Pain in neck & arm improved in both groups on VAS ($p < 0.05$ in own subgroup). Arm pain seemed to improve more ($p = 0.02$) with plate fixation. Study underpowered except for Million & Oswestry.	II	General improvement seen w/ ACDF or ACDFI. However, plating may lead to more profound relief of arm pain at 2 levels. Class II due to question of power.

* CSOQ = Cervical Spine Outcomes Questionnaire; PEEK = polyetheretherketone.

Plate Fixation Versus No Plate Fixation

Jacobs et al.[14] and Resnick and Trost[27] undertook systematic reviews of studies examining techniques for cervical interbody surgery, including plating. Jacobs and colleagues[14] used rigorous methodology for inclusion criteria in their systematic review. They reported 2 studies that met the criteria and dealt specifically with the issue of plating versus no plating.[31,42] These 2 studies involved 107 patients (ACDF in 52 and ACDFI in 55). The authors found that the subgroups were comparable but the reported outcomes were not. Therefore, no meta-analysis could be performed. The limited evidence reviewed indicated equivalency between surgery with and without a plate, however. Conflicting qualitative evidence, but moderate quantitative evidence from 1 study, supported greater improvement in arm pain with plating over no plating. Other functional criteria were not different. This study was graded Class III because of the limited number of studies included and the lack of data for meta-analysis.[14] Resnick and Trost[27] used broader inclusion criteria and did not test for homogeneity. They found no clear substantial evidence that plating improved outcomes in 1-level ACDF.

Zoëga et al.[42] reported a randomized study in 46 patients with 1-level disease (ACDF in 22 and ACDFI in 24). Randomization was performed using sealed envelopes. The authors assessed outcome using the Million Index, Oswestry Index, Zung Depression Scale, and VAS. Blinded observers were used, and external reliability was evaluated. The authors reported general improvement with all measures in both groups with respect to neck and arm pain. Arm pain seemed to improve more after plate fixation ($p < 0.02$). The study was underpowered except with respect to the Million and Oswestry Indices (Class II).[42] Bolesta et al.[5] reported on 40 patients (ACDF in 23 and ACDFI in 17). The majority of patients in the ACDF group underwent 1-level surgery, and 2-level surgery was performed in the majority of the ACDFI group. Using Odom's criteria, patients with plating did better with 2-level surgery but not 1-level surgery. Similar rates of nonunion were seen. Because of selection bias, this study was scored Class III.[5] Mobbs et al.[18] reported on 242 patients (ACDF in 130 and ACDFI in 112) who underwent 1- or 2-level ACDF, in 95 and 140 patients, respectively. The number of excellent clinical outcomes was similar between the 2 groups, 72 and 78% in the ACDF and ACDFI groups, respectively ($p = 0.31$). The use of plate fixation did result in a decrease in the rate of poor outcomes, however (1 vs 7%; $p < 0.05$). The complication rates were lower in the plate fixation group (1.8 vs 10%; no statistics presented). Fusion rates were > 90% and similar. This study was graded Class III due to the lack of criteria for defining fusion, the lack of fusion statistics, and the lack of blinded outcome assessment.[18] McLaughlin et

TABLE 3: Evidentiary summary of studies comparing fusion with static or dynamic plates

Authors & Year	Description	Results	Class	Conclusions
Goldberg et al., 2007	85 patients underwent 2-level ACDF. 43 were available w/ films for review beyond 6 mos. Dynamic radiographs were undertaken at 6–9 mos & 10–13 mos & digitized. Fusion was defined as <2° motion on digital analysis (good interobserver reliability).	Static plates in 21 patients w/ autograft & dynamic in 22 patients w/ allograft. Fusion per level was 87.8% for static & 89.8% for dynamic (p = 0.469). 5 levels in dynamic group could not be visualized for assessment. At 10–13 month interval, rate of fusion was 86.4% static vs 94.2% dynamic (no statistics). No symptomatic nonunions.	III	Dynamic plating does not significantly increase fusion rates. When nonunion found, it was asymptomatic. Class III because only 43 of 85 enrolled & difference in techniques.
Saphier et al., 2007	50 patients receiving either 1- (28–32%) or 2-level surgery (68–72%) w/ either a static (n = 25) or dynamic (n = 25) plate. Outcome by questionnaire w/ those lost to FU were replaced.	Degree of translation was 7.8% dynamic vs 9.5% static for 1-level (p < 0.01) & 6.7% dynamic vs 7.2% static for 2-level (p = NS). Pain scores were 5.8 static to 3.1 dynamic (p < 0.01) & function 10.6 to 4.7 (no statistics) but "significant." Satisfaction not significant (p = 0.1). Plate system correlated w/ pain & satisfaction, although satisfaction not significant. Fusion rates were 96% dynamic vs 92% static (p = NS).	III	Dynamic plates may improve function but not fusion rates. Levels of complications similar w/ screw failure higher for static but dysphagia higher for dynamic. Class III due to unblinded outcome observation, lack of reliability testing for questionnaire, patients lost to FU were replaced.
Stulik et al., 2007	132 patients receiving dynamic (n = 69) or rigid (n = 63) for 1- or 2-level disc disease treated w/ autograft fusion. Dynamic radiographs used to test instability by independent radiologist at 3 & 6 mos.	Results available in 77 patients (43 dynamic, 34 rigid). Segmental mobility at 3 & 6 mos was 1.4, 0.8 mm for dynamic compared w/ 1.8, 1.7 mm for rigid (p = 0.4 at 3 mos but p < 0.02 at 6 mos). 4 complications w/ rigid & none w/ control (p < 0.04).	III	Segmental mobility less w/ dynamic plate at 6 mos. Class III study because randomization or allocation concealment not described. No intraobserver reliability tested. FU in only 77/132.

al.[17] examined 64 patients who underwent 2-level ACDF (25 patients) or ACDFI (39 patients). These authors assessed clinical outcomes using Odom's criteria and an activities of daily living scale. The study reported good or excellent results in 23 (92%) of 25 patients who underwent ACDF and 36 (92%) of 39 who underwent ACDFI. However, return-to-work and resumption of driving were both faster with plating ($p < 0.05$). This study was graded Class III because of selection bias because the ACDF technique was performed first and ACDFI was used later in the series.[17] In these studies, plating improved arm pain after 2-level surgery, it improved activities of daily living faster, and it seemed to reduce the incidence of poor outcomes.

Several Class III studies examined fusion rates and graft issues with respect to plating. Caspar et al.[6] retrospectively reviewed 356 patients who underwent ACDF (210 patients) or ACDFI (146 patients). With the use of cervical plating, the repeated operation rate for pseudarthrosis was reduced from 4.8% for ACDF to 0.7% for ACDFI ($p < 0.04$). Repeated operation rates were reduced with plating for both 1-level and 2-level disease over 3 years (1-level: 5.1, 5.7, 6.2%; 2-level: 5.0, 12.8, 11.2%). Kaiser et al.[15] reported on 251 patients who underwent ACDFI, comparing them to a historical cohort of ACDF patients. The authors assessed fusion on dynamic radiographs. For 1-level surgeries, fusion was 96% with ACDFI, and 90% with ACDF ($p < 0.05$). For 2-level, fusion was 91% with ACDFI and 72% with ACDF ($p < 0.05$). Overall, fusion was 94% with ACDFI versus 88% with ACDF ($p < 0.03$). Complication rates were higher after ACDF (6 vs 1.3%; $p < 0.0001$).[15]

Several studies have examined the incidence of deformity and graft collapse after plating. Zoëga et al.[41] reported on 27 patients (ACDFI in 15 and ACDF in 12) randomized with sealed envelopes. The authors assessed outcome using RSA with tantalum markers and confirmed external reliability. The study used the VAS for clinical outcomes, and no clinical differences were detected. However, kyphosis developed in the ACDF group on RSA at 1 year postoperatively ($p < 0.04$). At 2 years, the difference in degree of kyphosis in patients who underwent ACDF with plate fixation compared to those who underwent ACDF without it was no longer significant ($p = 0.06$). Kyphosis was 5° for the ACDF group compared to 1° of lordosis after ACDFI at 2 years postoperatively. This study was graded Class II because of uncertainty regarding allocation concealment and the subjectivity of the VAS.[41] Troyanovich et al.[34] reported on 47 patients who underwent ACDF or ACDFI, 21 and 26 patients, respectively. An independent observer assessed overall lordosis pre- and postoperatively. After ACDF, the authors reported a 4.2° loss in overall lordosis compared to 0.9° after ACDFI. This difference was not statistically significant. In the ACDF group, lordosis decreased at the fused segment by 2.5° and increased by 5.7° after ACDFI ($p < 0.05$). This study was scored Class III because of uncertainty related to patient selection for plating.[34]

Wang et al.[36] examined graft collapse in 80 patients who underwent 1-level surgery (ACDF in 36 and ACDFI in 44) with outcome assessments using Odom's criteria and dynamic radiographs. The authors reported pseudarthrosis in 2 (4%) of 44 patients who underwent ACDFI compared to 3 (8%) of the 36 who underwent ACDF (p = NS). Graft collapse was 0.75 mm in the ACDFI group compared to 1.5 mm in the ACDF group ($p < 0.03$). However, the kyphotic change at the fused segment was not statistically different (1.2° with vs 1.9° without plate placement, $p > 0.07$). This study was graded Class III because of potential selection bias and its retrospective design.[36] Grob et al.[12] reported 50 patients with 1- or 2-level diseases stratified to ACDF (26 patients) or ACDFI (24 patients). Single-segment disease was present in 54% of the ACDF group and 62% of the ACDFI group. The authors reported similar fusion rates in both groups, 34 (97%) of 35 with plating and 34 (92%) of 37 without plating. Graft complications occurred in 5 (14%) of 37 patients who underwent ACDF, however. This study was scored Class III because it lacked randomization and unblinded observation.[12]

Despite the advantages conferred by using plates as described above, conflicting evidence exists regarding their overall benefit. The studies detailed above by Grob, McLaughlin, and Zoëga and their colleagues did not demonstrate an overall clinical benefit to instrumentation.[12,17,41,42] Nabhan and colleagues[21] reported on 37 patients who underwent 1-level ACDF with placement of a polyether-etherketone cage with (in 19 patients) or without (in 18 patients) plate fixation. Randomization was by sealed envelopes, and radiographic outcome was assessesd using RSA with tantalum markers. The VAS was assessed at 6, 12, and 24 months. Visual analog scale score improvement was 4.3 in neck pain and 6.1 in arm pain in patients without plate fixation, and 4.4 and 5.7, respectively, in those who did undergo plate fixation (p = NS). Radiostereometric analysis did not show any difference in motion between those with and without plate fixation over a 2-year follow-up period. This study was scored Class II; randomization was appropriate but no evidence was given that the subgroups were homogeneous.[21] Xie and Hurlbert[40] undertook a study (which was described above) in 45 patients who were randomized to ACD, ACDF, ACDFI (15 patients each). Neck pain improved in all groups, and there were no differences with respect to McGill Pain Questionnaire or the SF-36 results. Return-to-work rates between the groups were also similar. Extent of kyphosis was not different between ACDF and ACDFI groups. This study was graded as Class II because the randomization technique was not explained and there was no correction for multigroup comparisons.[40]

Savolainen et al.[31] reported on 91 patients divided evenly between ACD, ACDF, and ACDFI. The authors assessed outcome at 2 and 6 months and after 4 years using Odom's criteria. Radiographic analysis was available in only 71 patients (78%) after 2 years. Fusion was present in all patients in the ACDF with or without plate fixation. Kyphosis was present in 60% of patients in the ACDF group at early follow-up, versus 47% of patients in the ACDFI group (p = NS). After 2 years, kyphosis was present in 44 and 41% of patients in these groups, respectively (p = NS).[31] In 2 other Class III studies, Connolly et al.[7] and Samartzis et al.[29] reported on 43 and 69 patients, respectively. Both studies showed excellent, comparable fusion rates with and without plate fixation. Clinical outcomes using Odom's criteria were also similar, without significant differences between the groups. Both studies were scored Class III because of selection bias and different subgroup populations.

Rigid Versus Dynamic Fixation

The topic of rigid versus dynamic fixation was addressed in 3 Class III studies. Goldberg and colleagues[11] reviewed 85 patients, of whom follow-up was available in only 43 (51%): 21 with rigid and 22 with dynamic fixation. The authors digitized plain radiographs and assessed patient fixation at 6–9 and 10–13 months in both groups. Fusion per level was 87.8% in the rigid group and 89.8% in the dynamic group ($p = 0.47$). At the later time point, fusion rates were 86.4% in the rigid group versus 94.2% in the dynamic group. None of the nonunions were symptomatic. Because of the limited number of patients available for follow-up, this study was scored Class III.[11]

Saphier et al.[30] reported on 50 patients who underwent either rigid or dynamic plate fixation (25 patients each). Two-level surgeries were performed in 68–72% of cases and 1-level procedures in 28–32%. Outcome was assessed using a questionnaire for which reliability was not tested. Pain scores ($p < 0.05$) and functional scores (no statistics) showed greater improvement in the dynamic fixation group. There were no differences in patient satisfaction (p = NS), although the plate type correlated with outcome for pain, function, and satisfaction. The degree of translation was significantly higher in patients with rigid than in dynamic plate fixation for 1-level surgeries but not for 2-level surgeries. Fusion rates (96% dynamic vs 92% rigid), and overall complication rates were similar in both groups. Screw failure was more commonly observed with rigid plate fixation, whereas dysphagia was more commonly observed with dynamic plate fixation. This study was scored Class III because of unblinded outcome observation, lack of reliability testing for the questionnaire, and the fact that any patients lost to follow-up were replaced.[30]

Stulik et al.[32] reported on 132 patients who underwent dynamic (69 patients) or rigid (63 patients) plate fixation for 1- or 2-level cervical surgery. The authors used dynamic radiographs to assess instability at 3 and 6 months postoperatively. Follow-up was available in only 77 patients (58%) at 6 months. Segmental mobility was 1.4 mm at 3 months and progressed to 0.8 mm at 6 months in patients with dynamic plate fixation. For rigid plates, the values were 1.8 and 1.7 mm at 3 and 6 months, respectively. The difference was significant at 6 ($p < 0.04$) but not at 3 months ($p = 0.4$). This study was scored Class III because of poor follow-up (58%) and lack of details on randomization or allocation concealment.[32]

Arthroplasty for Cervical Degenerative Disease

The authors of several Class II studies have exam-

TABLE 4: Evidentiary summary of studies comparing arthroplasty to standard fusion*

Authors & Year	Description	Results	Class	Conclusions
Bertagnoli et al., 2005	16 patients who underwent 20 ProDisc-C arthroplasties for spondylosis, retrospective; clinical outcomes assessed w/ VAS & ODI; patients not blinded. Patients w/ >6 mos neck pain or >2 mos radiculopathy.	VAS/ODI measure at 3, 6, & 12 mos; improvement in ODI & VAS after placement of arthroplasty.	III	ODI & VAS may improve after arthroplasty.
Goffin et al., 2003	146 patients underwent 103 1-level or 43 2-level Bryan arthroplasties. Outcome assessed over 2 yrs w/ patients accruing w/ FU.	Odom's criteria showed success in >84% w/ arthroplasty.	III	Arthroplasty successful over several mos & several levels.
Robertson et al., 2005	103 patients w/ cervical disc degeneration underwent Bryan arthroplasty & compared w/ 202 patients w/ Affinity cages in a separate study. 2-yr FU examined adjacent-level disease.	FU available in 74 Bryan patients & 158 Affinity patients. Osteophyte enlargement was significantly worse w/ Affinity. New osteophyte, DDD, & ALL calcification no different. Only total radiography changes were increased w/ Affinity.	III	2 different studies compared on a "fishing expedition." No relevant case-control techniques. Poor FU.
Hacker, 2005	46 patients w/ cervical DDD single level. Randomized to Bryan arthroplasty or fusion. SF-36, NDI, Odom, & Neurological Outcome Form utilized over 24 mos (12-mo min).	Improvement seen in both groups at 1 yr w/ no statistical difference on NDI & SF-36.	II	Single center series of 46 patients randomized to Bryan disc or fusion; randomization technique not listed; patients probably not blinded; FU did not appear by independent observer; no clinical differences noted between groups.
Coric et al., 2006	33 patients w/ single level cervical DDD. Randomized to Bryan arthroplasty or fusion. Outcome SF-36, NDI, arm & neck pain scores over 24 mos.	Improvement in both groups w/o significant difference. Preservation of ROM w/ arthroplasty.	II	Uncertain about randomization technique; also, patients not blinded to Tx; 3 patients did not undergo ACDF when randomized; all patients improved but ROM greater w/ arthroplasty; it is uncertain that outcome assessment was blinded.
Pickett et al., 2006	74 patients (mixed) who underwent 96 Bryan disc prostheses for cervical DDD. Patients followed over 24 mos & assessed for complications from arthroplasty.	Periop complication rate 6/74 & 4/74 asymptomatic prosthesis problems. Late complications were 5/74. The complication rate was 11/74 (14.9%) or 11.4% per treated level. Total device problems 15/74 (20.3%) or 15.6% per treated level.	III	At best, periop complications were 6.2% per treated level w/ all complications far higher.
Porchet & Metcalf, 2004	55 patients, 27 randomized to Prestige II & 28 to fusion for single level cervical DDD. FU over 2 yrs.	With respect to NDI & SF-36, both groups improved significantly but no differences were observed between groups.	II	Class II case-control study. Randomization was not detailed. Single center results showed that improvement occurred w/ ACDF or arthroplasty using NDI & SF-36 as indices. Adverse events in both arms.
Pickett et al., 2005	20 patients w/ 1- or 2-level cervical DDD who underwent Bryan arthroplasty. Quantitative kinematical analysis over 24-mo FU.	In postop period, motion maintained at operated level (8.89–8.92°). Neck ROM increased significantly (47.2–56.1°). Mean translation stayed at 1.5 mm.	III	Arthroplasty does not change motion at single level or translation. Total neck motion does increase.
Pimenta & McAfee, 2004	53 patients w/ cervical DDD who received 82 Cervitech PCM arthroplasties. FU over 1 year w/ VAS & NDI primarily. Odom criteria also used.	VAS improved from 85 to 20 & NDI improved from 45 to 15 at 1 year postop. No statistics completed. 87% reported good or excellent results on Odom criteria.	III	Arthroplasty may improve pain & neck function. No control group.

(continued)

TABLE 4: Evidentiary summary of studies comparing arthroplasty to standard fusion* *(continued)*

Authors & Year	Description	Results	Class	Conclusions
Mummaneni et al., 2007	541 patients w/ cervical DDD randomized to Prestige arthroplasty (n = 276) or fusion (n = 265). 2-yr FU w/ NDI, neurological function, adverse events.	NDI scores & success criteria significantly improved at 3 mos in arthroplasty but not at 24 mos. Arthroplasty patients returned to work 16 days sooner (p = NS). Neck & arm pain scores & SF-36 scores improved in both groups (p = NS). Only w/ combination of NDI success & maintenance of neurological function was superiority seen w/ arthroplasty. 1 year had full FU & 24 mos did not have full FU.	II	Prestige & ACDF both improve function. With specific combination of improvement on NDI combined w/ maintenance of function & no adverse events, Prestige superior. However, FU was 80% in device & 75% in ACDF group.

* ALL = anterior longitudinal ligament; DDD = degenerative disc disease; ODI = Oswestry Disability Index; PCM = Porous Coated Motion.

ined arthroplasty compared to ACDF in cervical degenerative disease.[8,13,19,26] Mummaneni et al.[19] reported their randomized, controlled trial of 541 patients, 276 of whom underwent arthroplasty, and 265 who underwent ACDF. Patients had single-level cervical disc degeneration. Follow-up was undertaken using the Oswestry NDI, SF-36, neurological function testing, and the frequency of adverse events over a 24-month period. A successful outcome was considered to have occurred when all of the following were met: 1) the NDI improved > 15 points; 2) there was associated neurological improvement or maintenance of function; and 3) there were no adverse events. In this study, NDI scores, SF-36 scores, and pain perception improved significantly in both groups. When all criteria for success were used, the arthroplasty group had a superior outcome; however, multiple confounding factors, such as the use of medications, cervical collar immobilization, patient expectations, and lack of blinding, limit any conclusions from being drawn. This study was downgraded to Class II because follow-up was 80% in the arthroplasty group but only 75% in the ACDF group.[19]

Porchet and Metcalf[26] (55 patients), Hacker[13] (46 patients), and Coric et al.[8] (33 patients) all reported randomized series of patients with cervical degenerative disease who underwent either arthroplasty or ACDF. These individual reports were subgroups of patients included in a larger randomized controlled trial. In these studies, both the arthroplasty and ACDF groups showed clinical improvement without significant differences between groups at 24-months postoperatively on NDI and SF-36. Not surprisingly, the arthroplasty group experienced preservation of range-of-motion at the surgical level. These studies were graded Class II[8,13,26] because it was not evident how randomization occurred and whether the assessments were done blinded observers.

Goffin and colleagues[10] (103 patients with 1-level and 43 patients with 2-level surgeries), Pimenta et al.[25] (53 patients), and Bertagnoli et al.[4] (16 patients) each detailed a series of patients who underwent cervical arthroplasties. Outcome assessment was completed with Odom's criteria in the Goffin study, and with the VAS score and NDI in the latter 2 studies. In each group, patients improved steadily over the course of 1 year. These studies were graded Class III because of the lack of comparison groups, and the retrospective nature of the study design.[4,10,25] In 2 separate Class III series, Pickett et al.[23,24] described 74 patients and 20 patients, respectively, who underwent disc arthroplasty. In the smaller series of 20 patients,[23] preservation of motion was analyzed. In the postoperative period, motion was maintained at the operated level (8.89 to 8.92°). When aggregate neck motion was studied, it had increased significantly (from 47.2 to 56.1°). Mean translation measurements remained at 1.5 mm. In the larger series,[24] 6 (8%) of 74 patients experienced perioperative complications, while 4 (5%) had asymptomatic radiographic abnormalities. The late complication rate was 7% (in 5 patients), and the total complication rate was 15% (11 patients). These Class III studies indicate that arthroplasty can maintain motion but does have a moderate complication rate.

Robertson et al.[28] reported on 103 patients with cervi-

cal disc degeneration who underwent Bryan arthroplasty and compared their results to 202 patients who underwent Affinity cage placement in a separate study. This study examined adjacent level disease over a 2-year follow-up period. Follow-up was available in 74 (72%) of the patients with Bryan arthroplasty and 158 patients (78%) who received Affinity cages. Osteophyte enlargement was significantly worse in patients using Affinity compared to Bryan (8.9% vs 0%; $p < 0.01$). New osteophyte formation, cervical degeneration, and anterior longitudinal ligament calcification were no different between the groups, however. The total number of plain radiograph degenerative changes was increased with Affinity (34.6% vs 17.5% with Bryan arthroplasty; $p < 0.01$). The results of this study suggested that arthroplasty reduced the incidence of degenerative changes. However, it was graded Class III because it compared 2 studies in a retrospective fashion without controlling for homogeneity.

Summary

Despite the abundance of studies, there exists no Class I evidence to assess the efficacy of adding fusion or plate fixation to ACD. Furthermore, there is no Class I evidence indicating that arthroplasty is superior to ACDF. Class II evidence indicates that ACD and ACDF are equivalent treatment strategies for cervical disc degeneration with regard to the clinical outcomes as measured by the VAS, McGill Questionnaire, and Odom's criteria. Two Class II studies demonstrated equivalency for arm pain, and conflicting evidence was demonstrated for neck pain with 1 Class II study showing equivalence and another Class II study showing ACDF to be superior. The time to relief of neck or arm pain is shorter after ACDF (Class III). The ACDF technique is associated with better fusion (Class II) and avoidance of postoperative kyphosis (Class II).

Class II evidence indicates that plate fixation does not improve long-term outcome in patients wtih 1-level cervical disc degeneration but does improve arm pain associated with 2-level disc degeneration (Class II). The results in 2 Class II and 6 Class III studies indicate equivalent clinical and functional outcome with or without plate fixation. The use of a cervical plates improves cervical lordosis (Class II), reduces the risk of pseudarthrosis (Class III), and reduces the incidence of graft-related complications (Class III), but increases surgical blood loss (Class III). Dynamic plate fixation has not been shown to increase fusion rates compared to rigid plates (Class III). Class II evidence indicates that cervical arthroplasty is as effective as ACDF with plating for control of neck and arm pain in selected patients.

Key Issues for Future Investigations

The lack of definitive recommendations for a procedure as commonly performed as ACD with or without fusion or instrumentation clearly indicates the need for more methodologically rigorous studies. The number of these procedures performed each year is substantial. There is a need for uniform outcome parameters and standardized follow-up methods with consistent time points. This is an area in which our organized medical societies that focus on spinal surgery could play an important leadership role. The economic impact of a particular procedure on such factors as activity restriction and return-to-work may be potentially significant and worthy of study. Finally, long-term outcome data will be needed to assess the benefit of motion preservation with arthroplasty.

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