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Management of anterior cervical pseudarthrosis

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Object. The objective of this systematic review was to use evidence-based medicine to identify the best methodology for diagnosis and treatment of anterior pseudarthrosis.

Methods. The National Library of Medicine and Cochrane Database were queried using MeSH headings and key words relevant to pseudarthrosis and cervical spine surgery. Abstracts were reviewed, after which studies meeting inclusion criteria were selected. The guidelines group assembled an evidentiary table summarizing the quality of evidence (Classes I–III). Disagreements regarding the level of evidence were resolved through an expert consensus conference. 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. Evaluation for pseudarthrosis is warranted, as there may be an association between clinical outcome and pseudarthrosis. The strength of this association cannot be accurately determined because of the variable incidence of symptomatic and asymptomatic pseudarthroses (Class III). Revision of a symptomatic pseudarthrosis may be considered because arthrodesis is associated with improved clinical outcome (Class III). Both posterior and anterior approaches have proven successful for surgical correction of an anterior pseudarthrosis. Posterior approaches may be associated with higher fusion rates following repair of an anterior pseudarthrosis (Class III).

Conclusions. If suspected, pseudarthrosis should be investigated because there may be an association between arthrodesis and outcome. However, the strength of this association cannot be accurately determined. Anterior and posterior approaches have been successful. *(DOI: 10.3171/2009.2.SPINE08729)*

Key Words • **cervical spine** • **fusion** • **practice guidelines** • **pseudarthrosis** • **treatment outcome**

Recommendations

It is recommended that the physician evaluate for the presence of pseudarthrosis if the clinical outcome is poor and it is suspected that there is an association between the outcome and a pseudarthrosis. The strength of this association cannot be accurately determined because of the variable incidence of symptomatic and asymptomatic pseudarthroses (quality of evidence, Class III; strength of recommendation, D).

Indications: Pseudarthrosis. It is recommended that revision of a symptomatic pseudarthrosis be considered because arthrodesis is associated with improved clinical outcome (quality of evidence, Class III; strength of recommendation, D).

Technique: Anterior or Posterior Surgical Arthrodesis. It is recommended that either the posterior or anterior approach be considered for surgical correction of anterior pseudarthrosis. Posterior approaches may be as-

Abbreviations used in this paper: ACDF = anterior cervical discectomy and fusion; CSOQ = Cervical Spine Outcome Questionnaire; SF-36 = 36-Item Short Form Health Survey.

sociated with higher fusion rates following repair of an anterior pseudarthrosis (quality of evidence, Class III; strength of recommendation, D).

Rationale

Spinal surgeons have commonly used the anterior cervical approach to treat a wide variety of pathological processes. Management strategies for pseudarthrosis are therefore necessary for effective treatment in these patients. Fusion and stabilization are often coupled in the anterior approach to preserve or enhance spinal alignment.[1] The incidence of pseudarthrosis after an anterior cervical approach is used is dependent on the number of levels involved and ranges from 0 to 50%.[2,6,13,15,17,18,20] Despite the widespread application of anterior plates, clinicians have not been able to eliminate the development of pseudarthrosis.[11,24,25] Complaints associated with a cervical nonunion include persistent or recurrent axial neck pain, radiculopathy, and myelopathy. Development of a pseudarthrosis has also been associated with kyphotic deformity, potentially leading to pain and neurological deficits.

Search Criteria

We completed a computerized search of the database of the National Library of Medicine and the Cochrane database between 1966 and 2007 using the MeSH search terms "cervical pseudo-arthrosis," "cervical spine AND fusion failure," and "cervical spine AND revision surgery." We limited the search to the English language and human subjects. A total of 362 citations were retrieved, and we reviewed the titles and abstracts from each of these references. We selected studies that investigated the clinical significance and treatment of cervical pseudarthrosis, and obtained additional articles from the bibliographies of the selected manuscripts. We selected 18 manuscripts that described the presentation and treatment of patients with a cervical nonunion. These are listed in an evidentiary summary and evaluation in Table 1. An expanded list of the manuscripts evaluated from the search is contained in the references section.

Scientific Foundation

Clinical Presentation of Anterior Cervical Pseudarthrosis

There is debate regarding the clinical impact of a pseudarthrosis after attempted cervical fusion. Several studies have indicated a poor correlation between clinical and radiographic outcome.

De Palma and Cooke[8] reviewed the results in 146 patients who underwent anterior cervical interbody fusion with at least 12 months of follow-up. Clinical assessment was based on a 4-tiered qualitative scale, based on complaints referable to the cervical spine and their impact on daily activities, and rated as excellent, good, fair, or poor. The authors documented nonunion based on the motion between the involved spinous processes observed on flexion-extension radiographs. Sixteen patients (10.9%) received a diagnosis of nonunion. Satisfactory results (including all patients with excellent, good, or fair outcomes) occurred in 93.5% of patients with nonunion and in 89.6% of the entire cohort. The authors concluded that a solid arthrodesis is not necessary for clinical success. When the data were carefully reviewed, however, the percent of patients observed to have an excellent or good outcome was 60.5% for the entire cohort and only 37.4% for patients in whom a nonunion developed. Including patients with a fair outcome in the category of clinical success dramatically affected this observation and was of questionable validity—particularly since the observations were based on a nonvalidated outcomes instrument without objective data.

White et al.[26] reviewed their series of 65 patients who underwent anterior cervical fusion for cervical spondylosis. Utilizing a qualitative, subjective categorical assessment, the authors reported an overall success rate of 90%. When stratifying patients based on the development of a pseudarthrosis, the success rate for nonunion was 53%, and with successful fusion was 75%. This difference was not statistically significant, however. Therefore, the authors concluded that, although desirable, successful arthrodesis was not necessary for clinical success. Despite the lack of statistical significance, the data suggested a potential relationship between poor outcome and nonunion. One possible explanation for the lack of significance could have been the small number of included patients. As with the Depalma and Cooke[8] study, there were significant limitations to this study, including the authors' subjective definition of clinical success and lack of an objective, validated outcomes assessment.

These 2 studies have been quoted as providing evidence against an association between nonunion and adverse outcome. Other reports have presented data supporting an association between fusion and improved outcomes. Brunton et al.[4] reviewed their series of 75 patients who underwent anterior cervical decompression and fusion for spondylotic disease and trauma, and reported a clinical success rate of 76% in patients with solid union, and only 5% in those with a documented pseudarthrosis. Bohlman and colleagues[2] reviewed 122 patients who underwent ACDF and observed a pseudarthrosis rate of 20%. The authors reported a good or excellent outcome in 93% of patients in whom a solid arthrodesis was achieved. Based on their reported data, it was impossible to determine the percent of patients in whom a similar outcome was achieved after a pseudarthrosis developed; however, only 33% were pain free, and the authors reported a statistically significant association between the presence of a pseudarthrosis and continued arm and neck pain ($p < 0.01$). Newman[17] reviewed the case histories of 23 patients with documented pseudarthrosis. Seventy percent of the patients required further intervention due to persistent symptoms. Phillips et al.[18] reported that 67% of patients with a documented pseudarthrosis were symptomatic and 82% required further intervention. These authors reported clinical success in 100% of patients in whom solid fusion developed after the second operation. More recently, Carreon et al.[5] reported their results in 120 patients with symptomatic nonunion after ACDF. Four-

TABLE 1: Evidentiary summary of studies regarding management of pseudarthrosis*

Authors & Year	Class	Description of Study	Comments
White et al., 1973	III	The authors reviewed their series of 65 patients undergoing anterior cervical fusions to determine factors associated w/ a successful outcome. Clinical outcome was based on a 4-tiered, qualitative scale. Radiographic evidence of fusion was based on bridging trabeculae across the graft–host interface or "relative" immobility on dynamic views. A minimum FU of 2 yrs was required for inclusion. Statistical significance was determined using the chi-square method. 73% of patients w/ a solid union were considered to have an excellent or good outcome while only 53% of nonunion patients achieved the same result. The difference was not statistically significant. The authors concluded that fusion is desirable but not necessary for clinical success.	This retrospective case series used nonvalidated instruments to assess clinical & radiographic outcome. The authors failed to adequately account for possible confounding factors. The majority of cases were independently evaluated, but it is not known whether assessment was blinded to fusion status.
Brunton et al., 1982	III	The authors reviewed their series of 75 patients who underwent 88 anterior cervical procedures for various pathological conditions to determine the accuracy of cine radiography as a means of determining the correct level for fusion. Clinical outcome was based on a qualitative scale; however, the method of fusion determination was not described. The average FU was 4.5 yrs. A pseudarthrosis rate of 22.7% was observed w/ 95% considered clinical failures. This compares to a failure rate of 24% in patients obtaining a solid fusion. The authors concluded that a solid arthrodesis was almost essential for a successful outcome.	This retrospective case series used nonvalidated clinical outcomes instruments by independent reviewers. It is not clear that the reviewers were blinded to fusion status. The method of fusion assessment was inadequately described. The authors failed to account for confounding factors. No statistical analysis was performed.
Lindsey et al., 1987	III	Described the outcome in a patient who presented w/ a nonunion after 2-level ACDF. Nonunion was diagnosed based on a lucency observed on lateral tomograms. The patient underwent posterior cervical wiring & fusion. At 18-mos FU the patient was asymptomatic & demonstrated a circumferential fusion.	This is a case report of a single patient & therefore of questionable value. The clinical & radiographic criteria for success were not defined.
Fuji et al., 1986	III	The authors reviewed their series of 143 patients undergoing anterior cervical fusions & observed a nonunion rate of 22%. 9 patients were selected for Tx, but selection criteria were not described. The average FU was 26 mos. Radiographic criteria of nonunion included a lucent zone between the graft & vertebral body & motion detected on dynamic views. No clinical assessment was described. All patients underwent posterior wiring w/o fusion; 78% fusion rate. The authors concluded that posterior wiring w/o fusion was a viable option if the nonunion was treated "shortly" after the index procedure, the previous graft was still present, & osteosclerosis was observed on both sides of the radiolucent zone.	This retrospective case series in a small patient population was compromised by significant selection bias. The method of radiographic evaluation was subjective & of questionable validity. The method of data collection was not described, & no clinical results were provided. The authors' conclusions were primarily conjecture & not based on adequate data.
Farey et al., 1990	III	The authors described 19 patients who presented w/ symptomatic anterior cervical pseudarthrosis treated w/ a posterior decompression, stabilization, & fusion. 4 of the 19 patients had multiple attempts at an anterior revision prior to the posterior approach. Preop diagnosis of pseudarthrosis was based on a radiolucent gap at the graft–host interface or absence of bridging bone trabeculae between vertebral bodies. It is not clear if the same criteria were applied to assess fusion after the posterior revision. Subjective assessment of preop symptom relief was used as a measure of clinical outcome. The average FU was 44 mos, w/ clinical & radiographic evaluations performed at regular intervals. A solid circumferential fusion was achieved in 100% of patients. Significant clinical improvement was observed in 95% of patients. Complications were limited to the graft harvest site. The authors conclude that in the absence of myelopathy, the posterior approach is the preferred Tx for an anterior cervical pseudarthrosis.	This retrospective case series of a limited number of patients was evaluated w/ nonvalidated clinical outcomes instruments & incompletely defined radiological criteria. The method of data acquisition was not described. There was no control group, & no statistical analysis was performed.

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teen patients (12%) reported continued complaints related to persistent nonunion after the revision surgery.

These retrospective reviews appear to demonstrate an association between a poor clinical outcome and the development of a cervical nonunion. Unfortunately, studies that have attempted to describe the clinical presentation of a pseudarthrosis all suffer from similar limitations, most notably the lack of objective outcomes assessment. In no study was an adequate analysis of confounding factors performed to predict factors that correlate with poor outcome.

Surgical Intervention

The presence of a cervical nonunion is not an absolute indication for operative intervention. Longitudinal studies documenting the natural history of pseudarthro-

TABLE 1: Evidentiary summary of studies regarding management of pseudarthrosis* *(continued)*

Authors & Year	Class	Description of Study	Comments
Brodsky et al., 1992	III	This study compared the radiographic & clinical outcome of 34 patients presenting w/ a symptomatic anterior pseudarthrosis treated w/ either a reoperative anterior discectomy & iliac crest autograft or posterior wiring & onlay autologous iliac crest. The average FU was 60 mos. Patients were evenly distributed between the Tx alternatives. Clinical outcome was defined w/ a 4-point scale based on the persistence of preop neurological signs & symptoms. Radiographic assessment of fusion was based on the presence of bridging bone trabeculae, dissolution of vertebral endplates, graft remodeling, & decreased posterior osteophytes. The fusion rate in the posterior group was 94% & in the anterior group 76%. The clinical outcome was rated as excellent or good in 88% in the posterior group & only 59% in the anterior group. There was no mention of postop complications. The authors concluded that the posterior approach was more effective than the anterior approach for treating failed anterior cervical fusions.	This study is considered a poor-quality observational cohort study. Although the study claims to have randomized patients, there was no explanation of the randomization scheme. The method of fusion assessment was subjective & of questionable validity. Nonvalidated clinical outcomes instruments were utilized in a nonblinded fashion, w/o a control group. No statistical analysis was performed.
Newman, 1993	III	The case histories of 23 patients presenting w/ pseudarthrosis following anterior cervical fusion were retrospectively reviewed. Diagnosis of nonunion was based on persistent motion on dynamic radiographs. Clinical results were based on patients' self-assessment of pain relief, discontinuation of pain medication, & return to normal activities. 16 of the 23 patients underwent revision surgery, 14 through a repeated anterior approach & 2 via a posterior approach. 7 patients w/ persistent neck pain declined surgery. 81% of patients achieved a solid arthrodesis & 69.2% a successful outcome. There was no mention of surgical complications. The authors concluded that their series supports the hypothesis that a good clinical outcome is dependent on a solid arthrodesis.	This was a retrospective case series of a small number of patients compromised by selection bias. The radiographic assessment was subjective & of questionable validity. Nonvalidated outcome assessment was utilized & method of data collection not disclosed. A valid comparison of surgical approaches is impossible given the limited number of patients.
Shinomiya et al., 1993	III	This is a retrospective review of 443 patients who underwent various anterior cervical procedures for numerous diagnoses in order to classify types of surgical failure & discuss Tx strategies. 15 nonunions (3.4%) were diagnosed based on continued mobility demonstrated on dynamic radiography, 14 following vertebrectomy across multiple levels & 1 after a single-level fusion. 14 underwent a posterior fusion & wiring & 1 patient underwent an anterior revision. 4 out of 5 w/ progressive complaints, not defined, recovered. The clinical results of the remaining patients are not described. There is no description of the radiographic results for the revision procedures. The authors concluded that nonunion should be treated w/ a posterior approach to prevent kyphotic deformity & possible neurological deterioration; however, in their presence an anterior approach should be considered.	This retrospective case series provided little objective information. The patient population was poorly defined. There was no explanation regarding the method of clinical assessment. The clinical results were incomplete, w/o any mention of radiographic results of the revision procedures. No valid conclusions regarding the efficacy of revision surgery can be formulated.
Bohlman et al., 1993	III	Series of 122 patients who underwent ACDF for cervical spondylosis & radiculopathy. Average FU of 6 yrs was obtained in 113 patients & 18 mos for the remaining 9 patients. An interspinous distance between vertebrae of ≤1 mm, observed on dynamic radiographs, was considered a successful fusion. A qualitative clinical assessment, in part performed by the operating surgeon, was based on location & severity of pain, neurological deficit, pain medication use, & level of function. Statistics were performed to determine the association between pseudarthrosis & pain, sex, age, number of levels fused, & smoking. 24 patients (20%) demonstrated a nonunion; however, only 16 patients (67%) were symptomatic. Only 4 patients presented w/ symptoms significant enough to warrant reoperation. There was a significant association between the presence of a pseudarthrosis & postop pain. The presence of a nonunion was highly correlated to multilevel procedure; ($p < 0.01$) however, correlation to tobacco use, although suggested, was not shown to be significant ($p = 0.08$). Neither the approach nor the results of the revision procedures was discussed.	This retrospective review provided data regarding the incidence & presentation of cervical nonunions. The study benefited from a large patient cohort, extended FU period, & a negligible dropout rate. Fusion assessment was based on objective measures; however, nonvalidated outcomes instruments were used to assess clinical results. The operating surgeons were involved w/ the data collection introducing the possibility of reporting bias. No data regarding the outcome of pseudarthrosis Tx was provided.

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sis do not exist. Asymptomatic patients may not require any intervention, and nonoperative management may be adequate in patients with mild symptoms. Nonoperative management, however, becomes more challenging when symptoms attributed to a pseudarthrosis significantly affect the patient's quality of life. No study has been performed to determine the efficacy of conservative management in this patient population.

TABLE 1: Evidentiary summary of studies regarding management of pseudarthrosis* *(continued)*

Authors & Year	Class	Description of Study	Comments
Lowery et al., 1995	III	This study describes a single surgeon's experience treating symptomatic anterior cervical nonunion in 37 patients w/ either an anterior, posterior, or circumferential approach. 44 procedures were performed. The average FU was 28 mos, performed at regular intervals, w/ no patient lost to FU. Clinical outcome was based on self-assessment & analog pain scales for axial & appendicular pain. Radiographic criteria for nonunion included lucency at the graft–host interface or >2 mm motion on dynamic views at 12 mos after surgery. In the anterior group, axial & appendicular pain decreased by 43 & 56%, respectively. Overall improvement was reported in 40%. Solid fusion was observed in 45%; those patients not obtaining a solid union ultimately required further revision surgery. 94% from the posterior group achieved a solid arthrodesis, w/ 77% reporting improved axial pain, 83% reporting improved appendicular pain, & 82% reporting an overall improvement. In the circumferential group, successful fusion was observed in 100%, w/ a decrease in axial & appendicular pain observed in 68 & 65%, respectively. Overall improvement was noted in 71% of the circumferential patient group. Hardware failure was reported in 45% of the anterior group, 28% in the circumferential group, & 12% in the posterior group. Complications included 1 CSF leak in the anterior & circumferential group each, & 2 C-5 nerve root palsies, 1 permanent, in the posterior group. The authors concluded that the posterior approach was more effective & that the anterior approach should be reserved for deformity correction or removal of significant hardware failures.	This retrospective case series utilized objective measures to assess fusion; however, clinical outcome was based in part on nonvalidated instruments. There was insufficient demographic data to account for possible confounding factors. The method of data collection & radiographic analysis was not disclosed, introducing the possibility of reporting bias. No control group was defined & no statistical analysis was performed.
Zdeblick et al., 1997	III	This study describes the radiographic & clinical outcome of 35 patients treated for symptomatic anterior fusion failures. Patients were placed in 1 of 3 radiographic categories: failure of the anterior arthrodesis w/o deformity, migration of the bone graft, or kyphotic deformity. All patients underwent a repeat anterior cervical approach. The extent of decompression & fusion was dependent on the degree of spinal cord/nerve root impingement & kyphotic deformity. Iliac crest autograft was used for limited or multilevel decompressions while fibular allograft for greater than 2-level corpectomy. Radiographic outcome was assessed w/ static & dynamic radiographs, using >2 mm of motion between the spinous process tips as the criterion for nonunion. Clinical outcome was determined using a modified Odom scale, incorporating radiographic data. The average FU was 44 mos. The observed fusion rate was 97%. Outcome was considered excellent in 29 patients (83%), good for 1 patient (3%), fair in 4 patients (11%), & poor in 1 patient (3%). 4 patients suffered transient complications; single recurrent laryngeal nerve palsy, 2 draining wounds at the graft harvest site, & 1 CSF leak. The authors conclude that failed anterior cervical fusions can be successfully treated w/ a repeat anterior approach.	This retrospective case series utilized objective radiographic criteria; however, clinical assessment was based on nonvalidated modification of a commonly used outcome instrument. There was insufficient demographic data to account for confounding factors. The presenting mode of failure varied among patients, as well as the operative approach. The method of data collection was not defined, possibly involving the operating surgeons & introducing reporting bias.
Coric et al., 1997	III	This study describes the clinical & radiographic outcomes of 19 patients treated for symptomatic anterior cervical pseudarthrosis through a reoperative anterior approach using allograft bone & plate stabilization. The mean FU was 22.4 mos w/ a FU rate of 95%. Postop assessment of fusion was based on lateral dynamic images using the following criteria: obliteration of disc space by bone trabeculae, dissolution of the vertebral endplates, & evidence of graft remodeling. A modification of the Prolo scale was used to describe clinical outcome. Independent physicians other than the primary surgeon performed final radiographic & clinical evaluations. A 100% fusion rate was observed w/ 83.3% of patients demonstrating an excellent or good outcome. 2 patients (10.5%) suffered transient hoarseness that resolved. The authors concluded that an anterior revision approach utilizing allograft & plate stabilization is an effective & safe method for treating an anterior pseudarthrosis.	This was a retrospective case series utilizing a nonvalidated clinical outcomes instrument & subjective radiographic criteria for fusion assessment. There was no control group & no evaluation regarding possible confounding factors. The independent review of clinical & radiographic data reduced the possibility of reporting bias.

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TABLE 1: Evidentiary summary of studies regarding management of pseudarthrosis* *(continued)*

Authors & Year	Class	Description of Study	Comments
Phillips et al., 1997	III	The authors performed a retrospective review to evaluate the long-term outcome of 48 patients diagnosed w/ a pseudarthrosis following ACDF. The mean FU was 66 mos w/ clinical & radiographic assessment made at regular intervals. Clinical results were based on the patient's assessment of pain relief, use of prescription drugs, return to normal activities, & Odom's criteria. Diagnosis of nonunion was based on a radiolucent gap at the graft–host interface, lack of bridging bone trabeculae, or >2 mm of motion between spinous processes on flexion-extension radiographs. Data were independently collected from physicians not involved in patients' care. 16 patients required no further intervention at a mean of 5.1 yrs. 26 of the 32 symptomatic patients underwent revision surgery; however, the data from only 22 patients, who had ≥12 mos FU, is reported. An anterior revision was performed in 16 patients, w/ 14 (88%) achieving a successful fusion. 6 patients underwent a posterior fusion & 100% achieved a solid arthrodesis. All patients w/ preop motor weakness noted improvement, 5 in the anterior group & 1 in the posterior group. Of the 20 patients achieving successful fusion following the second surgery, 19 had an excellent outcome & 1 a good outcome based on Odom's criteria. The 2 patients w/ a nonunion after revision anterior surgery remained symptomatic. The authors concluded that surgical repair of symptomatic pseudarthrosis leads to acceptable results.	This was a retrospective case series utilizing objective radiographic & validated clinical outcomes measures. The results are compromised by selection bias since patients were excluded from the data analysis: 10 patients from the original 58 & 4 patients from the 26 surgical patients, were not adequately compared to the observational cohort. Selection bias was also introduced since operative procedure, anterior vs posterior, was based on surgeon's preference. There was no appropriate control group. The data analysis did not account for possible confounders & no statistical analysis was performed.
Siambanes & Miz, 1998	III	This case series describes the Tx of 14 patients who presented w/ symptomatic pseudarthrosis after anterior cervical fusion for spondylotic disease. All patients underwent a posterior wiring & fusion. Radiographic FU was obtained in all 14 patients, but clinical data were only available for 9 patients, at an average of 3.6 yrs postop. The assessment of fusion was based on osseous bridging & incorporation of the anterior graft &/or posterior bone bridging across the intralaminar space. Clinical evaluation was performed w/ visual analog scales & questionnaire evaluating work status, pain medication use, & satisfaction. All patients achieved a radiographic fusion, but clinical results were "good" & "fair" in 1 patient each & "poor" in the remaining 7. 2 wound complications were observed. The authors attributed the poor clinical outcome to socioeconomic factors, although no formal evaluation was performed, & continue to support operative intervention for nonunion.	This was a case series of a limited number of patients w/ a significant no. lost to FU (36%). Outcomes were based on nonvalidated clinical measures & subjective radiographic criteria. The method of data collection was not disclosed. The conclusions are not supported by the data.
Tribus et al., 1999	III	This series of 16 patients was treated for symptomatic anterior cervical pseudarthrosis via an anterior approach. The average FU period was 19.2 mos, w/ no patient lost to FU. 75% of patients underwent resection of pseudarthrosis, autologous iliac crest bone grafting, & plate stabilization across a single level. Fusion assessment was graded on a 5-point scale based on qualitative criteria obtained from lateral flexion-extension radiographs. Clinical outcome was based on self-assessment questionnaires regarding activities of daily living, medication use, pain, & work status. "Stability" was reported in all patients; however, a definitive fusion rate was not disclosed. 75% of patients reported pain improvement, 5 of 7 patients reported resolution of preop weakness, & 69% were judged to have good or excellent clinical result. Persistent dysphagia was observed in 1 patient. The authors concluded that w/ the proper patient selection an anterior revision for failed cervical fusion is an effective Tx alternative.	This is a retrospective case series utilizing nonvalidated clinical outcomes instruments & subjective radiographic criteria. The fusion rate is unknown since the authors did not indicate which radiographic "grade" constitutes a solid arthrodesis. It was impossible to verify the authors' observation of clinical success, because this definition is not provided. The method of data collection & radiographic review was not described, introducing possible reporting bias.

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Once the decision has been made to operate, the clinician and patient have the choice of either an anterior or posterior approach. If an anterior approach was previously attempted, avoidance of scar tissue compromising the natural tissue planes is a potential advantage to the posterior approach. The posterior approach essentially eliminates the risk of soft-tissue injury, leading to swallowing dysfunction and recurrent laryngeal nerve injury. The posterior approach also provides a fresh surface for fusion formation and internal fixation; however, it may be less effective in the presence of a kyphosis, anterior graft migration, or worsening neurological function due to a prominent ventral pathological entity. An anterior approach avoids the dissection of the posterior cervical musculature, leading to decreased postoperative discomfort. Our review of the literature yielded anecdotal evidence

TABLE 1: Evidentiary summary of studies regarding management of pseudarthrosis* *(continued)*

Authors & Year	Class	Description of Study	Comments
Kuhns et al., 2005	III	Series of 33 patients presenting w/ symptomatic anterior cervical pseudarthrosis treated w/ a posterior approach. A posterior decompression was performed in 18 patients presenting w/ radiculopathy, & all patients underwent posterior stabilization, w/ either lateral mass fixation or spinous process wiring, & arthrodesis, w/ either autologous iliac crest or locally harvested bone. The average FU was 46 mos. Fusion assessment was based on static & dynamic radiographs utilizing the following criteria for nonunion: a radiolucent gap at the graft–host interface, lack of bridging osseous trabeculae, &/or >2 mm of motion between spinous processes on flexion-extension images. Clinical outcome was assessed utilizing select measures from the CSOQ, the upper extremity & hand scale from the AIMS2, & SF-36, although no preop data was recorded. 25 of 33 patients (76%) completed the outcomes questionnaires, & all 33 patients underwent radiographic fusion assessment. A solid arthrodesis was observed in 100% of patients. Based on the CSOQ scale, pain was reported as absent or mild in 52%, "discomforting" in 20%, & severe in 28%. Both the SF-36 & AIMS2 scores correlated w/ the CSOQ data. 72% of patients who completed the outcomes questionnaires were satisfied w/ their results. The only complication was related to a retained drain that required surgical removal prior to discharge. The authors concluded that the posterior approach is a reliable Tx alternative for failed anterior cervical fusion, but both patient & surgeon must be aware that a relatively high percentage of patients will continue to suffer from significant pain.	This is a retrospective case series utilizing validated outcomes instruments & objective radiographic criteria for fusion assessment. Radiographs were independently reviewed. Only 76% of patients completed the outcomes questionnaires & analysis was performed to account for possible confounding factors. The Tx effect of surgery cannot be determined since no patient completed the questionnaires prior to the revision surgery & there is no control group.
Carreon et al., 2006	III	The authors compared the outcome in 120 patients who underwent either an anterior or posterior approach for repair of anterior cervical pseudarthrosis. Review of hospital & office records was performed to determine demographic data, surgical data, fusion status, & surgical revision rate. Revision surgery involved harvesting of autologous iliac crest & either anterior plate stabilization or posterior wiring or lateral mass fixation. 27 patients underwent an anterior approach & 93 the posterior approach, w/ similar demographic data (tobacco use, sex distribution, number of surgical levels). Nonunion requiring reoperation occurred in 44% of the anterior group & in only 2% of the posterior group. The complication rate was 4% in the anterior group & 8% in the posterior group. The posterior group demonstrated greater intraoperative blood loss & longer hospital stay. The authors concluded that the posterior approach was more successful for repair of an anterior cervical pseudarthrosis.	This was a retrospective chart review. Patients were not randomized between surgical approaches, and anterior revision was reserved for cases involving a neurological deficit or kyphosis; therefore, significant selection bias exists. There were insufficient data to determine radiographic outcome & no data regarding clinical outcome were provided. There was no control group & no statistical analysis was performed. It is impossible to construct a valid comparison between surgical alternatives.
Neo et al., 2006	III	This study described the radiographic outcome in 6 patients treated w/ a spinous process fixation plate for anterior cervical fusion failure, including graft dislodgement & plate migration. Patients were followed up for ≥18 mos. In addition to the spinous process fixation plate, a variety of anterior revision procedures were performed, either removal or replacement of anterior plate & interbody graft. Consolidation of the anterior graft was observed in all cases. The authors concluded that the spinous process fixation plate is safe & a viable alternative for salvage operations for anterior cervical nonunions.	This was a retrospective case series involving a very small patient population, subjective criteria for radiographic fusion assessment, & numerous operative approaches. No clinical data were provided, & there was no control group. At best, this study demonstrated the feasibility of this construct; however, valid conclusions regarding the efficacy cannot be formulated.

* The criteria for scoring each manuscript into a class are described in *Introduction and Methodology: Guidelines for the Surgical Management of Cervical Degenerative Disease*, which appears in this issue of the *Journal of Neurosurgery: Spine.* Abbreviations: AIMS2 = Arthritis Impact Measurement Scales-2; FU = follow-up.

in support of both approaches. Although the authors of several studies have performed a direct comparison, it is difficult to formulate valid conclusions because of the limitations of the study designs.

Evidence Supporting the Anterior Approach

A number of retrospective series have documented the outcome of anterior cervical revisions. Coric et al.[7] reviewed their series of 19 patients who presented with pseudarthrosis after undergoing ACDF without plate stabilization. Allograft iliac crest bone was used in conjunction with anterior plate stabilization from 1 to 3 levels. The authors measured clinical outcome utilizing a modified Prolo scale, including both functional and economic

measures. Radiographic assessment of fusion was based on a qualitative description of graft incorporation. A physician not involved with the surgery performed both the clinical and radiographic assessment. One patient died of unrelated causes 4 months after surgery; the remaining 18 patients demonstrated solid fusion across 28 levels, however. The authors reported an excellent or good outcome in 83.3% of patients and a fair or poor outcome in 16.7%. Two patients (10.5%) demonstrated transient hoarseness following surgery. The authors concluded that anterior revision for anterior cervical nonunion, utilizing allograft bone grafts and plate stabilization, was a safe and effective surgical alternative. This study was limited by its retrospective design, small patient population, subjective fusion criteria, and use of a nonvalidated outcomes instrument (the Prolo scale was modified and originally validated for lumbar disease[19]). The independent review reduces the potential of reporting bias, but it is not clear whether the assessment was made in a blinded fashion. This study is classified as Class III medical evidence.

Zdeblick et al.[27] reported the results in 35 patients who underwent repeated anterior fusion with either iliac crest autograft or allograft fibular strut placement for nonunion of discectomy or corpectomy, without plate stabilization. The authors report a 97% fusion rate with 86% achieving an excellent or good outcome based on modified Odom's criteria. Tribus et al.[23] investigated the outcome of anterior cervical revision in 19 patients and reported an overall success rate of 69%. A 5-point grading system, based on subjective assessment of graft incorporation and motion, was used to evaluate fusion. The authors considered all patients to be stable; however, it was difficult to determine the fusion rate since the authors failed to define a solid arthrodesis. The validity of the conclusions was questionable because of the study's retrospective design, heterogeneous patient population, surgical technique, use of subjective clinical and radiographic outcomes measures, potentially biased method of data collection, and insufficient analysis of confounding factors.

Evidence Supporting the Posterior Approach

As stated previously, treating an anterior cervical nonunion through a de novo posterior approach has theoretical and practical advantages and may have contributed to the greater volume of published case series. In many respects, however, these reports suffer from the same limitations as those describing anterior revision, including retrospective study design, lack of appropriate controls, limited patient populations, subjective clinical and fusion assessment, selection and reporting bias, and inadequate evaluation of confounding factors.

Farey et al.[9] described the outcome in 19 patients treated for symptomatic anterior nonunion with posterior decompression, wire stabilization, and fusion. The authors reported circumferential fusion in 100%, with 95% demonstrating clinical improvement. Complications were limited to the iliac crest harvest site. In 1998, Siambanes and Miz[22] published their results in their series of 14 patients who underwent posterior wiring and fusion for failed anterior fusions. Radiographic follow-up was available in all patients; however, only 9 patients completed the clinical evaluation at an average follow-up interval of 3.6 years. Radiographic fusion was achieved in all patients, but a poor outcome was reported in 78%. The authors speculated that the poor outcome was related to socioeconomic factors, without providing any evidence to support this claim.

Kuhns and associates[12] published a retrospective review describing the outcome in 33 patients in whom a posterior approach was used. In contrast to many of the previous reports, this study used validated clinical outcomes measures and objective radiographic criteria to assess fusion. Radiographs were independently reviewed; however, the authors did not describe the method of clinical data collection. Unfortunately, only 76% of patients completed the clinical assessment. All patients achieved a solid arthrodesis. Based on the CSOQ, pain was absent or mild in 52%, "discomforting" in 20%, and severe in 28% of patients. The results of the SF-36 and Arthritis Impact Measurement Scales-2 correlated with the CSOQ results. Seventy-two percent of patients were satisfied with the surgical results. Unfortunately, no preoperative assessment was performed, and it is therefore impossible to determine the treatment effect of surgery.

Comparison of Anterior and Posterior Approaches

A limited number of studies have compared the radiographic and clinical outcome between an anterior and posterior approach. No well-designed trial has been performed; therefore, determining the superiority of one technique is difficult, if not impossible. These retrospective series are limited by selection and reporting bias, utilization of nonvalidated outcomes measures, subjective radiographic assessment, and a lack of appropriate statistical evaluation.

In 1992, Brodsky et al.[3] compared the outcome in 34 patients who underwent either a reoperative anterior discectomy with iliac crest autograft, or a posterior wiring and onlay autologous iliac crest. Although the authors randomized patient group assignments, they did not detail the method for randomization. The authors reported a 94% fusion rate with the posterior approach compared to 76% after an anterior revision. The authors reported an excellent or good outcome in 88% of patients who underwent a posterior revision and only in 59% after anterior revision. Clinical assessment was based on nonvalidated outcomes measures and the rate of fusion was based on subjective criteria; no statistical analysis was reported. Despite these limitations, the authors concluded that the posterior approach was more effective.

Lowery et al.[14] reported on the outcome in 37 patients after 44 revision procedures with either an anterior, posterior, or circumferential approach. In the anterior group, axial and appendicular pain decreased by 43 and 56%, respectively. Reported overall improvement was 40%. The authors reported solid fusion in 45% of patients. Patients in whom solid union was not obtained ultimately required further revision surgery. A solid arthrodesis was achieved in 94% of patients in the posterior group, with improved axial pain in 77%, improved appendicular pain in 83%, and overall improvement in 82%. In the circumferential group, the authors reported successful fusion in 100% of

patients with a decrease in axial and appendicular pain observed in 68 and 65%, respectively. The overall improvement rate for the circumferential group was 71%. The authors reported a 45% rate of hardware failure for the anterior group, 28% for the circumferential group, and 12% for the posterior group. Complications included 1 CSF leak in the anterior and circumferential group each. There were 2 C-5 nerve root palsies in the posterior group, 1 of which was permanent. Although objective radiographic criteria were used for fusion assessment, clinical outcome was based on nonvalidated measures. The authors did not account for possible confounders and no statistical analysis was performed. The authors concluded that the posterior approach was the treatment of choice.

Phillips et al.[18] performed a retrospective review in 48 patients with documented pseudarthrosis following ACDF. Thirty-two patients (67%) were symptomatic and 26 underwent a revision procedure. Only 22 patients completed the minimal follow-up period of 12 months. Sixteen patients underwent an anterior revision with 88% achieving a successful fusion. Posterior revision surgery was performed in 6 patients, and solid arthrodesis was achieved in 100%. The authors did not compare clinical results between treatments; however, the 2 patients with nonunion in the anterior group remained symptomatic. All patients in whom solid fusion was achieved reported an excellent or good outcome based on Odom's criteria. Surgeon preference dictated treatment allocation, which introduced selection bias, and there was no reported statistical analysis. The authors did not comment on the superiority of 1 approach over the other but concluded that operative intervention for symptomatic nonunion leads to acceptable results.

Finally, Carreon and colleagues[5] compared the results in 27 patients who underwent anterior revision surgery to those in 93 patients who underwent a posterior approach for an anterior nonunion. Anterior revision included anterior plate stabilization and harvesting of iliac crest autograft, while the posterior approach involved posterior wiring, lateral mass fixation, or a combination of techniques. Nonunion necessitating another operation after the revision procedure occurred in 44% of patients in the anterior group and only 2% of those in the posterior group. The complication rates were 4 and 8% in the anterior and posterior groups, respectively. Data regarding clinical outcome were not reported. The authors concluded that the posterior approach was more effective for treating an anterior nonunion. The validity of this conclusion was questionable, however, given the lack of clinical data and patient randomization between treatment groups. The surgeon selected the anterior approach for cases involving a neurological deficit or kyphotic deformity, introducing significant selection bias. There was no statistical analysis.

Summary

Retrospective case series that are limited due to selection bias, use of nonvalidated clinical measures, subjective radiographic evaluations, reporting bias, and insufficient statistical analysis appear to form the basis of the current opinion regarding the presentation and treatment of anterior cervical pseudarthrosis. The authors of these studies suggest an association between poor clinical outcome and the presence of a pseudarthrosis. Many patients who have undergone operative intervention for pseudarthrosis and ultimately obtained a solid arthrodesis have demonstrated clinical improvement. However, current studies have not been able to determine the prognostic factors that would indicate a favorable outcome. Reoperative anterior and posterior approaches appear to be viable surgical alternatives. Valid conclusions regarding the superiority of one approach over another are debatable; however, the limited data suggests that the posterior approach may have a greater potential for solid arthrodesis and clinical improvement.

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References

1. Angevine PD, Arons RR, McCormick PC: National and regional rates and variation of cervical discectomy with and without anterior fusion, 1990-1999. **Spine 28:**931–939, 2003
2. Bohlman HH, Emery SE, Goodfellow DB, Jones PK: Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. Long-term follow-up of one hundred and twenty-two patients. **J Bone Joint Surg Am 75:**1298–1307, 1993
3. Brodsky AE, Khalil MA, Sassard WR, Newman BP: Repair of symptomatic pseudarthrosis of anterior cervical fusion. Posterior versus anterior repair. **Spine 17:**1137–1143, 1992
4. Brunton FJ, Wilkinson JA, Wise KS, Simonis RB: Cine radiography in cervical spondylosis as a means of determining the level for anterior fusion. **J Bone Joint Surg Br 64:**399–404, 1982
5. Carreon L, Glassman SD, Campbell MJ: Treatment of anterior cervical pseudarthrosis: posterior fusion versus anterior revision. **Spine J 6:**154–156, 2006
6. Connolly ES, Seymour RJ, Adams JE: Clinical evaluation of anterior cervical fusion for degenerative cervical disc disease. **J Neurosurg 23:**431–437, 1965
7. Coric D, Branch CL Jr, Jenkins JD: Revision of anterior cervical pseudarthrosis with anterior allograft fusion and plating. **J Neurosurg 86:**969–974, 1997
8. De Palma AF, Cooke AJ: Results of anterior interbody fusion of the cervical spine. **Clin Orthop Relat Res 60:**169–185, 1968
9. Farey ID, McAfee PC, Davis RF, Long DM: Pseudarthrosis of the cervical spine after anterior arthrodesis. Treatment by

posterior nerve-root decompression, stabilization, and arthrodesis. **J Bone Joint Surg Am 72:**1171–1177, 1990
10. Fuji T, Yonenobu K, Fujiwara K, Yamashita K, Ono K, Okada K: Interspinous wiring without bone grafting for nonunion or delayed union following anterior spinal fusion of the cervical spine. **Spine 11:**982–987, 1986
11. Kaiser MG, Haid RW Jr, Subach BR, Barnes B, Rodts GE Jr: Anterior cervical plating enhances arthrodesis after discectomy and fusion with cortical allograft. **Neurosurgery 50:** 229–236, 2002
12. Kuhns CA, Geck MJ, Wang JC, Delamarter RB: An outcomes analysis of the treatment of cervical pseudarthrosis with posterior fusion. **Spine 30:**2424–2429, 2005
13. Lindsey RW, Newhouse KE, Leach J, Murphy MJ: Nonunion following two-level anterior cervical discectomy and fusion. **Clin Orthop Relat Res 223:**155–163, 1987
14. Lowery GL, Swank ML, McDonough RF: Surgical revision for failed anterior cervical fusions. Articular pillar plating or anterior revision? **Spine 20:**2436–2441, 1995
15. Martin GJ Jr, Haid RW Jr, MacMillan M, Rodts GE Jr, Berkman R: Anterior cervical discectomy with freeze-dried fibula allograft. Overview of 317 cases and literature review. **Spine 24:**852–858, 1999
16. Neo M, Fujibayashi S, Yoshida M, Nakamura T: Spinous process plate fixation as a salvage operation for failed anterior cervical fusion. Technical note. **J Neurosurg Spine 4:**78–81, 2006
17. Newman M: The outcome of pseudarthrosis after cervical anterior fusion. **Spine 18:**2380–2382, 1993
18. Phillips FM, Carlson G, Emery SE, Bohlman HH: Anterior cervical pseudarthrosis. Natural history and treatment. **Spine 22:**1585–1589, 1997
19. Prolo DJ, Oklund SA, Butcher M: Toward uniformity in evaluating results of lumbar spine operations. A paradigm applied to posterior lumbar interbody fusions. **Spine 11:**601–606, 1986
20. Riley LH Jr, Robinson RA, Johnson KA, Walker AE: The results of anterior interbody fusion of the cervical spine. Review of ninety-three consecutive cases. **J Neurosurg 30:**127–133, 1969
21. Shinomiya K, Okamoto A, Kamikozuru M, Furuya K, Yamaura I: An analysis of failures in primary cervical anterior spinal cord decompression and fusion. **J Spinal Disord 6:**277–288, 1993
22. Siambanes D, Miz GS: Treatment of symptomatic anterior cervical nonunion using the Rogers interspinous wiring technique. **Am J Orthop 27:**792–796, 1998
23. Tribus CB, Corteen DP, Zdeblick TA: The efficacy of anterior cervical plating in the management of symptomatic pseudarthrosis of the cervical spine. **Spine 24:**860–864, 1999
24. Wang JC, McDonough PW, Endow KK, Delamarter RB: Increased fusion rates with cervical plating for two-level anterior cervical discectomy and fusion. **Spine 25:**41–45, 2000
25. Wang JC, McDonough PW, Kanim LE, Endow KK, Delamarter RB: Increased fusion rates with cervical plating for three-level anterior cervical discectomy and fusion. **Spine 26:** 643–646, 2001
26. White AA III, Southwick WO, Deponte RJ, Gainor JW, Hardy R: Relief of pain by anterior cervical-spine fusion for spondylosis. A report of sixty-five patients. **J Bone Joint Surg Am 55:** 525–534, 1973
27. Zdeblick TA, Hughes SS, Riew KD, Bohlman HH: Failed anterior cervical discectomy and arthrodesis. Analysis and treatment of thirty-five patients. **J Bone Joint Surg Am 79:** 523–532, 1997

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