

## Radiographic assessment of cervical subaxial fusion

MICHAEL G. KAISER, M.D.,<sup>1</sup> PRAVEEN V. MUMMANENI, M.D.,<sup>2</sup> PAUL G. MATZ, M.D.,<sup>3</sup> PAUL A. ANDERSON, M.D.,<sup>4</sup> MICHAEL W. GROFF, M.D.,<sup>5</sup> ROBERT F. HEARY, M.D.,<sup>6</sup> LANGSTON T. HOLLY, M.D.,<sup>7</sup> TIMOTHY C. RYKEN, M.D.,<sup>8</sup> TANVIR F. CHOUDHRI, M.D.,<sup>9</sup> EDWARD J. VRESILOVIC, M.D., PH.D.,<sup>10</sup> AND DANIEL K. RESNICK, M.D.<sup>11</sup>

<sup>1</sup>Department of Neurological Surgery, Neurological Institute, Columbia University, New York, New York; <sup>2</sup>Department of Neurosurgery, University of California at San Francisco, California; <sup>3</sup>Division of Neurological Surgery, University of Alabama, Birmingham, Alabama; Departments of <sup>4</sup>Orthopaedic Surgery and <sup>11</sup>Neurological Surgery, University of Wisconsin, Madison, Wisconsin; <sup>5</sup>Department of Neurosurgery, Harvard Medical School and Beth Israel Deaconess Medical Center, Boston, Massachusetts; <sup>6</sup>Department of Neurosurgery, University of Medicine and Dentistry of New Jersey—New Jersey Medical School, Newark, New Jersey; <sup>7</sup>Division of Neurosurgery, David Geffen School of Medicine, University of California at Los Angeles, California; <sup>8</sup>Department of Neurosurgery, University of Iowa Hospitals and Clinics, Iowa City, Iowa; <sup>9</sup>Department of Neurosurgery, Mount Sinai School of Medicine, New York, New York; and <sup>10</sup>Department of Orthopaedic Surgery, Milton S. Hershey Medical Center, Pennsylvania State College of Medicine, Hershey, Pennsylvania

**Object.** The objective of this systematic review was to use evidence-based medicine to identify the best methodology for radiographic assessment of cervical subaxial fusion.

**Methods.** The National Library of Medicine and Cochrane Database were queried using MeSH headings and keywords relevant to cervical fusion. Abstracts were reviewed and 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.** Pseudarthrosis is best assessed through the absence of motion detected between the spinous processes on dynamic radiographs (Class II). The measurement of interspinous distance on dynamic radiographs of  $\geq 2$  mm is a more reliable indicator for pseudarthrosis than angular motion of  $2^\circ$  based on Cobb angle measurements (Class II). Similarly, it is also understood that the pseudarthrosis rate will increase as the threshold for allowable motion on dynamic radiographs decreases. The combination of interspinous distance measurements and identification of bone trabeculation is unreliable when performed by the treating surgeon (Class II). Identification of bone trabeculation on static radiographs should be considered a less reliable indicator of cervical arthrodesis than dynamic films (Class III).

**Conclusions.** Consideration should be given to dynamic radiographs and interspinous distance when assessing for pseudarthrosis. (DOI: 10.3171/2009.3.SPINE08719)

**KEY WORDS** • cervical spine • fusion • practice guidelines • radiography • treatment outcome

### Recommendations

It is recommended that interpretation of radiographs obtained for the purpose of diagnosing a pseudarthrosis be performed in a blinded fashion because the combination of interspinous distance measurements and evaluation of bone trabeculation is unreliable when performed by the treating surgeon (quality of evidence, Class II; strength of recommendation, C).

It is recommended that the absence of motion de-

*Abbreviations used in this paper:* ROC = receiver operating characteristic; RS = roentgen stereophotogrammetry; VB = vertebral body.

ted between the spinous processes on dynamic radiographs be used to exclude pseudarthrosis and that the measurement of interspinous distance on dynamic radiographs of  $\geq 2$  mm be used as a more reliable indicator of pseudarthrosis than angular motion of  $2^\circ$  based on Cobb angle measurements (quality of evidence, Class II; strength of recommendation, B). Similarly, it is also understood that the pseudarthrosis rate will increase as the threshold for allowable motion on dynamic radiographs decreases (quality of evidence, Class III; strength of recommendation, D).

Identification of bone trabeculation on static radiographs should be considered a less reliable indicator of

cervical arthrodesis than dynamic films (quality of evidence, Class III; strength of recommendation, D). If the practitioner desires to base clinical decisions on the extent of bone trabeculation, it is recommended that 2D reformatted CT scans be considered to increase the accuracy of identification (quality of evidence, Class III; strength of recommendation, D).

There is insufficient evidence to recommend the use of MR imaging or other imaging techniques in the evaluation of the cervical spine for pseudarthrosis (quality of evidence, Class III; strength of recommendation, D).

### Rationale

Neurosurgeons and orthopedists commonly perform cervical fusions in an effort to treat degenerative spine disease. In addition to assessment of neurological outcome, surgeons often use the presence or absence of a solid arthrodesis as a measure of operative success. Although definitive data correlating clinical outcome to successful arthrodesis is lacking, there are reports indicating a possible relationship and that patients improve after revision surgery of a failed fusion.<sup>10,14,21,23</sup> Therefore, it is useful to be able to diagnose with accuracy the presence or absence of a solid arthrodesis after cervical fusion—particularly in patients with pseudarthrosis symptoms.

### Search Criteria

We undertook a computerized search of the National Library of Medicine and Cochrane databases between 1966 and 2007 using keywords and the MeSH search terms “cervical spine fusion assessment,” “cervical spine pseudarthrosis,” and “cervical spine fusion outcome.” The search was limited to the English language and human subjects. The search yielded a total of 1161 citations. We reviewed the titles and abstracts of each of these references, and selected studies concerning the diagnostic potential of an imaging technique in the assessment of cervical fusion or the diagnosis of pseudarthrosis. We culled additional articles from the bibliographies of selected manuscripts. The total yield was 22 manuscripts that provided either direct or supporting data regarding the diagnostic potential of various imaging modalities. The manuscripts we identified dealt with the subaxial spine; the craniocervical junction is a unique region requiring alternative methods and was not studied in this systematic review.

In keeping with prior surgical guidelines, a 3-class system for assessment of evidence was used (Class I–III).<sup>16</sup> Class I evidence evolved from well-designed randomized controlled trials. Class II evidence arose from randomized controlled trials with design problems or well-designed cohort studies. Class III evidence arose from case series or poorly designed cohort studies. We concluded that expert opinion and case reports did not add significantly to the evidence used for the formulation of recommendations and should not be separately classified. All studies containing at least Class III medical evidence are listed in Table 1. A complete list of the manuscripts chosen from the search is contained in the *References*.

### Scientific Foundation

The gold standard for cervical fusion assessment is difficult to establish. Variation in imaging techniques and definitions of successful arthrodesis has generated a significant degree of uncertainty as to the most accurate diagnostic technique. For practical and ethical reasons, surgical exploration has not been universally applied to the diagnosis of pseudarthrosis or validation of an imaging technique. The lack of a true gold standard has created design limitations in studies attempting to document the accuracy and reliability of any radiographic technique used to evaluate cervical fusion.

Published series describing the surgical correction of symptomatic pseudarthrosis fail to confirm the accuracy of these diagnostic techniques for the following reasons: 1) failure to define the radiographic criteria for pseudarthrosis; 2) failure to comment on observations made during the revision surgery; 3) selection of only those patients who presented with symptomatic pseudarthrosis, thereby generating selection bias; and 4) approaching the surgical correction from the contralateral side of the initial surgery, such as a posterior approach for a failed anterior fusion.<sup>2,4,5,7,10,12–14,21,23</sup> This final point, in contrast to many lumbar revision series, makes it frequently impossible to observe the site of suspected non-union directly.

### Image Interpretation

The evaluation of a diagnostic test is prone to bias when the physician who administered treatment and evaluated the response to therapy performs the interpretation. Under most circumstances, the treating surgeon performs the interpretation of postsurgical radiographs. Therefore, greater potential exists for a prejudiced radiographic evaluation.

Skolasky and colleagues<sup>19</sup> performed a multicenter prospective cohort study to investigate the degree of concordance between the treating surgeon's findings and those of an independent panel in evaluating postoperative images for fusion status, and the impact that clinical outcome, as interpreted by the surgeon, had on this agreement. The study group consisted of 181 patients from 23 centers who underwent single-level anterior cervical fusion. The study blinded the independent panel of 2 orthopedic surgeons and 1 neurosurgeon to the patient's clinical status and the treating surgeon's assessment. The presence of bridging trabeculae bone and lack of spinous process motion on dynamic radiographs formed the basis for the interpretation of fusion. Intraclass correlation coefficient determined agreement among the independent reviewers and between the panel and treating surgeon. A threshold value of 0.80 indicated acceptable reliability between evaluators.<sup>18</sup> The agreement between the independent reviewers was reliable with intraclass correlation coefficient values of 0.892 and 0.884 at 3 and 6 months, respectively. Poor overall concordance was evident between the surgeon and the independent panel: 0.358 at 3 months and 0.308 at 6 months. The agreement was significantly lower if the surgeon considered the patient to demonstrate clinical success regarding medical, neu-

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rological, and functional status. These results confirmed the authors' hypothesis that the treating surgeon is less stringent in review of the radiographs, particularly if the patient has demonstrated clinical improvement. This medical evidence was considered Class II, demonstrating how the treating physician's radiographic evaluation of a fusion may be unreliable. However, when applied in a blinded fashion, the combination of bridging bone trabeculae and interspinous distance measurements may be considered reliable markers of fusion.

### *Plain Radiography*

Traditionally, clinicians have used plain radiographs to evaluate patients after cervical fusion surgery. From a practical perspective, this technique is easy to reproduce, affordable, and poses little risk to the patient. A variety of criteria have been presented in the literature to define the presence of an arthrodesis; these include bridging bone trabeculae across the graft-host interface and the absence of motion on dynamic radiographs.<sup>7,8,14,21,23</sup> The authors of several studies have investigated the accuracy of these fusion definitions as well as their reliability.

Tuli et al.<sup>22</sup> investigated the reliability of plain radiographs to predict the status of an arthrodesis utilizing an established definition of fusion from the literature. The study abandoned definitions dependent on the accuracy of an instrument, such as degree of motion or kyphosis. The reliability and consistency of bone trabeculae bridging the graft interface was tested as a measure of successful arthrodesis. Two neuroradiologists blinded to clinical outcome and each other's interpretations evaluated anteroposterior and lateral radiographs obtained in 57 patients 6 and 12 weeks after either single or multilevel corpectomies. Agreement between the 2 neuroradiologists was determined using the Cohen kappa statistic. At 6 weeks, the degree of agreement was 0.61 (95% CI 0.32–0.89) and 0.44 (95% CI 0.017–0.86) for the superior and inferior interfaces, respectively. The result at 12 weeks for the superior interface was 0.18 (95% CI –0.21–0.58) and for the inferior interface was 1.00. The authors concluded that the reliability in predicting the presence or absence of bridging bone trabeculae was variable and rated poor to fair. Although considered Class III evidence, this study suggests that the ability to assess bone trabeculation, a commonly used criteria for successful arthrodesis, is an unreliable radiographic measure.

Cannada et al.<sup>3</sup> performed a retrospective review comparing the accuracy and reliability of Cobb angle measurements to interspinous process distance on flexion and extension radiographs. The study included 27 patients with either a "known" anterior fusion or pseudarthrosis for analysis. The authors defined a definitive fusion as mature, remodeled bony trabeculae bridging the disc space that was unequivocally solid. The study defined pseudarthrosis as either radiographic evidence of lucency in the area intended for fusion with motion on dynamic imaging or excessive motion observed during revision surgery. Fewer than half of pseudarthrosis cases were confirmed with operative exploration. Three independent physicians, blinded to the fusion status and clinical outcome, evaluated the radiographs. The interobserv-

er reliability was 0.95 for spinous process measurements, and 0.74 for the Cobb angle method. In determining the presence of a pseudarthrosis, the Pearson correlation was 0.77 ( $p < 0.001$ ) when using  $> 2$  mm of motion with interspinous process measurements, and only 0.28 ( $p > 0.10$ ) when using  $2^\circ$  of angular motion with Cobb angle measurements. Using the same criteria, the sensitivity and specificity for spinous process measurements were 91 and 89%, respectively, and only 82 and 39% with Cobb angle measurements. The authors also calculated the ROCs and found greater reliability with spinous process measurements, with an ROC of 0.98 compared to 0.66 for Cobb angle measurements. The authors concluded that measuring the distance between the spinous processes was more accurate than Cobb angle measurements. These data are considered Class II because the gold standard for fusion assessment was not universally applied, making it impossible to determine the accuracy of these measurements.

In an attempt to establish standard measurements for fusion assessment, Sudhakar et al.<sup>20</sup> evaluated changes in the anterior VB height, interspinous distance, and intervertebral angle between adjacent VBs on dynamic radiographs in patients who underwent anterior cervical discectomy without fusion and with the insertion of a biocompatible polymer. The authors assumed a solid arthrodesis if there was no change in any of the 3 measurements. All 3 indices accurately predicted pseudarthrosis, each demonstrating a 100% negative predictive value, but only intervertebral angle predicted fusion 100% of the time. Only 55% of patients presumed to have a solid arthrodesis were considered appropriate for follow-up. There was no control group to confirm the authors' fusion assumptions, and they did not indicate whether the reviewers of the radiographs were independent or blinded to either the procedure or the clinical results. The medical evidence was considered Class III because of the study design limitations.

To demonstrate the effect that motion threshold would have on the predicted rate of pseudarthrosis, Hipp et al.<sup>9</sup> retrospectively reviewed the imaging results in 200 patients who underwent anterior cervical fusion with plate stabilization. There was no indication that the reviewers were blinded to either the procedure or outcome, no control group was included, and no correlation to clinical outcome was made. The results demonstrated an increased pseudarthrosis rate, from 6 to 44%, when the motion threshold used to define a pseudarthrosis was decreased from  $4$  to  $1^\circ$ . Although the authors point out that the degree of intervertebral motion is important to defining a pseudarthrosis, the clinical significance of this measure is poorly understood. The authors emphasized the importance of defining a standard measure for pseudarthrosis, recognizing limitations imposed by the measurement technique when utilizing plain radiographs. The study does not provide adequate evidence to establish a standard and is therefore considered Class III evidence.

### *Computed Tomography Scanning*

The enhanced definition of bone on CT scans has made this imaging modality a popular technique for eval-

**TABLE 1: Evidentiary summary of studies regarding radiographic assessment of cervical fusion\***

Authors & Year	Class	Description of Study	Comments
Tuli et al., 2004	III	Prospective evaluation to determine the reliability of static radiographs in predicting fusion of 57 patients following cervical corpectomies & fusion w/ fibular allograft & anterior plate stabilization. Radiographic evaluation was performed by 2 independent neurologists blinded to each other's & the clinical results. The definition of fusion, presence of bone trabeculae crossing the graft-host interface, was based on a review of the literature. The degree of agreement at 6 wks was 0.61 (95% CI 0.32-0.89) & 0.44 (95% CI 0.017-0.86) at the superior & inferior interfaces respectively. At 12 wks the agreement at the superior aspect was 0.18 (95% CI -0.21 to 0.58) & for the inferior aspect 1.00. This study gave Class III evidence that the utilization of bone trabeculation, as a radiographic criterion for fusion, is unreliable.	There was no control group to assess the reliability of the radiologists. The presence or absence of fusion in the study population was not established w/ a gold standard test.
Hipp et al., 2005	III	Retrospective review of radiographs from 200 patients who underwent anterior cervical fusions to document the effect that motion threshold would have on apparent pseudarthrosis rate. Digitized radiographs were evaluated w/ software validated to measure intervertebral motion to within 0.5° of rotation & 0.5 mm of translation. No explanation is provided regarding the identity or characteristic of individuals reviewing the images. The apparent pseudarthrosis rate increased from 6 to 44% when the motion threshold decreased from 4 to 1°. The authors concluded that the apparent nonunion rate is highly dependent on the threshold level of motion used to define a pseudarthrosis. This study provided Class III evidence that the pseudarthrosis rate will increase as the motion threshold is decreased.	This study failed to define the characteristics of the individuals reviewing the imaging studies. It is impossible to determine the appropriate threshold of motion based on the data provided.
Cannada et al., 2003	II	Retrospective review to compare the accuracy of Cobb angle versus ISD in identifying a pseudarthrosis following anterior cervical fusion. The radiographs from 27 patients were evaluated by 3 independent physicians blinded to the radiographic & clinical outcome. Interobserver reliability, measured by Cronbach's alpha, for spinous process measurements was 0.95 & 0.74 w/ the Cobb angle method. The Pearson correlation between nonunion & spinous process method was 0.77 (p < 0.001) & 0.28 for the Cobb method (p > 0.10). The specificity & sensitivity for determining pseudarthrosis was 89 & 91%, respectively for the spinous process method, & only 39 & 82% for the Cobb method. The ROCs curve was 0.98 for spinous process method & only 0.66 for Cobb method. The authors concluded that measuring ISD is more accurate than Cobb angles in order to diagnosis pseudarthrosis. This study provided Class II evidence that the accuracy of measuring interspinous process distance is more reliable the Cobb angle measurements when evaluating for cervical pseudarthrosis.	The study was a retrospective review of a narrow spectrum of patients w/ a suspected condition; however, radiographs were evaluated in a prospective fashion. The study failed to establish the presence or absence of a pseudarthrosis w/ a gold standard diagnostic measure for all patients.
Skolasky et al., 2006	II	Prospective multicenter cohort study to determine agreement between independent reviewer & operating surgeon on radiographic assessment of fusion & the influence of patient's status on this agreement. The operating surgeon & 3 independent reviewers, blinded to clinical outcome & surgeon's assessment, evaluated flexion-extension radiographs obtained in 181 patients. Agreement between the independent panel & surgeon occurred in only 54% of cases, generating a value of 0.308 from a random-rater intraclass correlation coefficient calculation, consistent w/ poor overall concordance. The surgeon was more likely to report fusion than the independent panel when the patient demonstrated improved clinical outcome. This study provided Class II evidence that the combination of bone trabeculation & interspinous motion is a reliable indicator of fusion when applied in a blinded fashion however, evaluation by the operating surgeon is suspect & biased by the patients' clinical outcome.	The study failed to establish the diagnosis w/ a gold standard test. The authors performed appropriate controls to account for interobserver variability. An adequate number of evaluations were performed to generate the study results.
Epstein & Silvergleide, 2003	III	Prospective cohort study to investigate the accuracy of 2D CT compared to plain radiographs in assessing fusion following single level anterior cervical corpectomy. 2 radiologists, blinded to their previous & the other's evaluation, assessed the images from 46 patients at 3 & 6 mos following surgery. 83% of the radiographs were read as fused compared to 50% of CT scans at 3 months. At 6 mos 96% of radiographs & 70% of CT scans were interpreted as fused. The authors concluded that CT scans w/ 2D reconstructions were more accurate to assess fusion. This study provided Class III evidence that CT scanning will predict a higher pseudarthrosis rate than radiographs.	It is impossible to determine accuracy of these tests because the presence of fusion was not established w/ a gold standard. It is not clear whether radiologists were blinded to clinical outcome. The reliability of the observers was not determined w/ repeated measures.

(continued)

**TABLE 1: Evidentiary summary of studies regarding radiographic assessment of cervical fusion\* (continued)**

Authors & Year	Class	Description of Study	Comments
Ploumis et al., 2006	III	Prospective cohort study comparing the pseudarthrosis rate estimated by flexion & extension radiographs w/ 2D CT scans. 47 patients were evaluated 1 yr after cervical fusion by 4 independent, blinded reviewers. The average fusion rate assessed by CT was 74% compared to 81% for plain radiographs. A greater degree of uncertainty was associated w/ evaluation of the plain radiographs. Consistency was greater when evaluating CT scans, 89%, compared to plain radiographs, 81%. This study provided Class III evidence that the reliability to assess pseudarthrosis is greater w/ CT scanning than w/ radiographs.	The study failed to describe how the interpreters were "blinded." Consistency of observers was not determined w/ repeated measures.
Albert et al., 1993	III	A preliminary study that prospectively evaluated the changes to fusion mass on serial MRIs taken during the first 6 mos after anterior cervical fusion. A total of 26 MRIs in 7 patients were evaluated by a neuroradiologist & orthopedic surgeon. The graft demonstrated a hyperintense signal on T1-weighted images that decreased over 6 mos but remained hyperintense to the VBs. On T2-weighted images the graft demonstrated greater heterogeneity but was primarily isointense to the VBs. This study provides Class III evidence describing the changes in signal characteristics on MRI as a cervical interbody graft matures.	This is simply a descriptive study, characterizing changes on MRIs as a cervical graft matures. The reviewers were not blinded & no comparison was made to control group.
Coric et al., 1997	III	Retrospective review of 19 patients treated for pseudarthrosis through an anterior approach. In 8 patients screening radiographs were not conclusive, therefore, patients underwent SPECT scan. Increased uptake was identified in all patients at the level of suspected nonunion which was confirmed during the revision procedure. No evaluation of accuracy was performed. This study provides Class III evidence that SPECT scanning may provide useful information when attempting to diagnosis a cervical pseudarthrosis.	This was a descriptive cases series. It is impossible to determine the accuracy or reliability of SPECT scanning when diagnosing a pseudarthrosis.

\* 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*. Abbreviation: ISD = interspinous distance.

uating spinal fusion, particularly when 2D reformatted images are included.<sup>6,8,17</sup> The general acceptance that CT imaging is superior to plain radiography has made this radiographic technique the unsubstantiated gold standard for the assessment of fusion status. The authors of several studies have compared the utility of CT imaging to other radiographic techniques.

Epstein et al.<sup>6</sup> compared CT images with plain radiographs with dynamic views from 46 single-level anterior cervical corpectomies obtained 3 and 6 months after surgery. Two radiologists blinded to their previous evaluation as well as the other radiologist's interpretations evaluated the images. The criteria for successful arthrodesis included the presence of bone trabeculae across the graft-host interface and the lack of motion between spinous processes (< 1 mm) and translation between VBs. At 3 months postoperatively, the authors reported fusion in 38 (83%) of the 46 plain radiographs, whereas only 23 (50%) of 46 CT images confirmed solid arthrodesis. By 6 months, the study considered 44 (96%) of 46 radiographs to demonstrate fusion, but only 32 (70%) of 46 CT images. All patients diagnosed with a failed fusion on plain radiography were also considered to be in the nonfusion group as demonstrated on CT images. The authors concluded that 2D CT was more accurate than plain radiography with dynamic views, and that CT imaging should be included when evaluating for pseudarthrosis. This was considered Class III evidence because the authors assumed that CT provided unquestionable data regarding fusion status without an appropriate control group.

Ploumis and colleagues<sup>15</sup> prospectively compared the pseudarthrosis rates between dynamic radiographs and 2D reformatted CT images in 47 patients undergoing anterior cervical fusion. The authors selected patients whether or not they presented with a clinically significant pseudarthrosis. Four blinded reviewers, including 2 surgeons, a neuroradiologist, and a postgraduate spine fellow, evaluated the images. The average percentage of images documented as showing fusion was 81% for plain radiographs and 74% for CT scans. Interobserver consistency was greater with CT images (average 89%). On plain radiographs, successful agreement between the reviewers occurred on average only 81% of the time. The same reviewer was more likely to consider the spine fused when evaluating plain radiographs compared to CT scans. Given the inability to compare radiographic results with direct observations, it is impossible to determine the sensitivity and specificity of each technique. This study is considered Class III medical evidence.

### Magnetic Resonance Imaging

Few studies have documented the utility of MR images in assessing bone fusion. In addition to the inferior bone detail compared with CT images, MR images are subject to artifact produced by spinal instrumentation. Given the extent to which instrumentation is now applied when attempting cervical fusion, MR images appear to be at a distinct disadvantage in the assessment of cervical fusion.

Albert et al.<sup>1</sup> described the changes in MR imaging signal characteristics in a prospective and longitudinal

fashion in patients undergoing anterior cervical fusions following discectomy. The authors obtained a total of 26 MR images in 7 patients at 1, 3, and 6 months after anterior cervical fusion. The authors stated that, based on CT and plan radiographic examinations, no patient was believed to have a pseudarthrosis. However, they did not note the time at which the arthrodesis occurred. The study noted a general pattern of changes in graft signal postoperatively over a 6-month period. Hyperintense signal was demonstrated on T1-weighted images immediately after surgery, decreasing over time but remaining hyperintense to surrounding VBs. A heterogeneous graft signal was noted on T2-weighted images that varied from iso- to hyperintense compared to surrounding VBs. The authors speculated that the changing signal represented alterations in the content of "fatty marrow" within the graft. The authors commented that no image demonstrated complete loss of graft delineation and that imaging characteristics predictive of fusion would require further investigation. Because the study simply described imaging characteristics of an evolving fusion, it was considered Class III.

#### *Other Imaging Techniques*

Roentgen stereophotogrammetry is a radiographic technique used to calculate the translational and angular movements of a VB by tracking implanted metallic markers. Utilizing a pair of orthogonally oriented radiographic tubes, biplanar images, anteroposterior, and lateral views, are obtained in the neutral position as well as maximal flexion and extension. A direct linear relationship is established between the 2D coordinates of the metallic markers and its position in 3D space by the mathematical algorithm of direct linear transformation. Limitations of this technique include the technical difficulty, the amount of radiation exposure, and the potential for overestimating linear transformations. Although angular motions are not dependent on the position of the markers, translational movements may be altered depending on where the marker is positioned within the rigid body being studied. In addition, standards demonstrating clinically and radiographically significant motions are lacking.

Roentgen stereophotogrammetry was originally described to define spinal motions after lumbar arthrodesis. The application of this method in the cervical spine has been limited. Lee et al.<sup>11</sup> applied this technique to define the fusion process and cervical motion after 2 cervical stabilization procedures. These authors performed *in vitro* evaluations of this model, but failed to validate the technique *in vivo* for cervical application. One patient underwent a posterior atlantoaxial fusion with placement of iliac crest autograft and sublaminar wires while the second patient underwent an anterior cervical discectomy and fusion with plate stabilization. Three Vitallium beads were inserted into each VB of interest at the time of surgery. The authors performed RS at 3, 6, and 12 months postoperatively. In both cases, the authors reported that RS was more sensitive than dynamic radiography in detecting both angular and translational motion; the surgeries in both patients were considered clinical successes. This limited study was considered Class III evidence that suggested the feasibility of RS; however, it was impos-

sible to determine its efficacy. The invasive nature of the technique also limits its utility.

Coric et al.<sup>5</sup> described their experience in the treatment of 19 patients with symptomatic pseudarthrosis via an anterior approach with interbody allograft and plate stabilization. Radiographically, the study confirmed pseudarthrosis using a variety of modalities including dynamic radiographs, CT myelography, and MR imaging. In 8 patients, plain radiographs were inconclusive; therefore, these patients underwent SPECT. Focal uptake was present in all patients at the level of the suspected pseudarthrosis. During the anterior revision surgery, a pseudarthrosis was confirmed in all patients suspected of having one who underwent SPECT scanning. The authors theorized that SPECT scanning may have been useful to confirm the presence of a nonunion but acknowledged its limitations as a screening tool and the necessity to document the natural history of a developing arthrodesis on SPECT images. From a diagnostic perspective, this evidence in support of the use of SPECT scanning was considered Class III.

#### **Summary**

The evaluation of any diagnostic test requires the acceptance of a gold standard to confirm the test's validity. For both ethical and practical reasons, this is not possible after cervical fusion surgery because exploration to confirm arthrodesis is considered the gold standard. There are a limited number of studies investigating the diagnostic potential of the more common imaging techniques used to assess fusion status after cervical surgery. To date, there is no standardized radiographic method to confirm the presence of a solid arthrodesis. Evidence suggests that dynamic plain radiographs are more reliable than static images; however, this point holds true only when evaluated the radiographs are evaluated by an individual blinded to the patient's clinical status. A standard amount of motion required to confirm the diagnosis of a pseudarthrosis is lacking. Furthermore, the possibility of solid instrumentation masking a pseudarthrosis may exist when dynamic radiographs are used in this setting. Evidence-based recommendations are only as strong as the studies underlying them. In this review, the shortcomings are 2-fold. First, there is no definitive clinical study or method that defines fusion and therefore no consensus as to which is the best imaging study to use to affirm the presence of fusion or pseudarthrosis. The second shortcoming is the ability of anterior fixation to mask a pseudarthrosis if dynamic radiographs are used for diagnosis.

Computed tomography scanning compares favorably to dynamic plain radiography with evidence to suggest increased sensitivity and specificity for defining bone trabeculations. No study has definitively supported this claim, however. Although other methods exist, they tend to be less practical and more invasive than plain radiography and CT.

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Address correspondence to: Paul G. Matz, M.D., Neurosurgery and Neurology, LLC, 232 South Woods Mill Road, Chesterfield, Missouri 63017. email: matzpg@yahoo.com.