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Preoperative patient selection with magnetic resonance imaging, computed tomography, and electroencephalography: does the test predict outcome after cervical surgery?

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Object. The objective of this systematic review was to use evidence-based medicine to assess whether preoperative imaging or electromyography (EMG) predicts surgical outcomes in patients undergoing cervical surgery.

Methods. The National Library of Medicine and Cochrane Database were queried using MeSH headings and keywords relevant to the preoperative imaging and EMG. 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. Preoperative MR imaging and CT myelography are successful in confirming clinical radiculopathy (Class II). Multilevel T2 hyperintensity, T1 focal hypointensity combined with T2 focal hyperintensity, and spinal cord atrophy each convey a poor prognosis (Class III). There is conflicting data concerning whether focal T2 hyperintensity or cervical stenosis are associated with a worse outcome. Electromyography has mixed utility in predicting outcome (Class III).

Conclusions. Magnetic resonance imaging or CT myelography are important for preoperative assessment. Magnetic resonance imaging may be helpful in assessing prognosis, whereas EMG has mixed utility in assessing outcome. *(DOI: 10.3171/2009.3.SPINE08717)*

Key Words • **cervical spine** • **computed tomography** • **electromyography** • **magnetic resonance** • **practice guidelines** • **treatment outcome**

Recommendations

The use of preoperative MR imaging or CT myelography to confirm a compressive lesion in the setting of clinical cervical radiculopathy or myelopathy is recommended prior to elective cervical spine surgery (level of evidence, Class II; strength of recommendation, C).

It is recommended that patients be informed that hyperintensity at multiple levels in the cervical cord on preoperative T2-weighted MR images may predict a poor surgical outcome (quality of evidence, Class III; strength of recommendation, D).

It is recommended that patients be informed that preoperative MR imaging T1 hypointensity combined with T2 hyperintensity at the same level in the cervical cord may predict a poor surgical outcome (quality of evidence, Class III; strength of recommendation, D). There is conflicting Class III evidence of whether T2 hyperintensity alone at a single level predicts poor outcome.

It is recommended that patients with spinal cord atrophy (transverse area < 45 mm^2) be informed that this

Abbreviations used in this paper: ACCF = anterior cervical corpectomy with fusion; ACD = anterior cervical discectomy; ACDF = ACD with fusion; CDH = cervical disc herniation; CSM = cervical spondylotic myelopathy; EMG = electromyography; JOA = Japanese Orthopaedic Association; mJOA = modified JOA; OPLL = ossification of the posterior longitudinal ligament.

degree of atrophy may predict worse outcome (quality of evidence, Class III; strength of recommendation, D). There is conflicting Class III evidence whether the degree of canal stenosis predicts outcome.

It is recommended that preoperative EMG be used to evaluate the central and peripheral nervous system in patients with atypical or unusual symptoms or in those whose symptoms are multifactorial. However, the practitioner must be aware that EMG has poor sensitivity in detecting cervical radiculopathy, and its utility is mixed in predicting surgical outcome after surgery for cervical spine decompression (quality of evidence, Class III; strength of recommendation, D).

Rationale

The purpose of this evidence-based review is to summarize the prognostic significance of CT myelography, MR imaging, and EMG as diagnostic studies and predictors of outcome in patients undergoing surgery for cervical radiculopathy and myelopathy. Clinicians have long used radiographic imaging with CT myelography and/or MR imaging to assess the presence and extent of cervical nerve root and spinal cord compression. Similarly, clinicians have used EMG testing as a diagnostic tool to assess whether clinical symptoms are associated with cervical nerve root dysfunction or whether they are associated with an extraspinal cause such as peripheral nerve compression. The question arises whether these preoperative tests might predict or enhance surgical outcome.

Search Criteria

We completed a computerized search of the National Library of Medicine and the Cochrane database between 1966 and 2007. The search headings included the following terms: "Computed Tomography and Cervical Spine Surgery (1423 articles)," "Magnetic Resonance Imaging and Cervical Spine Surgery (1631 articles)," "Electromyography and Cervical Spine Surgery (103 articles)," "Radiographic Predictors and Cervical Spine Surgery (6 articles)," "Predictors of Outcome and Cervical Spine Surgery (19 articles)." These search terms yielded 3182 citations. The Cochrane database yielded 1 study regarding surgical outcome of cervical myeloradiculopathy.

Of these citations, we used only those in the English language and reviewed the abstracts along with selected applicable articles. We reviewed the references cited in the qualifying articles to cull any other applicable citations. The final list of applicable manuscripts was assembled into evidentiary tables (Tables 1–4). The tables reflect the types of prognostic questions.

Scientific Foundation

Electroencephalography, MR Imaging, and CT Myelography as Diagnostic Tools (Table 1)

Ashkan et al.2 retrospectively compared the accuracy of preoperative MR imaging and EMG in identifying cervical nerve root compression causing radiculopathy in 45 patients. They also examined the ability of these tests to predict outcomes after cervical decompression surgery. All patients presumably underwent posterior cervical foraminotomies to assess nerve root compression (although that is not specifically stated in the article). The authors found that the sensitivity of MR imaging to identifying cervical nerve root compression was 93% compared with only 42% for EMG. The positive predictive values for MR imaging and EMG were similar (91 vs 86%, respectively). However, MR imaging had a higher negative predictive value (25%) than EMG (only 7%). In 56% of cases, the EMG findings were not consistent with cervical radiculopathy; however, in all cases, cervical foraminal compression causing radiculopathy was accurately diagnosed on MR imaging and improved after decompression. This study included all patients. Because the authors assessed the presence of pathological nerve root compression after radiographic study interpretation and correlated it in an unbiased fashion, this study was graded Class II.

Alrawi et al.[1] prospectively investigated whether preoperative EMG could predict improvement after ACDF for radiculopathy in 20 patients. All of these patients reportedly had borderline surgical findings on preoperative CT myelography and MR imaging. The authors found that patients with preoperative EMG findings confirming radiculopathy had a better postoperative Prolo score than those without such findings ($p = 0.001$). This study was graded Class III because of its use of the Prolo scale, a nonvalidated outcome measure, and the use of unblinded reviewers for outcome measurement and patient selection.

Negrin et al.[25] reviewed a series of 26 patients (23 with CSM and 3 with CDH) who underwent preoperative CT myelography and EMG. They reported that compressive lesions evident on CT myelography correlated with EMG findings in 77% of cases. Fifteen patients with CSM and all patients with CDH underwent surgery (3 patients had Cloward ACDF and the rest received ACD without fusion). The authors concluded that preoperative EMG was not predictive of clinical outcome after cervical surgery. Standardized outcome measures were not reported in this series, making it Class III.

Outcome and Spinal Cord Hypointensity on T1-Weighted MR Images (Table 2)

Several studies found a negative relationship between the presence of T1 hypointensity/T2 hyperintensity and clinical outcome. Chibbaro et al.[5] reported on a series of 70 patients with CSM who underwent ACCF using titanium mesh cages filled with iliac crest and covered with cervical plates. At a mean follow-up of 42 months, the authors found that patients with hypointensity on preoperative T1-weighted images had lower postoperative mJOA scores ($p < 0.05$). In contrast, those with hyperintensity on preoperative T2-weighted images had higher postoperative mJOA scores ($p < 0.01$). This study was graded Class III because outcome reviewers were not blinded and due to possible bias in patient selection.

In a more recent article, Fernandez de Rota and colleagues[8] reported a series of 67 patients with myelopathy

TABLE 1: Evidentiary summary of articles studying preoperative MR imaging, CT, and EMG & functional outcome from surgery for cervical degenerative disease

Authors & Year	Class	Summary	Comments
Ashkan et al., 2002	II	45 patients w/ clinical cervical radiculopathy underwent surgical decompression. Patients underwent preop MRI & EMG.	The presence & improvement after surgery were correlated w/ preop findings. MRI had a higher sensitivity to nerve compression (92%) vs 42% for EMG.
Alrawi et al., 2007	III	20 patients w/ cervical radiculopathy & borderline findings on CT myelogram or MRI. EMG completed preoperatively. All underwent surgery.	Improved function on Prolo scale correlated w/ preop EMG abnormality ($p = 0.001$).
Negrin et al., 1991	III	26 patients underwent CT myelography & EMG. 18 patients underwent surgery.	CT myelogram abnormality correlated w/ EMG abnormality 77% of time. 18 patients who underwent surgery did not have outcomes that correlated w/ EMG abnormalities.

who underwent surgery: 43 underwent ACCF, 13 underwent ACDF, and 11 underwent laminoplasty. Patients were evaluated at a mean follow-up of 39 months using mJOA scale scores. The authors found that preoperative T1 hypointensities predicted poor prognosis after surgery. Furthermore, multisegmental T2 hyperintensity predicted a poor outcome ($p < 0.01$). However, single-segment, preoperative T2 hyperintensity did not predict a poor outcome.[8] This study was graded Class III because it was uncertain whether outcome assessment was blinded and whether interrater reliability was performed.

Morio et al.[21] reported on a series of 73 patients, 42 with CSM and 31 with OPLL, who underwent a mean 3.4-years of follow-up after laminoplasty. This retrospective study used regression analysis to show that patients with preoperative spinal cord T1 hypointensity and T2 hyperintensity had significantly more inferior outcomes after surgery than those who had T2 spinal cord hyperintensity only ($p = 0.026$). They also reported that the transverse cord area did not correlate with outcome.[21] This study was graded Class III because of the nonblinded allocation of groups and nonblinding outcome assessors. No interrater reliability was recorded for image viewing.

Suri et al.[31] reported a on prospective series of 146 patients with CSM: 109 underwent ACDF, 12 underwent ACCF, and 25 underwent either laminectomy or laminoplasty. The authors found that patients with preoperative spinal cord T1 hypointensity and T2 hyperintensity had the worst outcomes ($p < 0.001$). In contrast, patients with no preoperative cervical spinal cord signal changes on MR imaging and those with T2-weighted cord hyperintensity only had the best outcomes (no difference between these 2 groups).[31] This study was graded Class III because of the biased allocation of treatments and the uncertainty regarding blinding of outcome assessors.

Outcome and Hyperintensity on T2-Weighted Images (Table 3)

The issue of spinal cord hyperintensity on T2-weighted images was examined in multiple studies. These studies examined the prognosis of preoperative T2 hyperintensity at 1 level and also at multiple levels. Furthermore, a few studies examined the prognosis of postoperative resolution of T2 hyperintensity.

In the studies on T1 hypointensity above, Chibbaro et al.,[5] Fernandez de Rota et al.,[8] Morio et al.,[21] and Suri et al.[31] all discussed the prognosis of T2 hyperintensity as

TABLE 2: Evidentiary summary of articles studying preoperative MR imaging and T1 hypointensity for outcome after surgery for cervical degenerative disease

Authors & Year	Class	Summary	Comments
Chibbaro et al., 2006	III	70 patients w/ CSM underwent anterior surgery. Mean FU of 42 mos. Outcomes using JOA & compared w/ MRI.	Patients w/ T1 hypointensity had lower JOA scores ($p < 0.05$); patients w/ T2 hyperintensity had higher postop JOA scores ($p < 0.01$).
de Rota et al., 2007	III	67 patients w/ CSM followed up after surgery w/ mJOA scores. Mean FU of 39 mos correlated to MRI findings.	Multi-segmental T2 hyperintensity predicted poor outcome ($p < 0.01$) but single segment T2 hyperintensity not predictive. T1 hypointensity predictive of poor outcome.
Morio et al., 2001	III	73 patients (42 CSM, 31 OPLL) followed up after laminoplasty for 3.4 yrs. Regression used to correlate T1 hypointensity & T2 hyperintensity w/ outcome.	T1 hypointensity + T2 hyperintensity was associated w/ significantly worse outcomes compared to T2 hyperintensity alone ($p < 0.03$). Transverse area not associated w/ outcome.
Suri et al., 2003	III	146 CSM patients (121 anterior surgeries, 25 posterior surgeries). Compared outcomes w/ MRI findings.	No signal changes or T2 hyperintensity did better than those w/ T1 hypointensity/T2 hyperintensity together ($p < 0.001$).

TABLE 3: Evidentiary summary of articles studying preoperative MR imaging and hyperintensity on T2-weighted images and outcome after surgery for cervical degenerative disease*

Authors & Year	Class	Summary	Comments
Chen et al., 2001	III	64 patients w/ CSM underwent posterior decompression. Outcomes assessed w/ JOA scores & correlated to T2 signal on MRI.	Patients w/ T2 hyperintensity on MRI had a worse surgical outcome.
Chibbaro et al., 2006	III	70 patients w/ CSM underwent anterior surgery. Mean FU of 42 mos. Outcomes using JOA & compared to MRI.	Patients w/ T1 hypointensity had lower JOA scores ($p < 0.05$); patients w/ T2 hyperintensity had higher postop JOA scores ($p < 0.01$).
Chiles et al., 1999	III	76 patients w/ CSM underwent anterior surgery. Outcomes on JOA correlated to MRI findings.	Cord atrophy was associated w/ lower mJOA ($p < 0.01$); T2 hyperintensity trended toward lower mJOA score as well (p = NS).
Choi et al., 2005	III	47 patients w/ CSM/OPLL had preoperative MRI. Mean FU of 16 mos using Nurick scores.	T2 hyperintensity "snake eyes" appearance was not correlated w/ outcomes but trended to a good prognosis.
Fernandez de Rota et al., 2007	III	67 patients w/ CSM followed up after surgery w/ mJOA scores. Mean FU of 39 mos correlated to MRI findings.	Multisegmental T2 hyperintensity predicted poor outcome ($p < 0.01$) but single-segment T2 hyperintensity not predictive. T1 hypointensity predictive of poor outcome.
Houten & Cooper, 2003	III	38 patients CSM & OPLL underwent laminectomy & fusion. Patients followed up using the Cooper scale. Correlated w/ MRI.	No correlation of outcomes w/ T2 signal changes on MRI.
Huang et al., 2003	III	32 patients w/ CSM/OPLL underwent laminectomy & fusion. Outcome using Nurick correlated w/ MRI.	T2 hyperintensity on MRI did not appear to have prognostic value for outcome.
Koyanagi et al., 1998	III	42 patients w/ OPLL underwent decompressive surgery (anterior & posterior).	Patients w/ T2 hyperintensity had worse preop neurological deficits but did not necessarily have poor surgical prognosis.
Matsuda et al., 1991	III	29 patients: 12 w/ CDH, 16 w/ CSM, & 1 w/ OPLL. Patients treated w/ anterior surgery after MRI & evaluated w/ JOA scores.	Preop & postop T2 hyperintensity had worse JOA scores ($p < 0.05$). If T2 hyperintensity resolved, patients had better clinical improvement.
Matsuyama et al., 2004	III	44 patients w/ OPLL underwent laminoplasty. Patients evaluated w/ MRI. Outcome followed up w/ JOA scores.	Patients w/ triangular spinal shape of spinal cord (all of whom had T2 hyperintensity) had poorer recovery (no statistical analysis).
Mehalic et al., 1990	III	19 patients w/ CSM, 17 of these had preop MRI & had laminectomies w/ fusion.	Resolution of T2 hyperintensity was correlated w/ better w/ recovery than persistent T2 hyperintensity.
Mizuno et al., 2003	III	144 patients (82 CSM, 62 OPLL). 79 patients had T2 hyperintensity w/ 21/79 w/ snake eyes. All patients underwent anterior cervical surgery.	"Snake eye" appearance on T2 MRI was an unfavorable prognostic indicator ($p < 0.01$).
Morio et al.,1994	III	25 patients (8 CDH, 7 OPLL, 10 CSM) who underwent surgical decompression & were followed w/ JOA scores.	No correlation between T2 hyperintensity preoperatively & outcome.
Morio et al., 2001	III	73 patients (42 CSM, 31 OPLL) followed after laminoplasty for 3.4 yrs. Regression used to correlate T1 hypointensity & T2 hyperintensity w/ outcome.	T1 hypointensity & T2 hyperintensity was associated w/ significantly worse outcomes compared to T2 hyperintensity alone ($p < 0.03$). Transverse area not associated w/ outcome.
Naderi et al., 1998	III	27 CSM patients underwent laminectomies w/o fusion & were followed up w/ mJOA. Preop MRI (78%), CT (48%), & CT myelogram (15%).	T2 hyperintensity trended toward worse outcomes (p = NS). Loss of cervical lordosis correlated w/ worse outcome ($p < 0.001$).
Okada et al., 1993	III	74 patients (34 CSM, 23 OPLL, 17 CDH). Anterior surgery in 20 & posterior in 54.	Transverse area of cord on T1 MRI was correlated w/ recovery rate in patients w/ OPLL & CSM but not CDH ($p < 0.01$). T2 hyperintensity preop correlated w/ recovery as well ($p < 0.01$).
Papadopoulos et al., 2004	III	42 patients w/ CSM (18 laminectomies + fusion, 7 ACF, 17 combined). MRI correlation undertaken between outcome & T2 hyperintensity.	Preop T2 hyperintensity over ≥2 segments predicted a poor prognosis ($p < 0.001$).

(continued)

TABLE 3: Evidentiary summary of articles studying preoperative MR imaging and hyperintensity on T2-weighted images and outcome after surgery for cervical degenerative disease* *(continued)*

Authors & Year	Class	Summary	Comments
Park et al., 2006	III	80 patients (61 CSM, 11 OPLL, 8 CDH). 46 had anterior surgery & 34 laminoplasty. Outcomes assessed using Neurosurgical cervical spine score.	Best recovery seen in those w/ no preoperative T2 hyperintensity. Single-segment T2 hyperintensity had modest recovery & multisegment had worst recovery ($p < 0.02$). Resolution of hyperintensity correlated w/ improved recovery ($p < 0.001$).
Singh et al., 2001	III	69 CSM patients of whom 35 underwent anterior surgery & 34 underwent posterior surgery. Outcomes assessed using MDI & Nurick & Ranawat scores.	More levels of T2 hyperintensity correlated w/ greater recovery using Nurick walking scales ($p = 0.005$).
Suri et al., 2003	III	146 CSM patients (121 anterior surgeries, 25 posterior surgeries). Compared outcomes w/ MRI findings.	No signal changes or T2 hyperintensity did better than those w/ T1 hypointensity/T2 hyperintensity together ($p < 0.001$).
Takahashi et al., 1989	III	668 patients, 31 had decompressive surgery (type unknown). Outcomes compared w/ MRI findings.	Those w/out preop T2 hyperintensity had best outcome ($p < 0.05$).
Wada et al., 1995	III	31 CSM patients underwent laminoplasty. Patients evaluated w/ preop MRI & postop CT myelography. Outcomes correlated w/ JOA.	Preop T2 hyperintensity did not correlate w/ outcome.
Wada et al., 1999	III	50 patients w/ cervical myelopathy who had preop MRI & CT myelography. All patients had laminoplasty & outcome compared w/ JOA.	Recovery from surgery correlated w/ maximal compression of transverse cord w/ >40 mm^2 offering better prognosis. T2 hyperintensity correlated w/ poor recovery.
Yone et al., 1992	III	109 patients (45 OPLL, 64 CSM); 87 underwent laminoplasty & 22 CSM patients had anterior surgery. Outcomes by JOA & compared w/ MRI findings.	No correlation was seen between spinal cord diameter & outcome. No correlation observed between T2 hyperintensity & outcome.

* ACF = anterior cervical fusion; MDI = Myelopathy Disability Index.

well with each study providing Class III evidence. Each study noted that T2 hyperintensity at a single segment did not necessarily portend a poor outcome. In the studies of Morio and Suri et al., the prognosis with T2 hyperintensity appeared to be poor only when it was associated with T1 hypointensity. In the Fernandez de Rota[8] study, multilevel T2 hyperintensity or T1 hypointensity togethers with T2 hyperintensity forecast a worse outcome.

Chen et al.[4] reported on a series of 64 patients with CSM who underwent posterior cervical decompression (presumed to be laminectomy or laminoplasty, but not specifically stated).[4] The outcomes were assessed using JOA scores with independent, blinded reviewers. They found that patients with preoperative, well-defined hyperintensity on T2-weighted images had a significantly worse surgical outcomes ($p = 0.001$). This study was scored Class III because of concerns over selection bias. The types of surgeries were not stated, which leads to uncertainty regarding inclusion criteria.

Chiles et al.[6] reported a series of 76 patients with cervical disc herniation or CSM who underwent ACDF. Patients with preoperative hyperintensity on T2 MR imaging trended to a lower postoperative mJOA score, but this was not statistically significant ($p = 0.14$).[6] However, they found that patients with spinal cord atrophy preoperatively had lower postoperative mJOA scores ($p < 0.01$). This study was scored Class III since it was not evident whether outcome assessors were blinded and whether interrater reliability was established on films. Since the study was retrospective, selection bias in whom to enroll also played a role.

Choi and colleagues[7] reported on a series of 47 myelopathic patients with OPLL who underwent ACCF. Although it was not specifically stated in the article, it appears that all of these patients underwent preoperative CT and MR imaging. The mean follow-up period was 16 months, and Nurick grades were used for assessment. The authors reported that hyperintensity on preoperative T2-weighted MR images in a "snake eyes" pattern did not correlate with clinical outcome. They also noted that the finding of snake eyes—a symmetrical, round, high-signal intramedullary axial T2 hyperintensity—trended to a good prognosis, albeit not statistically significant. This study was graded Class III because of the nonvalidated outcome measure and the lack of blinding to those measuring outcomes and grading MR images.

Houten and Cooper[11] reported on 38 patients with myelopathy (76% with CSM, 18% with OPLL, and 5% with both) who underwent laminectomies and fusion. The patients were followed up for a mean of 30.2 months using the Cooper scale. They authors reported no correlation of outcomes with hyperintensity on preoperative T2-weighted MR images. This study was graded Class III because it lacked a validated outcome measure.

Huang et al.[12] reported on 32 patients (28 with CSM and 4 with OPLL) who underwent laminectomy and fusion. They reported a mean follow-up of 15 months using Nurick scores. These authors found that abnormal hyperintensity on T2-weighted images carried no prognostic value but this result was not statistically significant ($p = 0.64$). This study was graded Class III because it lacked

a validated outcome measure and did not use unblinded reviewers.

Koyanagi and associates[14] reported on a series of 42 patients with OPLL. Twenty-six patients underwent ACCF with iliac crest grafts, 6 underwent laminectomy, and 10 underwent laminoplasty. These authors reported a concordance between preoperative MR imaging findings and prognosis but did not provide any statistical analysis. They further reported that preoperative hyperintensity on T2-weighted images did not indicate a poor functional prognosis, although patients with preoperative T2 hyperintensity had worse preoperative neurological deficits. This study was graded Class III because of the lack of statistical analysis and nonblinded measurement of outcomes.

Matsuda et al.[16] reported on 29 patients (12 with CDH, 16 with CSM, and 1 with OPLL). Patients underwent anterior surgery with either ACDF (in 19 patients) or ACCF (in 10 patients) and underwent evaluation with the JOA scale. The authors reported that patients with preoperative T2 cord hyperintensity had worse pre- and postoperative JOA scale scores ($p < 0.05$). Furthermore, if the T2 hyperintensity resolved on the postoperative MR images, patients had a trend to better clinical improvement. This study was graded Class III because of patient selection, lack of blinded assessors, and lack of standardized surgical interventions.

Matsuyama et al.[18] reported on a series of 44 patients with OPLL who underwent laminoplasty. The authors used preoperative MR imaging to assess the cross-sectional area and shape of the spinal cord. Postoperatively, patients were clinically evaluated using JOA scale scores. The authors reported that patients with a "triangular shape" of the spinal canal (all of whom had preoperative T2 hyperintensity) had the worst recovery rate. No statistical analysis was provided. This study was graded Class III due to lack of statistical analysis.

Mehalic et al.[19] reported on 19 patients with CSM–17 of whom underwent preoperative MR imaging and 2 of whom underwent preoperative CT myelography. Seventeen patients underwent laminectomies without fusion while 2 underwent ACDF. The authors reported that the patients with postoperative resolution of T2 hyperintensity had better recovery than those with persistent T2 hyperintensity. This study was graded Class III because it lacked standardized outcome measures.

Mizuno et al.[20] reported on a series of 144 patients (82 with CSM and 62 with OPLL). One hundred forty-one patients had myelopathy, and 79 of them had spinal cord hyperintensity on T2-weighted images. Of the 79 with preoperative T2 hyperintensity, in 21 there was a "snake eyes" appearance. All patients underwent either ACCF or ACDF with titanium cages without plate fixation. The authors discovered that the snake eyes appearance on preoperative T2-weighted images was an unfavorable prognostic indicator ($p < 0.01$).[20] This study was scored Class III because it lacked blinded outcome assessment.

Morio et al.[22] reported on a series of 25 patients with myelopathy (8 with CDH, 7 with OPLL, and 10 with CSM) and conducted follow-up with JOA scale scores. The authors used a variety of approaches including ACDF, ACCF, and laminoplasty in the treatment of these patients. There was no statistically significant correlation between cord hyperintensity on T2-weighted MR images and outcome. This study was graded Class III because of the heterogeneous patient population and the variety of treatments and the use of unblinded outcome and MR imaging assessors.

Naderi et al.[23] reported on a series of 27 patients with CSM who underwent laminectomy. They conducted follow-up in these patients using mJOA scale scores. Seventy-eight percent of patients underwent preoperative MR imaging, 48% had preoperative CT, and 15% had preoperative CT myelography. The authors found that preoperative cord hyperintensity on T2-weighted images trended toward worse outcome; however, this finding was not statistically significant. Loss of cervical lordosis preoperatively, however, did predict worse outcome ($p < 0.001$).[23] This study was graded Class III due to nonblinded allocation with different patients receiving different diagnostic studies. Interrater reliability was not assessed, and it was unclear whether outcome assessors were blinded.

Okada et al.[26] reported on a series of 74 patients (34 with CSM, 23 with OPLL, and 17 with CDH). The specific surgical procedure used was not stated in this paper, but 20 patients underwent anterior cervical surgery and 54 underwent posterior cervical surgery. The authors reported that preoperative cord hyperintensity on T2-weighted MR images significantly correlated with recovery rates in patients with CSM and OPLL but not in those with CDH ($p < 0.01$).[26] This study was graded Class III because of the lack of detail regarding treatment. It was uncertain with interrater reliability was tested and whether radiographic assessment was done in a blinded fashion.

Papadopoulos et al.[27] reported on a series of 42 patients with CSM. In this series, they used several different surgical approaches including laminectomies and fusion in 18 patients, ACCF in 7, and combined anterior/posterior decompression with fusion in 17. The authors found that preoperative hyperintensity on T2-weighted MR images in ≥ 2 segments of the cervical cord predicted a poor prognosis after surgery ($p < 0.0.001$).[27] This study was graded Class III because of the different treatments undertaken and the lack of interrater reliability for outcome assessment. In addition, it was not evident whether the outcome assessors were blinded.

Park and associates[28] reported on a series of 80 patients: 61 with CSM, 11 with OPLL, and 8 with CDH. In this series, 36 were underwent ACDF, 10 ACCF, and 34 received laminoplasty. The authors assessed outcomes using the Neurosurgical Cervical Spine Scale. The authors found that patients without any hyperintensity on preoperative T2-weighted images had the best recovery. Patients with 1 segment of spinal cord hyperintensity on T2-weighted images had modest postoperative neurological recovery. Patients with > 1 segment of spinal cord hyperintensity on T2-weighted images had the worst recovery rate ($p = 0.018$). The authors also found that if the hyperintense signal resolved after surgery then the patients had an improved neurological recovery ($p < 0.001$). This study was graded Class III because it was not evident whether radiographic assessors were blinded to

TABLE 4: Evidentiary summary of articles studying degree of canal stenosis and/or spinal cord area and outcome after surgery for cervical degenerative disease*

Authors & Year	Class	Summary	Comments
Bucciero et al., 1993	III	35 patients w/ CSM w/ high T2 signal on MRI. Compared APCR with outcome.	APCR > 15% improved w/ surgical decompression whereas < 10% did not improve w/ surgery.
Chiles et al., 1999	III	76 patients w/ CSM underwent anterior surgery. Outcomes on JOA correlated to MRI findings.	Cord atrophy was associated w/ lower mJOA ($p < 0.01$); T2 hyperintensity trended toward lower mJOA score as well (not significant).
Fujiwara et al., 1989	III	50 patients w/ cervical myelopathy due to CDH, OPLL, CSM on CT myelography treated w/ surgery.	Predictive factors for outcome were transverse area of cord > 30 mm^2 for OPLL & CDH ($p < 0.01$). For CSM, trend better if transverse area > 30 mm^2.
Fukushima et al., 1991	III	55 patients (CDH, OPLL, CSM) underwent CT myelography & MRI. All patients underwent laminoplasty. Evaluated by JOA scores.	Preop spinal cord area < 0.45 cm^2 on MRI had JOA outcomes that were worse ($p < 0.01$).
Kasai & Uchida, 2001	III	128 CSM patients underwent laminoplasty. Outcomes were evaluated using JOA. AP compression assessed on MRI.	Preop MRI compression was reliable predictor for outcome.
Koyanagi et al., 1993	III	103 patients w/ CSM (44), OPLL (39), CDH (20) evaluated w/ CT myelography. Outcome compared to transverse area of cord.	CSM & OPLL improvement correlated w/ transverse area of cord ($p < 0.01$); not true for CDH.
Matsuyama et al., 2004	III	44 patients w/ OPLL underwent laminoplasty. Patients evaluated w/ MRI. Outcome followed w/ JOA scores.	Patients w/ triangular spinal shape of spinal cord (all of whom had T2 hyperintensity) had poorer recovery (no statistical analysis).
Matsuyama et al., 1995	III	44 patients (26 CSM & 18 OPLL) underwent laminoplasty. Compression ratio calculated as (sagittal diameter × 100)/transverse diameter.	Relationship established between cord cross-sectional area & recovery rate w/ 28% compression ratio being the critical point.
Morio et al., 2001	III	73 patients (42 CSM, 31 OPLL) followed after laminoplasty for 3.4 yrs. Regression used to correlate T1 hypointensity & T2 hyperintensity w/ outcome.	T1 hypointensity + T2 hyperintensity was associated w/ significantly worse outcomes compared to T2 hyperintensity alone ($p < 0.03$). Transverse area not associated w/ outcome.
Nagata et al., 1996	III	51 CSM patients w/ MRI T1 sequences evaluated (44 anterior surgeries, 7 posterior surgeries). Cord compression stratified into I (slight), II (<1/3), III (>1/3).	Outcome using JOA correlated w/ degree of compression. Class I had better scores than Class II or III.
Okada et al., 1993	III	74 patients (34 CSM, 23 OPLL, 17 CDH). Anterior surgery (20) & posterior (54).	Transverse area of cord on T1-weighted MRI was correlated w/ recovery rate in patients w/ OPLL & CSM but not CDH ($p < 0.01$). T2 hyperintensity preop correlated w/ recovery as well ($p < 0.01$).
Satomi et al., 2001	III	204 patients (106 OPLL, 88 CSM, 10 CDH) followed for 5 yrs after laminoplasty. Outcomes assessed w/ JOA.	Preop spinal canal diameter did not correlate w/ outcome. It was unclear whether the preop spinal canal diameter was measured by plain radiographs or MRI.
Wada et al., 1999	III	50 patients w/ cervical myelopathy had preop MRI & CT myelography. All patients had laminoplasty & outcome compared to JOA.	Recovery from surgery correlated w/ maximal compression of transverse cord w/ > 40 mm^2 offering better prognosis. T2 hyperintensity correlated w/ poor recovery.
Yamazaki et al., 2003	III	64 CSM patients divided into 2 groups by age (older or younger than 65 yrs). All underwent laminoplasty. Preop CT myelography & MRI. Outcomes measured w/ JOA scale scores.	Transverse area of cord > 30 mm^2 predicted better outcome in both age groups. T2 hyperintensity did not predict poor outcome in younger patients; trend toward predicting poor outcome in older patients but not significant.

* APCR = anteroposterior compression ratio.

functional/clinical outcomes. It was also not evident that interrater reliability was tested.

Singh et al.[30] reported on a series of 69 patients with CSM. Of this group, 35 patients underwent ACDF, 21 underwent laminoplasty, 11 underwent laminectomy without fusion, and 2 underwent laminectomy with fusion. The authors assessed outcomes using the Myelopathy Disability Index, Nurick Functional Walking, and Ranawat scores. The authors paradoxically found that more levels of cord hyperintensity on T2-weighted images predicted better recovery with surgery as measured with the Nurick Functional Walking and the Myelopathy Disability Index ($p = 0.005$). This study was graded Class III because outcome measures were not all validated. It was also uncertain whether radiographic outcome assessors were blinded to clinical outcome and whether interrater reliability was tested.

Takahashi et al.[32] reported on a series of 668 patients. Only 31 underwent "decompressive surgery" (specific type of surgery was not discussed). Of this group, those without preoperative T2 cord hyperintensity had the best outcomes ($p < 0.05$). This was graded Class III because of the selection bias (31 of 668) and the lack of treatment specifics.

Wada and coworkers[33] reported on a retrospective series of 31 patients with CSM who underwent laminoplasty. The authors evaluated patients with preoperative MR imaging and postoperative CT myelography. The study assessed outcomes using JOA scale scores. The authors found that preoperative T2 hyperintensity did not correlate with outcome. This study was considered Class III because of selection bias of patient cohort.

Wada et al.[34] reported on a series of 85 patients, but only 50 patients underwent preoperative MR imaging or CT myelography. All patients underwent laminoplasty and were followed up using JOA scale scores. The authors reported that T2 hyperintensity in the cervical spinal cord correlated poorly with the recovery rate. This study was graded Class III because of selection bias since analysis was done on 50 patients of 85. Furthermore, it was not clear whether the radiographic and outcome assessors were blinded.

Yamazaki and colleagues[35] reported on 64 patients divided into 2 groups according to age older or younger than 65 years. The authors evaluated patients using CT myelography and MR imaging. Spinal cord hyperintensity on preoperative T2-weighted images did not predict outcome in the younger age group, but it did tend to predict worse outcome in patients older than 65 years of age, although this finding did not reach statistical significance. This study was graded Class III because of selection bias, as the JOA scale scores in the older group were lower. There were also significant sex differences between the groups.

Yone et al.[36] reported on a series of 109 patients with cervical stenosis (45 with OPLL and 64 with CSM). A detailed review of the article revealed that all patients with OPLL underwent laminoplasty, and 42 of the 64 patients with CSM also underwent laminoplasty. The remaining 22 patients with CSM underwent ACDF or ACCF. The study assessed outcomes using JOA scale scores. No correlations were found between surgical outcomes and preoperative cord hyperintensity on T2-weighted images or cord diameter. This study was graded Class III due to nonblinding of outcome assessors. It was also not certain whether all patients with pathological cervical stenosis were included.

The relationship between hyperintensity on T2-weighted images and outcome is complex. There was conflicting Class III data regarding discrete T2 hyperintensity in the cervical spinal cord and outcome. The authors of several studies indicated that the presence of T2 hyperintensity portended a poor outcome while several other Class III studies did not corroborate this relationship. For multisegmental T2 hyperintensity, the authors of 3 Class III studies appeared to establish a negative relationship to outcome, whereas 1 study did not support this conclusion. Finally, 3 Class III studies indicated that postoperative resolution of T2 hyperintensity correlated with improved outcome.

Spinal Canal Stenosis, Spinal Cord Atrophy, and Outcome

Bucciero et al.[3] reported on a series of 35 patients with CSM all of whom had T2 hyperintensity on MR imaging. All patients underwent surgery with either multilevel ACDF or ACCF. They found that an anteroposterior compression ratio (ratio of the anteroposterior diameter to the transverse diameter) of ≥ 15% improved with surgery while those with anteroposterior compression ratio ≤ 10% remained unchanged with surgery. Three patients had postoperative resolution of T2 signal changes. This study was graded Class III because the outcome measure was not validated or tested for reliability and because outcome assessors were not blinded.

Chiles et al.[6] reported on a series of 76 patients with CDH or CSM who underwent ACDF. With regard to spinal cord morphological characteristics, the authors found that patients with preoperative spinal cord atrophy had lower postoperative mJOA scale scores ($p < 0.01$). This study was scored Class III because it was not evident whether outcome assessors were blinded and whether interrater reliability was established on radiographs. Because the study was retrospective, bias in patient selection also played a role.

Fujiwara et al.[9] reported on a series of 50 patients with cervical myelopathy who underwent preoperative CT myelography and either anterior or posterior cervical surgery (ACCF, ACDF, laminoplasty, or laminectomy). In patients with CDH or OPLL, the most significant predictive factor for improved outcome was a preoperative transverse area of the spinal cord measuring > 30 mm^2 on CT myelography ($p < 0.01$). In patients with CSM, there was a trend to better outcome if the transverse cord area > 30 mm^2 on the preoperative CT myelogram, but this was not statistically significant. This study was graded Class III because it was uncertain if outcome assessment was blinded.

Fukushima et al.[10] reported on 55 patients (13 with CDH, 29 with CSM, and 13 with OPLL) who underwent preoperative MR imaging and CT myelography. All patients presumably underwent laminoplasty, although that was not explicitly stated. The length of follow-up was

not reported, and the JOA scale was used to evaluate outcomes. The authors found that patients with a preoperative spinal cord area < 0.45 cm^2 on MR imaging had worse outcomes in terms of JOA scale scores ($p < 0.01$). This study was graded Class III because the authors did not specify surgical approach, length of follow-up, and blinding of outcome assessors.

Kasai and Uchida[13] reported on 128 patients with CSM who underwent laminoplasty. The study assessed outcomes using JOA scale scores. These authors introduced a new system for scoring the degree of anterior and posterior compression on preoperative MR images. They found that compression on preoperative MR imaging was a highly reliable predictor of outcome ($p < 0.01$). This study was graded Class III because it used a new scoring system that had not yet been validated. The authors showed an association with the degree of compression and JOA scale scores, but did not undertake a formal validation study. It was also unclear whether the study used blinded outcome observers.

Koyanagi et al.[15] reported on a series of 44 patients with CSM, 39 with OPLL, and 20 with CDH who underwent preoperative CT myelography evaluation. In the patients with CSM and OPLL, the transverse area of the spinal cord predicted recovery ($p < 0.01$). Patients with CDH showed improvement regardless of the preoperative transverse area of the cord. This study was scored Class III because of the significant variation in disease presentation on diagnosis, leading to concerns about selection bias. In the treatment arms, surgical therapy varied and included laminoplasty, anterior surgery, and circumferential surgery, raising concerns over selection bias. It was not clear whether blinded outcome assessors were used.

Matsuyama et al.[17] reported on a series of 44 patients (26 CSM and 18 OPLL) who underwent laminoplasty. These patients had preoperative CT myelography from which a compression ratio was calculated (compression ratio = sagittal cord diameter × 100/ transverse diameter). The authors found no significant relationship between clinical recovery rate and the degree of cord compression noted on preoperative CT myelography. However, in posthoc subgroup analysis, the authors did find a significant correlation between preoperative cord cross-sectional area and recovery rate. A 28% compression ratio was determined to be the critical point differentiating worse outcomes. This study was graded Class III because observers were not necessarily blinded to JOA scale scores, and because of uncertainty regarding selection bias as to who was chosen for surgery.

Matsuyama et al.[18] also reported on a series of 44 patients with OPLL who underwent laminoplasty. The authors used preoperative MR images to assess the cross-sectional area and shape of the spinal cord. Postoperatively, the study evaluated patients with JOA scale scores. The authors reported that patients with a "triangular shape" of the spinal canal had the worst recovery rate. Incidentally, all of these patients had T2 hyperintensity in the cervical spinal cord. No statistical analysis was provided. This study was graded Class III because it lacked statistical analysis.

Nagata et al.[24] reported on a series of 51 patients with CSM who underwent preoperative T1-weighted MR imaging only (T2-weighted MR imaging sequences were not reported). In this series, 44 patients underwent ACDF or ACCF, and 7 underwent laminoplasty. The authors stratified patients into classes of preoperative cord compression. Those with Class I cord compression ("slightly compressed") had better postoperative JOA scale scores than those with Class II (< 1/3 of cord compressed) or Class III compression (> 1/3 of cord compressed). This finding was statistically significant ($p < 0.05$). This study was graded Class III because of the mix of treatments and the uncertainty regarding blinding of assessors. It was also not evident whether interrater reliability was tested.

Okada et al.[26] reported on a series of 74 patients (34 with CSM, 23 with OPLL, and 17 with CDH). The specific surgical procedure used was not stated, but 20 patients underwent anterior cervical surgery and 54 underwent posterior cervical surgery. The authors found that the transverse area of the cervical cord on preoperative T1-weighted MR images was significantly correlated with recovery rate in patients with OPLL and CSM but not in those with CDH ($p < 0.01$).[26] This study was graded Class III because of the lack of detail regarding treatment. It is unclear whether interrater reliability was tested or whether radiographic assessment was done in blinded fashion.

Satomi et al.[29] reported on a series of 204 patients (106 with OPLL, 88 with CSM, and 10 with CDH) who were followed up for 5 years after laminoplasty. The authors assessed outcomes using JOA scale scores. The authors reported that preoperative spinal canal diameter did not correlate with outcome. It was uncertain from the methodology whether the preoperative spinal canal diameter was measured via lateral radiographs or MR imaging. This study was graded Class III because only a subgroup of 80 patients was analyzed. This would have introduced bias. Furthermore, it was uncertain if outcome assessors were blinded.

Wada et al.[34] reported on a series of 85 patients with CSM, but preoperative MR imaging or CT myelography was performed in only 50 patients. All patients underwent laminoplasty and were followed up with JOA scale scores. The authors found that the recovery rate from surgery was correlated with a maximum compression of 40-mm^2 transverse cord area on preoperative MR imaging or CT myelography ($R = 0.584$). This study was graded Class III because of selection bias of reporting on 50 of 85 patients. Furthermore, it was not clear whether blinding of radiographic and outcome assessors was undertaken.

Yamazaki et al.[35] reported 64 patients with CSM divided into 2 groups (divided by age younger or older than 65 years). The authors evaluated patients using CT myelography and MR imaging. The measurement of spinal cord transverse area in both of these imaging methods was similar. In both age groups, the transverse area of the spinal cord predicted outcome. Patients with better outcomes (assessed using JOA scale scores) had transverse cord areas > 30 mm^2 on their preoperative imaging studies ($p = 0.042$ for patients younger than 65 years old and $p = 0.03$ for patients older 65 years). Cord hyperintensity

on T2-weighted images did not predict outcome in the younger age group, but it did tend to predict worse outcome in the older age group (not significant). This study was graded Class III because of selection bias–the JOA scale scores in the older group were lower, and there were also significant sex differences between groups.

Conventional wisdom would suggest that outcome would strongly correlate with spinal cord atrophy. This relationship was evident in 7 Class III studies in which low transverse cord areas were correlated with poor surgical outcome (range < 30–45 mm^2). The degree of canal stenosis was less predictable: 4 Class III studies indicated that the severity of canal stenosis correlated with poor outcome while the results of 2 Class III studies did not support this relationship.

Summary

Preoperative evaluation with EMG, CT myelography, and MR imaging has become commonplace prior to cervical spine surgery. The question arises: can these tests predict outcomes following cervical decompressive surgery? There is little evidence available on the utility of EMG for prediction of outcome after cervical surgery. Although EMG has been suggested to be a predictor of outcome in the lumbar spine, few studies have examined this issue in the cervical spine. There is conflicting Class III evidence suggesting that EMG may predict outcomes in cervical spine surgery, but more studies are needed to examine this issue in detail.

Radiographic imaging prior to advances in MR imaging was largely through myelography and CT myelography. Because MR imaging is noninvasive, it has largely supplanted CT myelography as the initial imaging study in the evaluation of cervical myelopathy and radiculopathy. Computed tomography myelography is often used when MR imaging is not possible or when additional diagnostic information is needed. There is Class II evidence that an MR imaging finding of nerve root compression when correlated with clinical symptoms of radiculopathy may predict outcome after cervical decompressive surgery.

With respect to prognostic significance of imaging results, there is Class III evidence that multisegmental high signal changes in the cervical cord on preoperative T2-weighted MR imaging evaluation predicts a poor outcome following cervical surgery. There is also Class III evidence that T1 hypointensity when combined with T2 hyperintensity predicts a worse outcome. Conflicting Class III data exists on the significance of focal cervical cord T2 hyperintensity. Some studies have shown focal T2 hyperintensity as a negative prognostic indicator while others have not. This is a shortcoming of the evidence-based approach and serves to remind the reader that evidence-based recommendations are only as strong as the studies which underlie them.

With regard to canal stenosis and cord atrophy, there is Class III evidence that restricted transverse spinal cord area on preoperative CT myelography or MR imaging may portend a poor surgical prognosis. There is conflicting Class III evidence on whether the degree and/or severity of stenosis may predict outcome.

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