Value of Intraoperative neurophysiological monitoring to reduce neurological complications in patients undergoing anterior cervical spine procedures for cervical spondylotic myelopathy: A systematic review

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Abstract:

Objective: The primary aim of this study is to conduct a systematic review of reports concerning patients with cervical spondylotic myelopathy to assess the value of intraoperative monitoring (IOM), such as SSEPs, TcMEPs, and EMG, in anterior cervical procedures.
Methods: A search strategy was first conducted in order to collect a small database of relevant papers using key words describing both disorders and procedures of interest. The database was then shortlisted using selection criteria and data from these finalized reports was extracted to identify complications as a result of anterior cervical procedures treating cervical spondylotic myelopathy for outcome analysis on a continuous scale.
Results: In the 22 studies that matched the screening criteria, only two involved the use of IOM. The 22 studies had an average of 173 patients. In studies with procedures done without IOM a mean change in JOA score of 3.94 points and a mean change in Nurick score by 1.20 points (both less severe post-op) were observed. Within our sub-group analysis, worsening myelopathy and/or quadriplegia had a mean outcome of 2.71% of cases for studies without IOM and a mean outcome of 0.91% of cases for studies with IOM.
Conclusions: Based on the review of published studies sufficient evidence does not exist to negate or reinforce the use of IOM in hopes of reducing neurological complications during anterior cervical procedures. There is no standardized evaluation method to measure these complications. In addition, the modalities used for IOM have not been overwhelmingly confirmed.

Key Words: Cervical spondylotic myelopathy, cervical degenerative myelopathy, anterior cervical discectomy fusion, anterior cervical interbody fusion, anterior cervical corpectomy, anterior cervical decompression

Introduction:

Anterior cervical spine decompression (ACD) represents one of the most common surgical treatments for cervical radiculopathy, radiculomyelopathy, and cervical spondylotic myelopathy (CSM)[1,2]. The procedure is associated with neurological complications such as worsening of myelopathy[3], cervical nerve root palsy [15,164,5], recurrent laryngeal nerve palsy (RLN) [3,6,7] and dysphagia [1,7]. Intraoperative neurophysiological monitoring (IOM) with somatosensory evoked potentials(SSEP) [2,8,9], transcranial motor evoked potentials(TcMEPs)[10], and electromyography(EMG)[9,11,12], have been used to reduce the risk of complications including myelopathy, C5 root palsy, and recurrent laryngeal nerve palsy (RLN)[13,14]. Significant intraoperative changes in latency and amplitude of SSEPs, and TcMEPs are generally used to alert the surgeon about impending neurological change, leading them to alter the surgical procedure in some cases[15,16]. However some studies have **not found** SSEPs[17,18] and or TcMEPs[19] to be useful during anterior cervical spine surgery. The efficacy of the above approach remains controversial and has not been universally accepted as a standard of care. Randomized controlled trials in these settings are believed to lead to significant ethical issues[20], however rigorous evaluation of surgical innovation is both achievable and necessary[21]. Our primary aim is to perform a systemic review of the published studies to

evaluate the value of intraoperative neurophysiological monitoring to reduce neurological deficits in patients who underwent ACD for CSM.

I. Methods:

A. Search Strategy:

We searched MEDLINE and the Web of Science, for studies through February 2013 on anterior cervical spine surgery for cervical spondylotic myelopathy and neurological complications irrespective of whether the studies used intraoperative neurophysiological monitoring. Our search was stratified into the condition, the procedure, where we used terms "cervical myelopathy", "cervical spondylotic myelopathy", "spondylotic myelopathy", and "cervical degenerative myelopathy" for the condition. We used the terms "anterior cervical discectomy fusion", "anterior cervical fusion", "anterior cervical interbody fusion", "anterior cervical corpectomy", "anterior cervical decompression fusion", and "anterior cervical discectomy" for the procedure.

B. Study Selection:

Studies were included if they 1] were randomized, cohort and observational studies, , 2] involved patients with cervical spondylotic myelopathy who underwent only anterior cervical spine procedures, 3] were conducted with and without the use of intraoperative neurophysiological monitoring, using SSEPs, TcMEPs, EMG, and 4] reported post-operative neurological deficits including but not limited to new onset paraparesis, paraplegia, worsening of myelopathy, deltoid weakness, dysphagia, dysphonia. Since we analyzed mean and standard deviation, studies that reported data using median and range could not be included. Studies where the reason for the procedure was failure of primary surgery, Infection, trauma, tumor, with no clear documentation on post-operative neurological complications were excluded. Studies that were primarily about technical reviews, review of procedures, and surveys were excluded. Studies published in languages other than English were excluded except those for which abstracts with results were available in English. Studies with number of patients less than 50 with CSM were excluded. Our search criteria as well inclusion and exclusion criteria was optimized to minimize bias common in observational studies[22].

Two reviewers (PDT and AM) screened all titles and abstracts independently to identify studies that met the inclusion criteria and extracted data. Each title and abstract was classified into a specific group based on the selection criteria. The included studies were pooled and reconciled between the authors. The second stage of data extraction from full text was also done independently and later reconciled.

C. Data Extraction:

The data was screened to see if a predetermined criterion was used to identify the complications of cervical spondylotic myelopathy in those who underwent anterior cervical

procedure, as this is the focus of the patient population in this study. The primary outcomes were weakness including worsening myelopathy, new onset weakness, paraparesis, and paraplegia. The secondary outcomes were cervical root palsy including deltoid weakness, dysphagia, and dysphonia from recurrent laryngeal nerve palsy. To evaluate the neurological complications, the studies were screened to identify if pre and postoperative documentation was provided. To further classify the severity of the neurological complications, we classified the deficits as transient or permanent. The mode of testing for confirmation of dysphonia and dysphagia was also evaluated. Finally the follow period of the study was noted. We tabulated the studies but did not provide quality assessment as there is no standard quality assessment tool for observational studies, and many of the tools that are available lack a rationale or are used improperly[23].

D. Data Analysis:

For binary measures of outcome, we extracted data on the number of events and total number of participants to calculate the proportions of patients affected by neurological complications in each study using Microsoft Excel 2007 ®, Microsoft Corporation WA. We used StatsDirect software (Stats Direct Ltd, Cheshire, UK) for random effects meta-analysis (inverse variance method) to generate a weighted average (from all the included studies) of the proportion of participants afflicted by neurological complications.

For outcome measures that were recorded on a continuous scale, we calculated the mean, SD, and the 95% confidence intervals for the neurological outcomes after the procedures.

II. Results:

A. Study Selection:

Our search yielded 1390 reports from the various databases of which 1283 reports were excluded on basis of title or abstract. The study selection process is summarized in the figure 1. Our review included 22 reports on patients who underwent anterior cervical procedure for cervical spondylotic myelopathy of which 2 reports had data on the use of intraoperative neurophysiological monitoring during the procedure (Figure 1).

B. Study Characteristics:

We identified 22 studies that matched the search criteria explained above. The general characteristics of each study are listed in Table 1, which is separated into the studies done with intraoperative monitoring and studies done without intraoperative monitoring. For the studies in which data was missing in certain parameters, we simply labeled those parameters with “ND” or “No Data.” The follow up duration varied from study to study with an average of 51 months. The average number of patients across all studies was 173 patients (range 60-1,445) with an average age of 55 years.

C. Outcomes:

Tables 2-6 show the outcomes of the studies including the change in the neurological deficit before and after the procedure (post-op score - pre-op score). The mean change in Japanese Orthopaedic Association (JOA) score for the studies that used this scale was 3.94 points. For studies that used the Nurick scale, the mean change was 1.20. Both the studies selected that used intraoperative monitoring assessed patients clinically and therefore did not have a quantifiable change in any myelopathy scale.

When looking specifically at neurological deficits, the mean outcome was 9.30% of cases, with an average of 19.94% transient cases and 2.32% permanent cases among the studies conducted without intraoperative monitoring. For studies that used intraoperative monitoring, the mean outcome was 1.33% and three transient cases (2.52% of all cases) and zero permanent cases were observed (Table 3).

D. Subgroup Analysis:

Worsening myelopathy and/or quadriplegia were reported in 8 of the studies that intraoperative monitoring was not used and both studies that used monitoring. The mean outcome for studies done without IOM was 2.71% of cases, with an average of 1.42% transient and 1.02% permanent cases. In studies done with IOM, the mean outcome was 0.91% of cases, all of which were transient (Table 4).

C5 root and deltoid palsy were other fairly common neurological deficits that occurred after the anterior procedures were executed. In studies done without IOM, the mean outcome of C5 root/deltoid palsy was 4.56% of cases (3.74% transient and 0.47% permanent). In procedures involving IOM, only one documented case (0.84%) of C5 root/deltoid palsy was recorded in the Bose et al, 2004 study. This occurrence was reported as transient (Table 5).

Dysphonia was recorded in 8 studies without IOM with a mean outcome of 6.77% of cases. Dysphagia had a mean outcome of 6.23% of cases in 9 studies involving procedures done without IOM. No data was provided in both studies conducted with IOM regarding dysphonia or dysphagia post-operatively in patients (Table 6).

E. Other Neurological Deficits:

There were two other reported cases of neurological deficit in the Chibbaro and Emery study, which were not found in any other studies shortlisted for the systematic review. Horners syndrome was reported in a patient in the Chibbaro et al, 2009 study and complete loss of sensation was reported in a patient in the Emery et al, 1998 study.

F. Outcomes Analysis:

There were only two outcomes that were commonly reported amongst the monitored and non-monitored studies. The Figures are reported as proportions (0 to 1) in Figures 2 & 3. The

striking feature is the huge heterogeneity in the Forest Plots. For instance, in the unmonitored studies, the proportion of patients with neurological deficit ranged from 0% to 54%, with a weighted average of 7.9% (95% CI 3.8% to 13.3%). Equally, even within the two monitored studies, one has unusually low proportion (0.14%) of patients with neurological deficits as compared to the other that reported complications in 2.5% of participants.

III. Discussion:

Our systematic review of studies comparing the use of Intraoperative neurophysiological monitoring to reduce neurological complications in patients undergoing ACD for CSM did not yield any substantive evidence to support or refute its use. There was substantial heterogeneity in the complication rates in the studies in addition low proportion of patients with complications who used intraoperative neurophysiological monitoring.

Significant variations existed in the motor complications including worsening myelopathy and quadriplegia reported between studies. The variation in rate of complications could be secondary to variation in surgical techniques or evaluation methodology. Forty percent of our studies used a JOA or Nurick score to report group outcomes, and did not include individual motor deficits. The studies which did not report results of individual patients could not be included in the analysis. A review of various scores to evaluate CSM found that JOA and Nurick both have advantages and disadvantages based on its ability to assess clinical symptoms and economic impact[24]. Hence reporting complications from individual patients in addition to a score will be helpful in analyzing the value of IOM for ACD in the future.

Dysphagia and Dysphonia are known complications after anterior cervical spine procedures Dysphagia could be secondary to the injury of superior[25], recurrent laryngeal nerve[26], hypoglossal[27] and glossopharyngeal nerve[25]. The incidence of this complication varies from 2 to 50 % depending on the type of study and evaluation methodology[28,29]. Prospective studies which utilized objective methods Videofluroscopic swallow evaluation, and fiberoptic endoscopic evaluation to evaluate dysphagia reported complication rates of 50%[29]. The studies in our review used both subjective and objective evaluation methods to report the incidence of dysphagia after ACD for CSM. The mechanisms of cranial nerve injury resulting in dysphagia are unclear, and intraoperative monitoring techniques like electromyography (EMG) have not been robustly evaluated to determine its efficacy.

Dysphonia secondary to recurrent laryngeal nerve palsy could be secondary to indirect stretch or focal pressure on the nerve[30]. The incidence of vocal cord paralysis varies from 1-13 % depending on the type of study and evaluation methodology[2,31,32]. Prospective studies which utilized objective methods such as indirect laryngoscopy and 3 months follow up reported an incidence rate of 13.3%[31]. The studies in our review used a subjective evaluation method to report the incidence of dysphagia after ACD for CSM. Though theories exist about the course of RLN as well the mechanism of injury, intraoperative monitoring techniques using EMG have been evaluated [14] but the efficacy of it yet to be determined.

Intraoperative neurophysiological monitoring techniques include SSEPs[8,16], TcMEPs[15] can be used to reduce the incidence of neurological deficits after cervical, thoracic and lumbar spinal procedures. SSEPs[16] and TcMEPs[15] monitor the dorsal column and the motor pathways in the spinal cord and reduce neurological deficits after spinal surgeries. EMG has been used for placement of pedicle screws[33], as well the incidence of cranial nerve deficits in during thyroidectomy[34] and skull base tumor removal[35]. The techniques though useful, have not be validated based on the alarms and subsequent surgical interventions used to modify the procedure. The alarms are significant changes in SSEPs, TcMEPs and EMG which can indicate significant impending risk of reversible neurological injury if not addressed during the surgery.

Our review is clearly limited due to significant heterogeneity with patient outcomes. As indicated this could be secondary to the procedure or evaluation methodology. Modalities used in Intraoperative neurophysiological monitoring have not been appropriately validated. The alarm criteria used and the interventions secondary to the alarms are not yet standardized.

IV. Conclusions:

Based on the review of published studies no evidence exists to refute or support the use of intraoperative neurophysiological monitoring to reduce neurological complications during anterior cervical procedures. Significant variations exist in evaluation of methodology of the complications after anterior cervical spinal procedures. The modalities and their respective alarm criteria's used for intraoperative neurophysiological monitoring including SSEPs, TcMEPs and EMG have not been robustly validated. A prospective trial with controlled data collection with validated diagnostic tools for use in decompressive spinal procedures might be valuable to reduce the risk of complications in addition to testing appropriate therapeutic interventions.

V. Figure Legend:

Figure 1: Study Selection Prism
Figure 2: Proportion Meta-Analysis Plot: Myelopathy
Figure 3: Proportion Meta-Analysis Plot: Neurological Deficit

VI. Table Legend:

Table 1: Characteristics of Studies Involved in Systematic Review
Table 2: Evaluation of Myelopathy between Groups
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Table 4: Worsening Myelopathy/Quadriplegia
Table 5: C5 Root and Deltoid Palsy
Table 6: Dysphonia and Dysphagia

Figure 1: Study Selection Prism

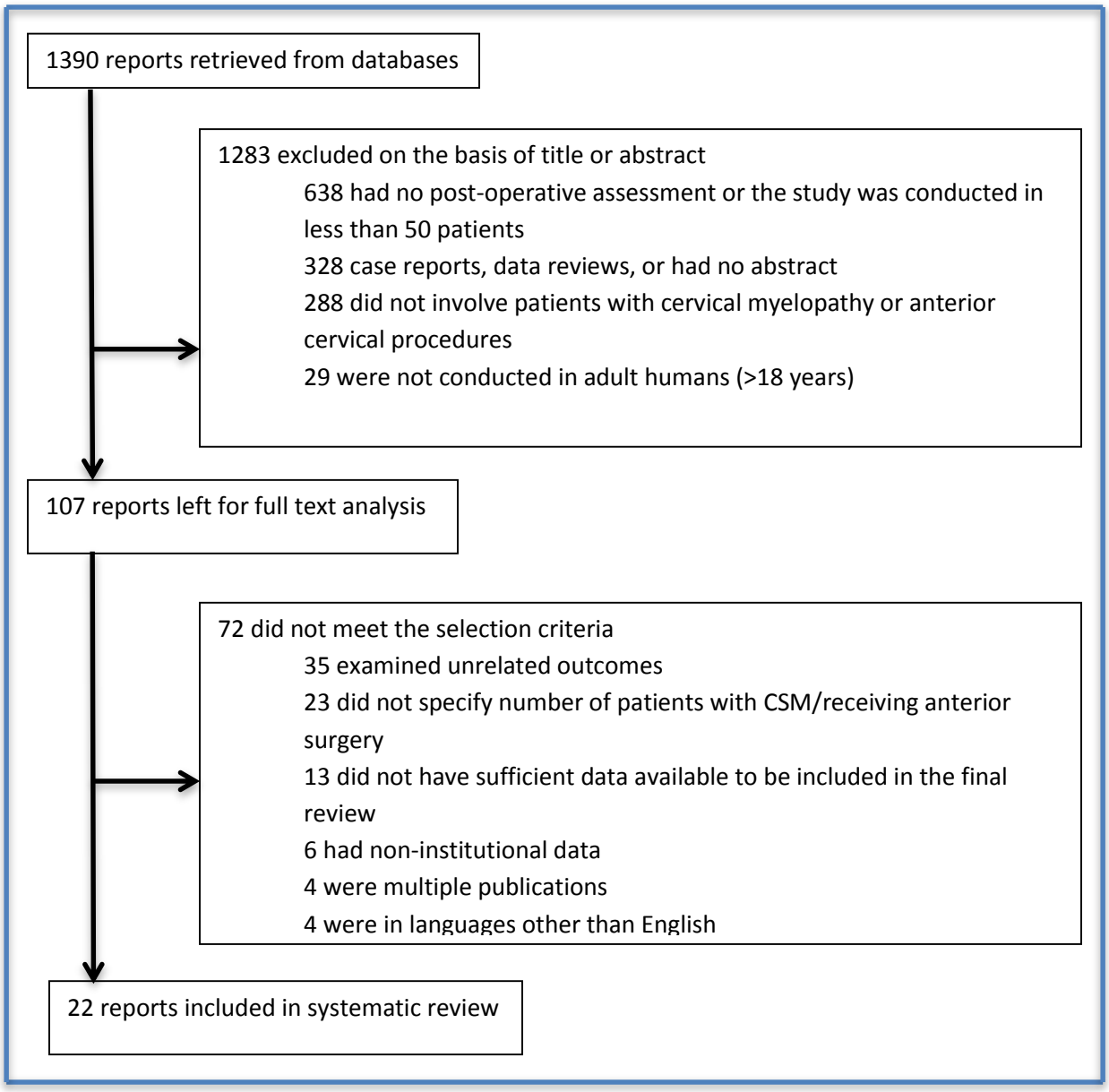
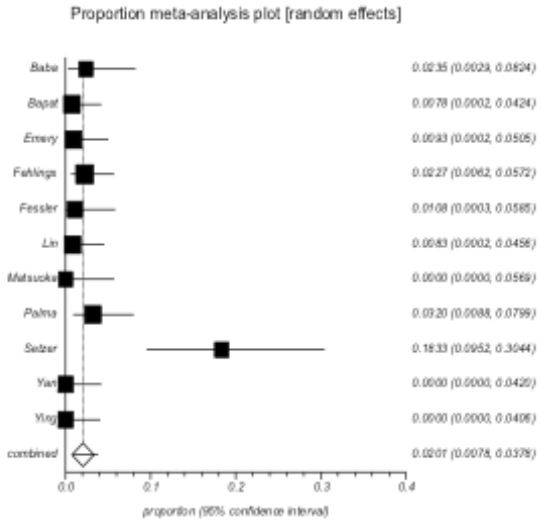


Figure 2: Proportion Meta-Analysis Plot: Myelopathy

Myelopathy

No Monitoring



Monitored

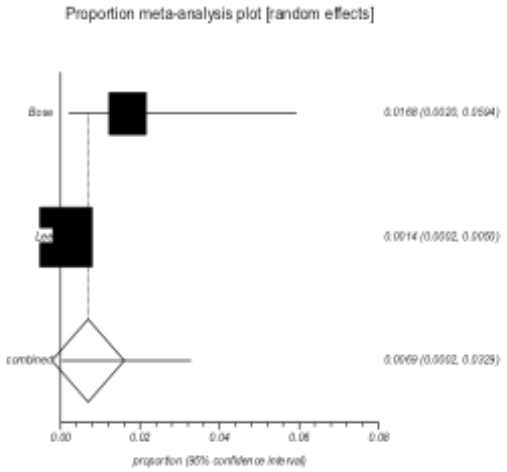


Figure 3: Proportion Meta-Analysis Plot: Neurological Deficit

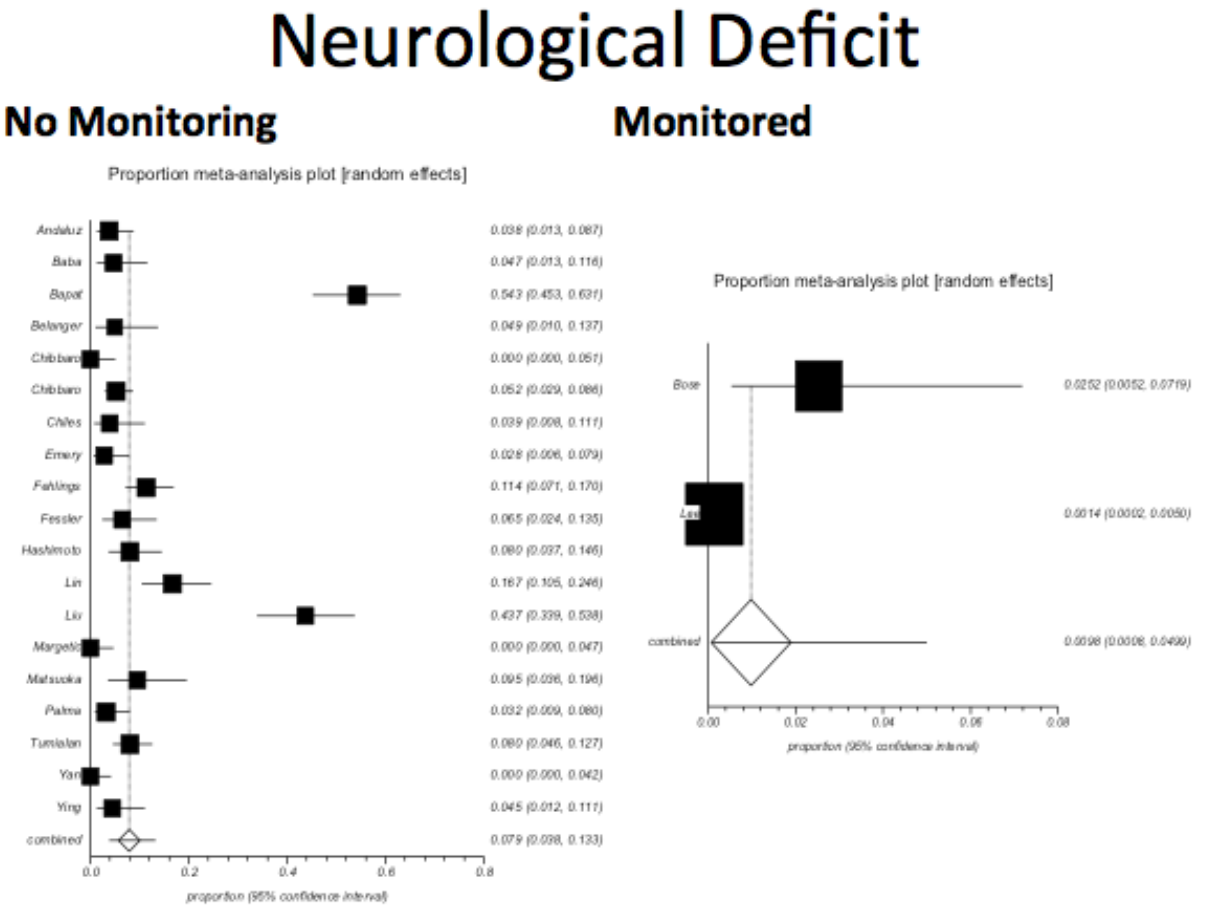


Table 1: Characteristics of Studies Involved in Systematic Review

Source	Sample Size, n	Study Design	Disease	Type of Procedure	Intraoperative Monitoring	Modality (Type of Monitoring)	Pre-Op Clinical Evaluation	Post-Op Clincal Evaluation	Average Follow Up	Duration, mo	Age	Gender
Group 1-Studies Done Without Intraoperative Monitoring												
Andaluz et al, 2012	130	R	CSM/RM	ACC	No	-	JOA	JOA		45	58.4	126 male 4 female
Baba et al, 1994	85	RR	MR	ADF	No	-	JOA	JOA		99.6	49	72 male 13 female
Bapat et al, 2008	129	PA	CSM	ACD	No	-	JOA	JOA		33.6	49	109 male 20 female
Belanger et al, 2005	61	R	CM	ACD	No	-	Nurick	Nurick	>24		61	39 male 22 female
Chibbaro et al, 2006	70	RR	CSM	ACC	No	-	JOA	JOA		42	57	47 male 23 female
Chibbaro et al, 2009	268	PA	CSM	MOC	No	-	Clinical/MRI	Clinical/MRI		96	58	161 male 107 female
Chiles et al, 1999	76	RR	CSM	ACD	No	-	CMS	CMS	Unknown		56	47 male 28 female
Emery et al, 1998	108	RR	CSM	ADA	No	-	Nurick	Nurick	Unknown		58	69 male 39 female
Fehlings et al, 2012	176	PA	CSM	ACD	No	-	JOA	JOA	Unknown		52.3	ND ND
Fessler et al, 1998	93	RR	CSM	ACC	No	-	Nurick	Nurick		39	ND	ND ND
Hashimoto et al, 2010	113	RR	CSM/C5 Palsy	ASF	No	-	Clinical/MRI	Clinical/MRI	Unknown		ND	ND ND
Lin et al, 2012	120	RR	CSM	ACDF and ACCF	No	-	JOA	JOA		24	58.3	81 male 39 female
Liu et al, 2012	103	RR	CSM	ACDF	No	-	JOA	JOA	Unknown		53.5	57 male 46 female
Margetic et al, 2009	77	RR	CSM	AN	No	-	JOA and Nurick	JOA and Nurick		12	61	44 male 31 female
Matsuoka et al, 2001	63	R	CSM	AFM	No	-	JOA	JOA	>120		57	45 male 18 female
Palma et al, 2010	125	R	CMR	ACD	No	-	VAS/Clinical	VAS/Clinical		135.6	-	54 male 71 female
Setzer et al, 2009	60	PA	CSM	AMD	No	-	JOA	JOA		18.8	61.5	40 male 20 female
Tumialan et al, 2008	200	RR	CSM	ACDF	No	-	Nurick	Nurick		16.7	53.9	97 male 103 female
Yan et al, 2011	86	R	CSM	ACCR	No	-	JOA	JOA	Unknown		ND	ND ND
Ying et al, 2007	89	RR	CSM	ACC	No	-	JOA	JOA	Unknown		47.2	61 male 28 female
Group 2-Studies Done With Intraoperative Monitoring												
Source	**Sample Size, n**	**Study Design**	**Disease**	**Type of Procedure**	**Intraoperative Monitoring**	**Modality (Type of Monitoring)**	**Pre-Op Clinical Evaluation**	**Post-Op Clincal Evaluation**	**Average Follow Up**	**Duration, mo**	**Age**	**Gender**
Bose et al, 2004	119	RR	CSM	ACSD	Yes	SSEPs and tceME	Clinical/MRI	Clinical/MRI	Unknown		46	ND ND
Lee et al, 2006	1,445	R	CSM	ACC	Yes	tceMEPs, SSEPs,	Clinical/MRI	Clinical/MRI	Unknown		ND	ND ND

Decompression; ACDF-Anterior Cervical Discectomy and Fusion; ACSD-Anterior Column Surgery or Decompression; ADA-Anterior Decompression and Arthrodesis; ADF-Anterior Decompression and Fusion; AFM-Anterior Floating Method; AMD-Anterior Microsurgical Decompression; AN-Anterior Neurodecopression; ASF-Anterior Spinal Fusion; CM-Cervial Myelopathy; CMR-Cervical Myeloradiculopathy; CMS-Cooper Myelopathy Scale; CSM-Cerivcal Spondolytic Myelopathy; JOA-Japanese Orthopaedic Association; MOC-Multilevel Cervical Corpectomy; MR-Myeloradiculopathy; PA-Prospective Analysis; R-Retrospective; RM-Radiculomyelopathy; RR-Retrospective Review; VAS-Visual Analog Scale

Table 2: Evaluation of Myelopathy between Groups

Group 1-Studies Done Without Intraoperative Monitoring						
Source	**Pre-Op JOA**	**Post-Op JOA**	**Change in Neuro Scale**	**Pre-Op Nurick**	**Post-Op Nurick**	**Change in Neuro Scale**
Andaluz et al, 2012	11.91	14.90	2.99	ND	ND	-
Baba et al, 1994	7.00	13.60	6.60	ND	ND	-
Bapat et al, 2008	10.40	15.76	5.36	ND	ND	-
Belanger et al, 2005	ND	ND	-	2.30	1.10	1.20
Chibbaro et al, 2006	12.20	15.40	3.20	ND	ND	-
Chibbaro et al, 2009	8.10	12.50	4.40	ND	ND	-
Chiles et al, 1999	12.40	14.90	2.50	ND	ND	-
Emery et al, 1998	ND	ND	-	2.40	1.20	1.20
Fehlings et al, 2012	13.60	ND	-	ND	ND	-
Fessler et al, 1998	ND	ND	-	ND	ND	-
Hashimoto et al, 2010	ND	ND	-	ND	ND	-
Lin et al, 2012	9.25	13.86	4.61	ND	ND	-
Liu et al, 2012	10.20	14.80	4.60	ND	ND	-
Margetic et al, 2009	9.15	13.01	3.86	3.05	1.80	1.25
Matsuoka et al, 2001	8.30	13.60	5.30	ND	ND	-
Palma et al, 2010	ND	ND	-	ND	ND	-
Setzer et al, 2009	10.32	11.53	1.21	ND	ND	-
Tumialan et al, 2008	ND	ND	-	1.42	0.26	1.16
Yan et al, 2011	ND	ND	-	ND	ND	-
Ying et al, 2007	12.54	15.16	2.62	ND	ND	-
Mean Outcomes	10.41	14.09	3.94	2.29	1.09	1.20
Standard Deviation of Outcomes	2.01	1.29	1.50	0.67	0.63	0.04
Error of the Mean	2.22	3.00	0.84	0.49	0.23	0.26
95% Confience Interval Lower Bound	6.06	8.20	2.29	1.33	0.63	0.70
95% Confience Interval Upper Bound	14.76	19.97	5.58	3.25	1.55	1.70
Group 2-Studies Done With Intraoperative Monitoring						
Source	**Pre-Op JOA**	**Post-Op JOA**	**Change in Neuro Scale**	**Pre-Op Nurick**	**Post-Op Nurick**	**Change in Neuro Scale**
Bose et al, 2004	ND	ND	-	ND	ND	-
Lee et al, 2006	ND	ND	-	ND	ND	-

T:Transient; P: Permanent; ND: No Data *averages in Baba paper calculated among all three patient groups combined

Table 3: Neurological Deficits

Group 1-Studies Done Without Intraoperative Monitoring				
Source	**Neurological Deficit**	**Neurological Deficit (%)**	**T (%)**	**P (%)**
Andaluz et al, 2012	5	3.85	-	3.85
Baba et al, 1994	4	4.71	4.71	0.00
Bapat et al, 2008	70	54.26	51.16	3.10
Belanger et al, 2005	3	4.92	-	-
Chibbaro et al, 2006	0	0.00	-	-
Chibbaro et al, 2009	14	5.22	-	-
Chiles et al, 1999	3	3.95	3.95	-
Emery et al, 1998	3	2.78	-	-
Fehlings et al, 2012	20	11.36	-	-
Fessler et al, 1998	6	6.45	-	-
Hashimoto et al, 2010	9	7.96	-	-
Lin et al, 2012	20	16.67	-	-
Liu et al, 2012	45	43.69	-	-
Margetic et al, 2009	0	0.00	-	-
Matsuoka et al, 2001	6	9.52	-	-
Palma et al, 2010	4	3.20	-	-
Setzer et al, 2009	0	0.00	-	-
Tumialan et al, 2008	16	3.00	-	-
Yan et al, 2011	0	0.00	-	-
Ying et al, 2007	4	4.49	-	-
Mean Outcomes		9.30	19.94	2.32
Standard Deviation of Outcomes		14.28	27.04	2.04
Error of the Mean		1.98	4.25	0.49
95% Confience Interval Lower Bound		5.41	11.61	1.35
95% Confience Interval Upper Bound		13.19	28.27	3.28
Group 2-Studies Done With Intraoperative Monitoring				
Source	**Neurological Deficit**	**Neurological Deficit (%)**	**T (%)**	**P (%)**
Bose et al, 2004	3	2.52	2.52	-
Lee et al, 2006	2	0.14	-	-
Mean Outcomes		1.33	2.52	-
Standard Deviation of Outcomes		1.68	-	-
Error of the Mean		0.94	-	-
95% Confience Interval Lower Bound		-0.51	-	-
95% Confience Interval Upper Bound		3.17	-	-
T:Transient; P: Permanent; ND: No Data				

Table 4: Worsening Myelopathy/Quadriplegia

	Group 1-Studies Done Without Intraoperative Monitoring				
Source	**Worsening Myelopathy/Quadriplegia**	**Worsening Myelopathy/Quadriplegia (%)**	**T (%)**	**P (%)**
Andaluz et al, 2012	ND	ND	-	-
Baba et al, 1994	2	2.35	2.35	0
Bapat et al, 2008	1	0.78	-	0.78
Belanger et al, 2005	ND	ND	-	-
Chibbaro et al, 2006	ND	ND	-	-
Chibbaro et al, 2009	ND	ND	-	-
Chiles et al, 1999	ND	ND	-	-
Emery et al, 1998	1	0.93	-	-
Fehlings et al, 2012	4	2.27	-	2.27
Fessler et al, 1998	1	1.08	1.08	-
Hashimoto et al, 2010	ND	ND	-	-
Lin et al, 2012	1	0.83	0.83	-
Liu et al, 2012	ND	ND	-	-
Margetic et al, 2009	ND	ND	-	-
Matsuoka et al, 2001	0	0.00	-	-
Palma et al, 2010	4	3.20	-	-
Setzer et al, 2009	11	18.33	-	-
Tumialan et al, 2008	ND	ND	-	-
Yan et al, 2011	0	0	-	-
Ying et al, 2007	0	0	-	-
Mean Outcomes		2.71	1.42	1.02
Standard Deviation of Outcomes		5.29	0.82	1.16
Error of the Mean		0.58	0.30	0.22
95% Confience Interval Lower Bound		1.58	0.83	0.59
95% Confience Interval Upper Bound		3.84	2.01	1.44
	Group 2-Studies Done With Intraoperative Monitoring			
Source	**Worsening Myelopathy/Quadriplegia**	**Worsening Myelopathy/Quadriplegia (%)**	**T (%)**	**P (%)**
Bose et al, 2004	2	1.68	1.68	-
Lee et al, 2006	2	0.14	-	-
Mean Outcomes		0.91	1.68	-
Standard Deviation of Outcomes		1.09	-	-
Error of the Mean		0.64	-	-
95% Confience Interval Lower Bound		-0.35	-	-
95% Confience Interval Upper Bound		2.17	-	-

T:Transient; P: Permanent; ND: No Data

Table 5: C5 Root and Deltoid Palsy

Group 1-Studies Done Without Intraoperative Monitoring					
Source	**C5Root/Deltoid palsy**	**C5Root/Deltoid palsy (%)**	**T (%)**	**P (%)**	
Andaluz et al, 2012	ND	ND	-	-	
Baba et al, 1994	2	2.35	2.35	0	
Bapat et al, 2008	1	0.78	0.78	0	
Belanger et al, 2005	3	4.97	4.97	-	
Chibbaro et al, 2006	ND	ND	-	-	
Chibbaro et al, 2009	0	0	-	-	
Chiles et al, 1999	1	1.32	-	1.32	
Emery et al, 1998	2	1.85	-	-	
Fehlings et al, 2012	5	2.84	2.27	0.57	
Fessler et al, 1998	2	2.15	2.15	-	
Hashimoto et al, 2010	9	7.96	-	-	
Lin et al, 2012	5	4.17	4.17	-	
Liu et al, 2012	22	21.36	-	-	
Margetic et al, 2009	0	0.00	-	-	
Matsuoka et al, 2001	6	9.52	9.52	-	
Palma et al, 2010	ND	ND	-	-	
Setzer et al, 2009	ND	ND	-	-	
Tumialan et al, 2008	ND	ND	-	-	
Yan et al, 2011	ND	ND	-	-	
Ying et al, 2007	ND	ND	-	-	
Mean Outcomes		4.56	3.74	0.47	
Standard Deviation of Outcomes		5.82	2.90	0.62	
Error of the Mean		0.97	0.80	0.10	
95% Confience Interval Lower Bound		2.65	2.18	0.27	
95% Confience Interval Upper Bound		6.46	5.30	0.67	
Group 2-Studies Done With Intraoperative Monitoring					
Source	**C5Root/Deltoid palsy**	**C5Root/Deltoid palsy (%)**	**T (%)**	**P (%)**	
Bose et al, 2004	1	0.84	0.84	-	
Lee et al, 2006	ND	ND	-	-	

T:Transient; P: Permanent; ND: No Data

Table 6: Dysphonia and Dysphagia

Group 1-Studies Done Without Intraoperative Monitoring											
Source	**Dysphonia**	**Dysphonia (%)**	**T (%)**	**P (%)**	**Method of Eval**	**Dysphagia**	**Dysphagia (%)**	**T (%)**	**P (%)**	**Method of Evaluation**
Andaluz et al, 2012	2	1.54	-	1.54	ND	3	2.31	-	2.31	ND
Baba et al, 1994	ND	ND	-	-	-	ND	ND	2.00	0	-
Bapat et al, 2008	38	29.46	28.68	0.78	Subjective	31	24.03	22.48	1.55	Subjective
Belanger et al, 2005	ND	ND	-	-	-	ND	ND	-	-	-
Chibbaro et al, 2006	ND	ND	-	-	-	ND	ND	-	-	-
Chibbaro et al, 2009	ND	ND	-	-	-	0	0	-	-	Objective
Chiles et al, 1999	ND	ND	-	-	-	2	2.63	-	-	Objective
Emery et al, 1998	ND	ND	-	-	-	ND	ND	-	-	-
Fehlings et al, 2012	1	0.57	-	0.57	Subjective	9	5.11	5.11	-	Subjective
Fessler et al, 1998	3	3.23	1.08	2.15	ND	1	1.08	-	-	Subjective
Hashimoto et al, 2010	ND	ND	-	-	-	ND	ND	-	-	-
Lin et al, 2012	5	4.17	4.17	-	ND	9	7.50	7.50		Objective
Liu et al, 2012	10	9.71	-	-	ND	13	12.62	-	-	Objective
Margetic et al, 2009	ND	ND	-	-	-	ND	ND	-	-	-
Matsuoka et al, 2001	ND	ND	-	-	-	ND	ND	-	-	-
Palma et al, 2010	ND	ND	-	-	-	ND	ND	-	-	-
Setzer et al, 2009	ND	ND	-	-	-	ND	ND	-	-	-
Tumialan et al, 2008	2	1.00	-	-	ND	14	7	-	-	Objective
Yan et al, 2011	ND	ND	ND	ND	-	ND	ND	ND	ND	-
Ying et al, 2007	4	4.49	4.00	-	ND	0	0	-	-	ND
Mean Outcomes		6.77	9.48	1.26			6.23	9.27	1.29	
Standard Deviation of Outcomes		9.61	12.88	0.73			7.41	9.09	1.18	
Error of the Mean		1.44	2.02	0.27			1.33	1.98	0.27	
95% Confience Interval Lower Bound		3.94	5.52	0.73			3.63	5.40	0.75	
95% Confience Interval Upper Bound		9.60	13.44	1.78			8.83	13.15	1.82	
Group 2-Studies Done With Intraoperative Monitoring										
Source	**Dysphonia**	**Dysphonia (%)**	**T (%)**	**P (%)**	**Method of Eval**	**Dysphagia**	**Dysphagia (%)**	**T (%)**	**P (%)**	**Method of Evaluation**
Bose et al, 2004	ND	ND	-	-	-	ND	ND	-	-	-
Lee et al, 2006	ND	ND	-	-	-	ND	ND	-	-	-

T:Transient; P: Permanent; ND: No Data

References:

1. Fountas KN, Kapsalaki EZ, Nikolakakos LG, et al. Anterior cervical discectomy and fusion associated complications. *Spine (Phila Pa 1976).* Oct 1 2007;32(21):2310-2317.
2. Zeidman SM, Ducker TB, Raycroft J. Trends and complications in cervical spine surgery: 1989-1993. *J Spinal Disord.* Dec 1997;10(6):523-526.
3. Bertalanffy H, Eggert HR. Complications of anterior cervical discectomy without fusion in 450 consecutive patients. *Acta Neurochir (Wien).* 1989;99(1-2):41-50.
4. Sevki K, Mehmet T, Ufuk T, Azmi H, Mercan S, Erkal B. Results of surgical treatment for degenerative cervical myelopathy: anterior cervical corpectomy and stabilization. *Spine (Phila Pa 1976).* Nov 15 2004;29(22):2493-2500.
5. Sakaura H, Hosono N, Mukai Y, Ishii T, Yoshikawa H. C5 palsy after decompression surgery for cervical myelopathy: review of the literature. *Spine (Phila Pa 1976).* Nov 1 2003;28(21):2447-2451.
6. Jung A, Schramm J. How to reduce recurrent laryngeal nerve palsy in anterior cervical spine surgery: a prospective observational study. *Neurosurgery.* Jul;67(1):10-15; discussion 15.
7. Mayr MT, Subach BR, Comey CH, Rodts GE, Haid RW, Jr. Cervical spinal stenosis: outcome after anterior corpectomy, allograft reconstruction, and instrumentation. *J Neurosurg.* Jan 2002;96(1 Suppl):10-16.
8. Khan MH, Smith PN, Balzer JR, et al. Intraoperative somatosensory evoked potential monitoring during cervical spine corpectomy surgery: experience with 508 cases. *Spine (Phila Pa 1976).* Feb 15 2006;31(4):E105-113.
9. Eggspuehler A, Sutter MA, Grob D, Jeszenszky D, Porchet F, Dvorak J. Multimodal intraoperative monitoring (MIOM) during cervical spine surgical procedures in 246 patients. *Eur Spine J.* Nov 2007;16 Suppl 2:S209-215.
10. Bose B, Sestokas AK, Schwartz DM. Neurophysiological monitoring of spinal cord function during instrumented anterior cervical fusion. *Spine J.* Mar-Apr 2004;4(2):202-207.
11. Bose B, Sestokas AK, Schwartz DM. Neurophysiological detection of iatrogenic C-5 nerve deficit during anterior cervical spinal surgery. *J Neurosurg Spine.* May 2007;6(5):381-385.
12. Fan D, Schwartz DM, Vaccaro AR, Hilibrand AS, Albert TJ. Intraoperative neurophysiologic detection of iatrogenic C5 nerve root injury during laminectomy for cervical compression myelopathy. *Spine (Phila Pa 1976).* Nov 15 2002;27(22):2499-2502.
13. Dimopoulos VG, Chung I, Lee GP, et al. Quantitative estimation of the recurrent laryngeal nerve irritation by employing spontaneous intraoperative electromyographic monitoring during anterior cervical discectomy and fusion. *J Spinal Disord Tech.* Feb 2009;22(1):1-7.
14. Jellish WS, Jensen RL, Anderson DE, Shea JF. Intraoperative electromyographic assessment of recurrent laryngeal nerve stress and pharyngeal injury during anterior cervical spine surgery with Caspar instrumentation. *J Neurosurg.* Oct 1999;91(2 Suppl):170-174.
15. Macdonald DB, Al Zayed Z, Al Saddigi A. Four-limb muscle motor evoked potential and optimized somatosensory evoked potential monitoring with decussation assessment: results in 206 thoracolumbar spine surgeries. *Eur Spine J.* Nov 2007;16 Suppl 2:S171-187.
16. Thirumala PD, Bodily L, Tint D, et al. Somatosensory-evoked potential monitoring during instrumented scoliosis corrective procedures: validity revisited. *Spine J.* Oct 19 2013.
17. Smith PN, Balzer JR, Khan MH, et al. Intraoperative somatosensory evoked potential monitoring during anterior cervical discectomy and fusion in nonmyelopathic patients--a review of 1,039 cases. *Spine J.* Jan-Feb 2007;7(1):83-87.

18. Taunt CJ, Jr., Sidhu KS, Andrew SA. Somatosensory evoked potential monitoring during anterior cervical discectomy and fusion. *Spine (Phila Pa 1976).* Sep 1 2005;30(17):1970-1972.

19. Kim DH, Zaremski J, Kwon B, et al. Risk factors for false positive transcranial motor evoked potential monitoring alerts during surgical treatment of cervical myelopathy. *Spine (Phila Pa 1976).* Dec 15 2007;32(26):3041-3046.

20. Resnick DK, Anderson PA, Kaiser MG, et al. Electrophysiological monitoring during surgery for cervical degenerative myelopathy and radiculopathy. *Journal of neurosurgery. Spine.* Aug 2009;11(2):245-252.

21. Ergina PL, Cook JA, Blazeby JM, et al. Challenges in evaluating surgical innovation. *Lancet.* Sep 26 2009;374(9695):1097-1104.

22. Simunovic N, Sprague S, Bhandari M. Methodological issues in systematic reviews and meta-analyses of observational studies in orthopaedic research. *The Journal of bone and joint surgery. American volume.* May 2009;91 Suppl 3:87-94.

23. Deeks JJ, Dinnes J, D'Amico R, et al. Evaluating non-randomised intervention studies. *Health Technol Assess.* 2003;7(27):iii-x, 1-173.

24. Vitzthum HE, Dalitz K. Analysis of five specific scores for cervical spondylogenic myelopathy. *Eur Spine J.* Dec 2007;16(12):2096-2103.

25. Martin RE, Neary MA, Diamant NE. Dysphagia following anterior cervical spine surgery. *Dysphagia.* Winter 1997;12(1):2-8; discussion 9-10.

26. Apfelbaum RI, Kriskovich MD, Haller JR. On the incidence, cause, and prevention of recurrent laryngeal nerve palsies during anterior cervical spine surgery. *Spine (Phila Pa 1976).* Nov 15 2000;25(22):2906-2912.

27. Park SH, Sung JK, Lee SH, Park J, Hwang JH, Hwang SK. High anterior cervical approach to the upper cervical spine. *Surg Neurol.* Nov 2007;68(5):519-524; discussion 524.

28. Caspar W, Barbier DD, Klara PM. Anterior cervical fusion and Caspar plate stabilization for cervical trauma. *Neurosurgery.* Oct 1989;25(4):491-502.

29. Smith-Hammond CA, New KC, Pietrobon R, Curtis DJ, Scharver CH, Turner DA. Prospective analysis of incidence and risk factors of dysphagia in spine surgery patients: comparison of anterior cervical, posterior cervical, and lumbar procedures. *Spine (Phila Pa 1976).* Jul 1 2004;29(13):1441-1446.

30. Kahraman S, Sirin S, Erdogan E, Atabey C, Daneyemez M, Gonul E. Is dysphonia permanent or temporary after anterior cervical approach? *Eur Spine J.* Dec 2007;16(12):2092-2095.

31. Jung A, Schramm J. How to reduce recurrent laryngeal nerve palsy in anterior cervical spine surgery: a prospective observational study. *Neurosurgery.* Jul 2010;67(1):10-15; discussion 15.

32. Bulger RF, Rejowski JE, Beatty RA. Vocal cord paralysis associated with anterior cervical fusion: considerations for prevention and treatment. *J Neurosurg.* May 1985;62(5):657-661.

33. Glassman SD, Dimar JR, Puno RM, Johnson JR, Shields CB, Linden RD. A prospective analysis of intraoperative electromyographic monitoring of pedicle screw placement with computed tomographic scan confirmation. *Spine (Phila Pa 1976).* Jun 15 1995;20(12):1375-1379.

34. Dralle H, Sekulla C, Lorenz K, Brauckhoff M, Machens A. Intraoperative monitoring of the recurrent laryngeal nerve in thyroid surgery. *World J Surg.* Jul 2008;32(7):1358-1366.

35. Thirumala PD, Mohanraj SK, Habeych M, et al. Value of free-run electromyographic monitoring of lower cranial nerves in endoscopic endonasal approach to skull base surgeries. *J Neurol Surg B Skull Base.* Aug 2012;73(4):236-244.