Review Article

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Recovery patterns from C5 palsy after anterior cervical decompression and fusion, posterior cervical decompression and fusion, and laminoplasty for degenerative cervical myelopathy: systematic review and meta-analysis of 748 C5 palsy cases

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Despite the favorable postoperative prognosis of C5 palsy (C5P), a certain proportion of these patients have less satisfactory outcomes. The current systematic review and meta-analysis thus aimed to comprehensively evaluate existing literature and identify the onset, recovery patterns, and outcomes of C5P following diverse surgical approaches. Five different databases (Google Scholar, Embase, PubMed, Web of Science, and Cochrane Library) were thoroughly searched for relevant literature on October 15, 2024. Studies reporting on incidences of C5P following surgery for degenerative cervical conditions with recovery data published until 2024 were scrutinized. Narrative or systematic reviews, opinions, letters to the editor, and manuscripts published in non-English languages were excluded. A total of 30 articles involving 8,116 patients who underwent undergoing surgery for degenerative cervical myelopathy with 748 reported C5P cases were included for analysis. The overall time to palsy reported in the included studies was 3 days (95% confidence interval [CI], 2.56–3.60). Palsy occurred earliest with anterior cervical decompression and fusion (ACDF) at 2 days (95% CI, 0.35–4.54), followed by laminoplasty (LP) at 3.2 days (95% CI, 2.02–4.34) and posterior cervical decompression and fusion (PCDF) at 3.6 days (95% CI, 2.81–4.37). Patients with palsy showed improved recovery with time. At the 1-year follow-up, the reported recovery rates were 100%, 52.9%, and 50% for ACDF, LP, and PCDF, respectively. C5P demonstrated a delayed presentation, with mean onset of 3 days after surgery, which can range from 2 days for ACDF to 3.6 days for PDCF. Recovery improved progressively with time and varied for different surgical procedures, with ACDF showing the best recovery and PDCF for cervical myelopathy showing the poorest recovery.

Keywords: Postoperative complications; Surgical decompression; Laminectomy; Laminoplasty; C5 palsy

Introduction

C5 palsy (C5P) is a common adverse event that has been reported to complicate the postoperative recovery of patients who had undergone cervical decompression surgery [1,2]. Since its initial description by Scoville [3] in 1961, diverse hypotheses have been presented to describe the etiopathogenesis of this adverse event. However, the present consensus is in favor of a mixture of etiologies leading to the clinical presentation, rather than a unique disease pathology [4]. This complication is quite frustrating for both health providers and patients given that causes substantial impairment of the patients' recovery, functional outcomes, and satisfaction, especially during the early postoperative period [5,6]. The overall incidence of this complication has been reported to range from 0.5%–2% and 7%–12% following anterior cervical decompressive procedures and posterior cervical surgeries, respectively [5-7].

Fortunately, a majority of patients demonstrate significant improvement in their motor weakness, with 41% experiencing complete recovery [5,6]. Studies have reported that some patients may even take up to a year to reach baseline functionality, which would necessitate interventions, such as physical therapy and exercises, to achieve such recovery [8-10]. However, a certain proportion of these patients do sustain a permanent residual deficit, including a minority of patients who experience no recovery at all, whereas others have an inordinately prolonged recovery process [1,2,5,6,9,10]. The need for identifying the pattern of recovery and understanding the factors associated with poor neurological outcomes after C5P can therefore not be understated, considering that such persistent weakness can significantly accentuate the total care expenditure following cervical decompression [1,2,4-10]. In this context, two questions may be of substantial relevance: (1) What is the pattern of C5P onset and (2) what is the recovery or neurological outcome patterns of C5P following different surgical approaches? The current meta-analysis therefore aimed to comprehensively analyze existing literature and address the aforementioned questions in clinically relevant scenarios.

Methods

This study was conducted in accordance with to the guidelines set forth for the conduction and reporting of systematic reviews as per Cochrane Collaboration [11] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [12].

Literature search

Five different databases (Google Scholar, Embase, PubMed, Web of Science and Cochrane Library) were thoroughly searched for relevant literature on October 15, 2024. Studies reporting on C5P published until 2024 were scrutinized. The search was performed using the following keywords in combination with Boolean operators: (((ACDF) OR (cervical fusion) OR (laminoplasty) OR (global fusion) OR (posterior decompression)) AND (C5 palsy)).

Inclusion or exclusion criteria

Studies that reported on the occurrence, management, or recovery of C5P following surgery for the management of degenerative cervical myelopathy were considered for inclusion. Studies reporting on C5P associated with procedures for cervical radiculopathies were excluded to make meaningful comparisons across the procedures performed for a given condition (i.e., myelopathy). Narrative or systematic reviews, opinions, letters to the editor, and manuscripts published in non-English languages were also excluded. The selection

Table 1. Inclusion and exclusion criteria of selection of articles to be included in the review

	Inclusion criteria	Exclusion criteria
Patient	Patients with cervical myelopathy due to degenerative causes	Patient with cervical myelopathy due to other causes such as trauma, tumor, infection, or inflammatory conditions
Intervention	Decompressive surgery	-
Comparison	None	-
Outcome	C5 palsy recovery	-
Time frame	Since inception till 2024	-
Study design	Clinical studies of both prospective and retrospective nature, from case reports, case series to randomized controlled trials	-
Language	English	Non-English

criteria are detailed in Table 1. To avoid heterogeneity, we only included cases explicitly diagnosed with C5P in the manuscripts following cervical spine surgeries based on a reduction in muscle power and only those who experienced complete recoveries during follow-up.

Manuscript selection and data extraction

Search outputs were downloaded from the specific databases. They were then extracted to EndNote, de-duplicated, and then selected manually. Title screening was independently performed by two authors, after which individual manuscripts were separately screened as described in the aforementioned criteria. Thereafter, the next round of screening was performed, which involved extracting the complete manuscripts and detailed analysis in duplicate. The final selection of articles was then completed. Any discrepancy among the authors was clarified based on mutual discussions with the senior author.

Table 2. Quality assessment of the included studies

No.	Author	Selection				Comparability	Outcome		
		Representativeness	Non-exposed cohort	Exposure	Outcome at study initiation		Assessment	Follow-up for outcome	Follow-up adequacy
1	Yonenobu et al. [14] (1991)	*	*	*	*	*	*		*
2	Tsuzuki et al. [37] (1996)	*	*	*	*	*	*	*	
3	Edwards et al. [15] (2000)	*	*	*	*	*	*	*	*
4	Chiba et al. [13] (2002)	*	*	*	*	*			*
5	Ikenaga et al. [16] (2005)	*	*	*	*	*	*	*	
6	Kaneko et al. [17] (2006)	*	*	*	*	*	*	*	*
7	Guo et al. [18] (2011)	*	*	*	*	*	*	*	*
8	Zhao et al. [19] (2011)	*	*	*	*	*	*	*	*
9	Chang et al. [21] (2013)	*	*	*	*	*	*	*	
10	Eskander et al. [20] (2012)	*	*	*	*	*	*		*
11	Wu et al. [22] (2014)	*	*	*	*	*	*	*	*
12	Macki et al. [23] (2016)	*	*	*	*	*	*	*	*
13	Takenaka et al. [24] (2016)	*	*	*	*	*	*	*	*
14	Lee et al. [25] (2016)	*	*	*	*	*	*	*	*
15	Kang et al. [26] (2017)	*	*	*	*	*	*	*	*
16	Nori et al. [27] (2017)	*	*	*	*	*	*	*	*
17	Chen et al. [28] (2018)	*	*	*	*	*	*	*	*
18	Sun et al. [29] (2019)	*	*	*	*	*	*	*	*
19	Pennington et al. [5] (2019)	*	*	*	*	*	*	*	*
20	Pennington et al. [6] (2019)	*	*	*	*	*	*	*	
21	Lubelski et al. [30] (2014)	*		*	*		*	*	*
22	Houten et al. [38] (2020)	*	*	*	*	*	*	*	*
23	Wang et al. [32] (2021)	*	*	*	*	*			
24	Pennington et al. [31] (2021)	*	*	*			*	*	*
25	Takano et al. [33] (2021)	*	*	*	*	*	*	*	*
26	Odate et al. [10] (2021)	*	*	*	*	*	*	*	*
27	Saadeh et al. [39] (2022)	*		*			*	*	*
28	Shah et al. [34] (2022)	*	*	*	*	*	*	*	*
29	Kang et al. [36] (2023)	*	*	*	*	*	*	*	*
30	Levi et al. [35] (2023)	*	*	*	*	*		*	*

Quality assessment

The included studies were assessed for quality based on the Newcastle Ottawa Scale for non-randomized studies, with the results being presented in Table 2 [5,6,10,13-39]. The studies demonstrated sufficient quality for inclusion.

Statistical analysis

This meta-analysis was performed using Stata ver. 16.0 software (Stata Corp., College Station, TX, USA). Reported incidences in the included studies were pooled and calculated along with their 95% confidence intervals (CIs). The random-effects meta-analysis model was used for data synthesis when the studies had high heterogeneity (I^2>50%; p<0.10); otherwise, the fixed-effects model was implemented. Sensitivity and subgroup analyses were performed if heterogeneity was noted among the reported results. Recovery according to reported follow-up time points were analyzed using Kaplan-Meyer analysis.

Results

Overall, our literature search yielded a total of 3,903 articles. After removing duplicates and compiling the studies, 2,247 manuscripts were selected. After screening the titles of the selected articles, 244 manuscripts found to be qualified for the next level of screening. Finally, after the screening of the abstracts and full manuscript texts, 30 articles were selected for the systematic review. Fig. 1 depicts the PRISMA flow diagram for the selection of studies included in this review. The general characteristics and outcomes from individual studies included in the analysis are presented in Table 3 [5,6,10,13-39]. The included studies analyzed a total of 21,231 patients who underwent surgery for cervical myelopathy. Most of the included studies were retrospective in nature (n=86; 88.7%). The follow-up period in the included studies ranged from 1 month to 12 years, as shown in Table 3.

Time to C5P

A total of 30 studies including 21,231 patients with 748 C5P cases provided information on the time to C5P following surgery. To analyze this, we used the random-effects model considering the heterogeneity in the reported incidence across the included studies. The overall time to C5P reported in the included studies was 3 days (95% CI, 2.56–3.60). As shown in Fig. 2 [5,6,10,13-39], C5P occurred earlier following anterior cervical discectomy/decompression and fusion (ACDF) at 2 days (95% CI, 0.35–4.54), followed by laminoplasty (LP) at 3.2 days (95% CI, 2.02–4.34) and posterior cervical decompres-

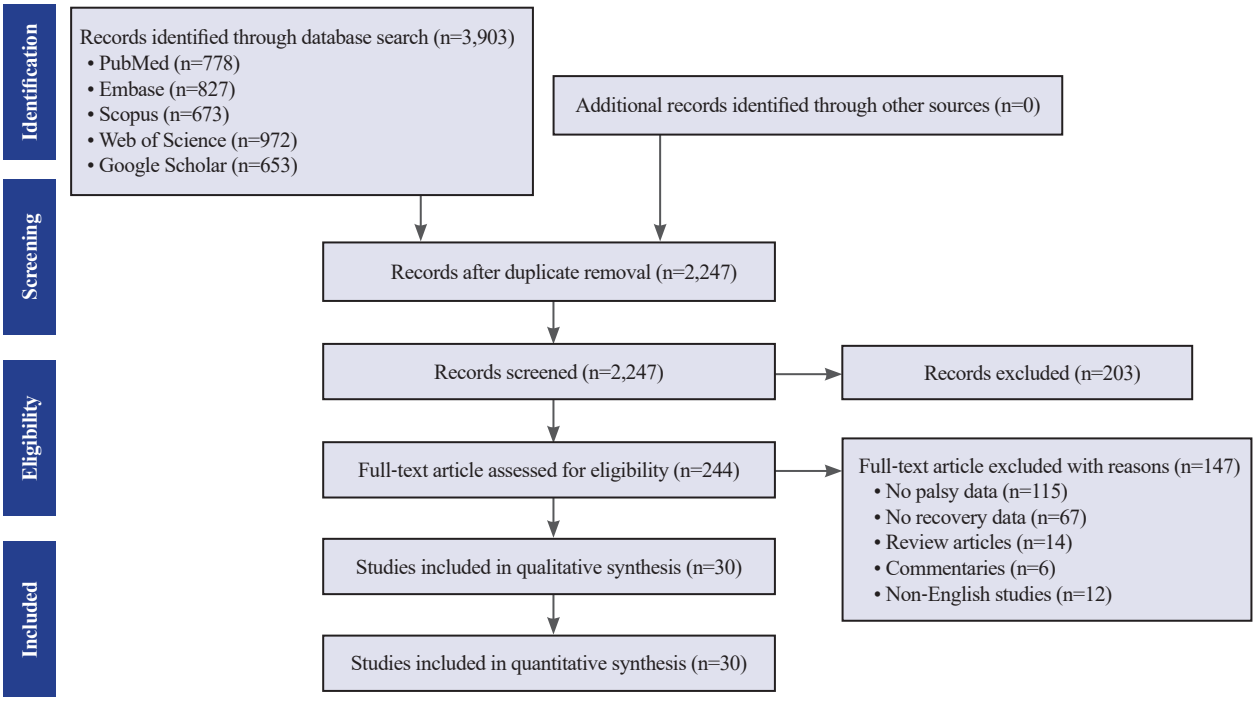

Fig. 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram of inclusion of studies.

Table 3. General characteristics of studies included in the review

No.	Author	Country	Sample size	Type	Age (yr)	M:F	Palsy incidence	Time to palsy	Procedure	Follow-up
1	Yonenobu et al. [14] (1991)	Japan	384	Retrospective cohort study	56.7	298:86	13	5.5±1.2 days	ACDF; LP	6.1 yr
2	Tsuzuki et al. [37] (1996)	Japan	198	Retrospective cohort study	59	NA	20	3 days	PCDF; LP	54 mo
3	Edwards et al. [15] (2000)	USA	18	Retrospective cohort study	54	13:5	1	<24 hr (1)	LP	18 mo
4	Chiba et al. [13] (2002)	Japan	141	Retrospective cohort study	56	NA	11	4.6 days	LP	2 yr
5	Ikenaga et al. [16] (2005)	Japan	549	Retrospective cohort study	NA	NA	18	1.4 days	ACDF; LP	12 mo
6	Kaneko et al. [17] (2006)	Japan	66	Retrospective cohort study	67	38:28	5	2±1 days	LP	2 yr
7	Guo et al. [18] (2011)	China	53	Retrospective cohort study	53.4±9.5	35:18	1	0.25 days	ACDF	37.3±7 mo
8	Zhao et al. [19] (2011)	China	82	Retrospective cohort study	57.6	47:35	2	3.5 days	PCDF; LP	41.6 mo
9	Chang et al. [21] (2013)	USA	176	Retrospective cohort study	49.7±11.4	NA	12	1.7 days	ACDF	NA
10	Eskander et al. [20] (2012)	Taiwan	364	Retrospective cohort study	55.9±12	224:140	12	2.5±1.2 days	ACDF; LP; global	12 mo
11	Wu et al. [22] (2014)	China	102	Retrospective cohort study	58.4	76:26	16	3.43 days	LP	16.3 mo
12	Macki et al. [23] (2016)	USA	511	Retrospective cohort study	NA	NA	43	3±2.3 days	PCDF	36±34.5 mo
13	Takenaka et al. [24] (2016)	Japan	800	Retrospective cohort study	64.5	543:257	54	<2.5 days (26), >2.5 days (28)	PCDF	27.4 mo
14	Lee et al. [25] (2016)	South Korea	190	Retrospective cohort study	59.5±11.8	105:85	30	3.2 days	PCDF; LP	38.5 mo
15	Kang et al. [26] (2017)	South Korea	70	Retrospective cohort study	60.3	47:23	10	3.5 days	PCDF	12 mo
16	Nori et al. [27] (2017)	Japan	263	Retrospective cohort study	63±10.8	190:73	11	6.5 days	PCDF	12 mo
17	Chen et al. [28] (2018)	China	118	Retrospective cohort study	58	94:24	12	2-42 days	LP	36 mo
18	Sun et al. [29] (2019)	USA	242	Retrospective cohort study	62.4	160:82	42	3.1±2.6 days	PCDF	27.9 mo
19	Pennington et al. [5] (2019)	China	80	Retrospective cohort study	57.2±12	42:38	5	3.4 days	ACDF; LP	12 mo
20	Pennington et al. [6] (2019)	USA	221	Retrospective cohort study	63	119:102	27	3.9±1.4 days	PCDF	12.9 mo
21	Lubelski et al. [30] (2014)	USA	77	Retrospective cohort study	64.5±7.6	61:16	77	2.9±2.4 days	PCDF	17.6±23.6 mo
22	Houten et al. [38] (2020)	USA	642	Retrospective cohort study	65	325:317	18	4.6 days	ACDF; PCDF	20±10.7 mo
23	Wang et al. [32] (2021)	USA	77	Retrospective cohort study	64	52:25	77	3 days	PCDF	11 mo
24	Pennington et al. [31] (2021)	China	184	Retrospective cohort study	63±11.4	76:108	26	3.9 days	PCDF	12 mo
25	Takano et al. [33] (2021)	Japan	108	Retrospective cohort study	66.1±11.7	88:20	5	4.6 days	LP	12 mo
26	Odate et al. [10] (2021)	Japan	839	Retrospective cohort study	59.1±11.6	NA	57	4.6±5.6 days	ACDF	55±17 mo
27	Saadeh et al. [39] (2022)	USA	1,024	Retrospective cohort study	60	588:436	52	1±1 day	ACDF; PCDF	NA
28	Shah et al. [34] (2022)	USA	72	Retrospective cohort study	62.5	46:26	72	2.9 days	ACDF; PCDF	12 mo
29	Kang et al. [36] (2023)	USA	272	Retrospective cohort study	59.9	NA	7	<24 hr (5), >24 hr (2)	PCDF; LP	24 mo
30	Levi et al. [35] (2023)	South Korea	193	Retrospective cohort study	59.7±11.9	135:58	12	3.2 days	LP	38.1±15.1 mo

Values are presented as number or mean±standard deviation.
M, male; F, female; ACDF, anterior cervical decompression and fusion; LP, laminoplasty; NA, not applicable; PCDF, posterior cervical decompression and fusion.

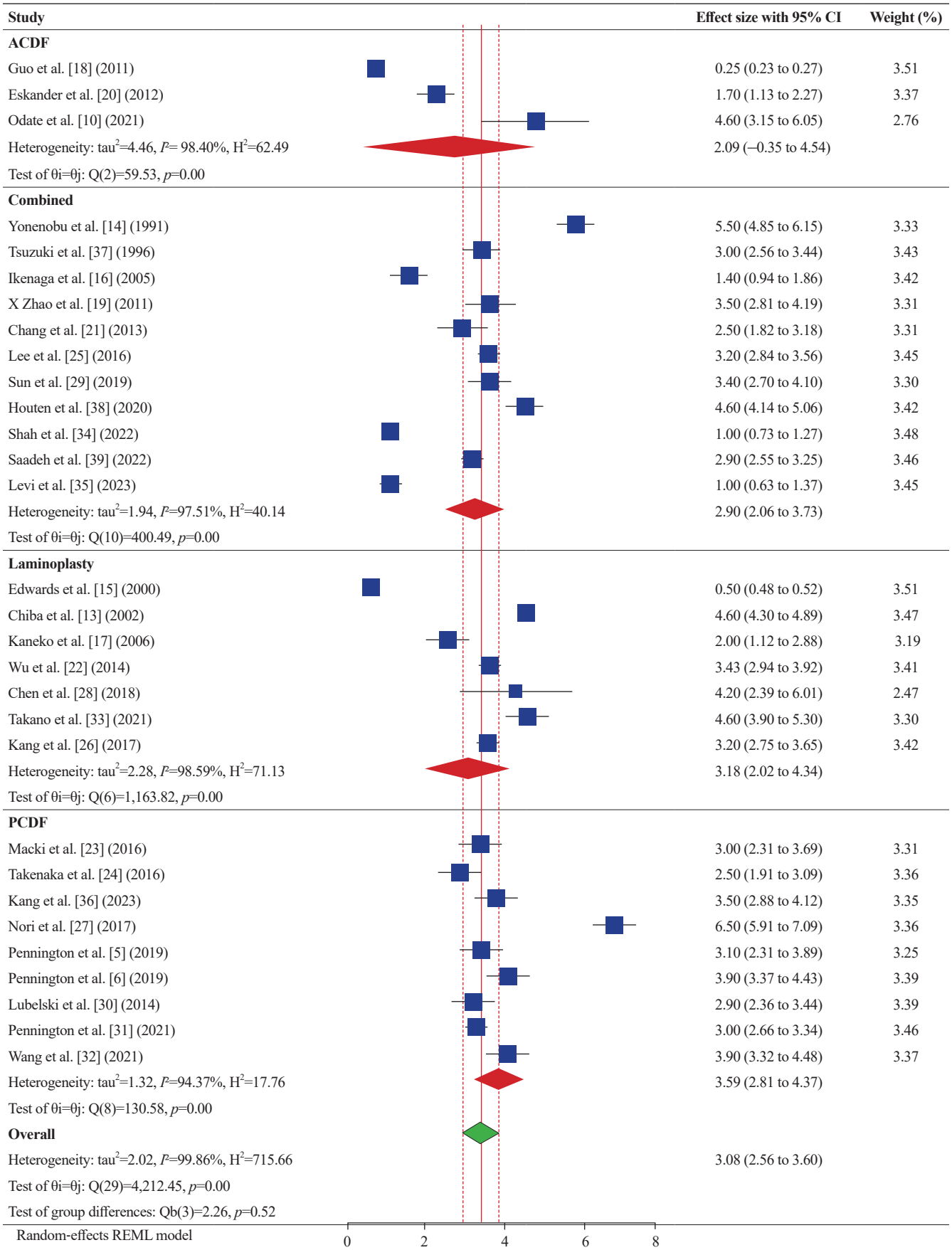

Fig. 2. Forest plot showing the pooled time to C5 palsy following surgery for cervical myelopathy. CI, confidence interval; ACDF, anterior cervical decompression and fusion; PCDF, posterior cervical decompression and fusion.

sion and fusion (PCDF) at 3.6 days (95% CI, 2.81–4.37). However, no significant difference in the time to C5P was noted among the procedures as shown in Fig. 2 (p=0.520). Significant heterogeneity was noted among the included studies despite categorizing them based on procedure. We considered that the heterogeneity in the subgroups according to individual procedures could possibly be due to variations in patient population, surgical technique, and rehabilitation protocols followed in the individual studies.

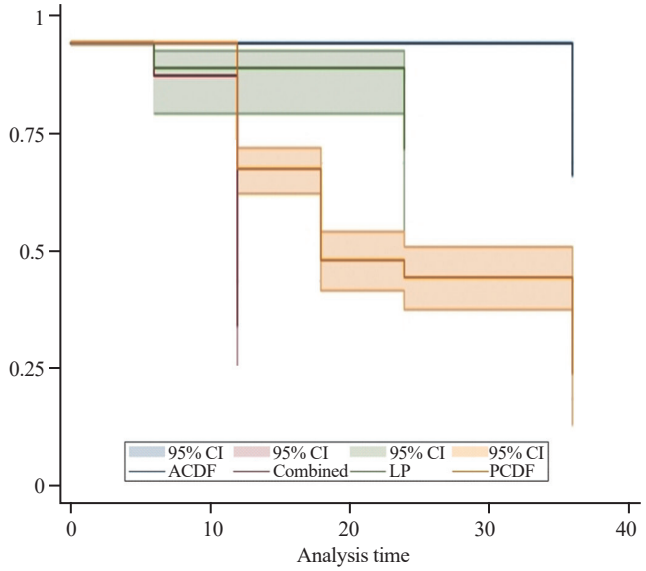

Fig. 3. Kaplan-Meyer recovery analysis of C5 palsy following various procedures for cervical myelopathy. CI, confidence interval; ACDF, anterior cervical decompression and fusion; LP, laminoplasty; PCDF, posterior cervical decompression and fusion.

C5P recovery

Recovery from C5P improved with time. The included studies reported recovery data at serial follow-up points, such as 3 months (four studies), 6 months (six studies), 12 months (10 studies), 18 months (three studies), 24 months (seven studies), and 36 months (nine studies). Kaplan-Meyer analysis of recovery at the reported follow-up timepoints is summarized in Fig. 3. Notably, recovery success rates were significantly higher with ACDF than with PCDF based on the reported recovery pattern at various timepoints. At the 1-year follow-up, the reported recovery rates were 100%, 50%, and 52.9% for ACDF, PCDF, and LP, respectively (p<0.001). We noted that recovery rates with PCDF improved from 27.9% at 3 months to 39.5% at 6 months and 50% at 12 months, further improving to 90.7% at the 2-year follow-up. Similarly, improved C5P recovery rates were observed with LP, with rates of 40%, 66%, 52.9%, and 100% having been observed at 3, 6, 12, and 18 months, respectively. C5P recovery rates for all the included procedures at all reported timepoints are presented in Fig. 4.

Discussion

Postoperative C5P has been attributed to diverse etiopathogenic mechanisms, such as intraoperative iatrogenic insult [3], thermal injury [40], traction injury of the nerve root secondary to spinal cord shift [37,41], spinal cord dysfunction [42], brachial plexitis, ischemic injury [43], and reperfusion injury [44]. Studies have

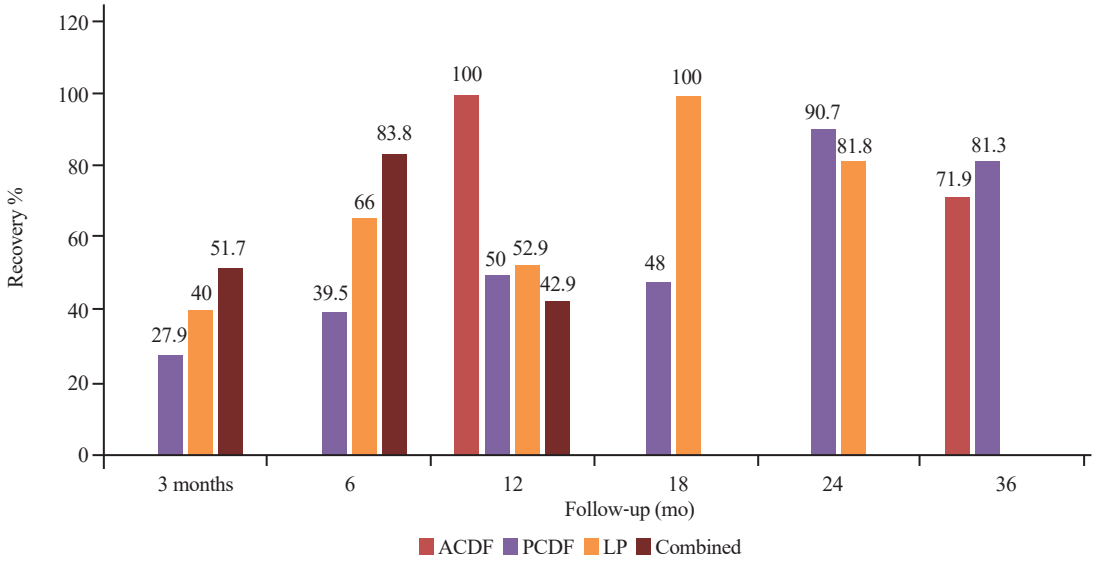

Fig. 4. Reported C5 palsy recovery rates at various time points for various procedures for cervical myelopathy. ACDF, anterior cervical decompression and fusion; LP, laminoplasty; PCDF, posterior cervical decompression and fusion.

reported that C5P is a relatively common phenomenon following cervical decompressive procedures, with estimated incidence rates ranging from 5% to 15% [43,45-48]. Its prognosis is largely favorable, with complete recovery rates having been reported to vary from 41% to 91% [49]. Nevertheless, studies have shown that a subset of patients (as high as 17%) do experience no meaningful neurological recovery [50].

C5P prognosis

A study by Pennington et al. [5,6] found that at a mean final follow-up of 11.85 months, 40.7%, 56%, and 3.3% of patients experienced complete, partial, and no (or minimal) recovery of symptoms, with the mean time to recovery ranging from 5 to 45 weeks (mean of 35 weeks). Saadeh et al. [9], in their series of 38 patients, demonstrated that 52.8%, 34.7%, and 12.5% exhibited full, partial, and no recovery of useful strength in the antigravity musculature (shoulder abduction and elbow flexion), respectively, at the end of the 12th postoperative month.

Palsy resolution has also been correlated with the severity of the deficit [51]. Sakaura et al. [43] demonstrated that although 47.8% of mild deficits recovered within 3 months, 52% of severe C5P tended to persist for at least 6 months after surgery [52]. A study by Nassr et al. [47] reported a mean time to recovery of 20.9 weeks. Overall, studies have reported that 19.1% to 33% of patients are usually left with some degree of residual weakness [53,54]. However, studies have also shown that recovery, in specific situations, may even extend until 5 years following surgery [8,49]. No study has shown any significant association between intraoperative neuromonitoring signal changes and the onset, severity, and duration of recovery of C5P [38].

Time to C5P and recovery pattern

Overall, we observed that the mean time to C5P onset after surgery was 3 days. The pattern of onset varied between the different surgical procedures. While C5P developed the earliest following ACDF (after a mean duration of 2 days following surgery), it developed more gradually in patients undergoing LP and PDCF (at 3.2 and 3.6 days, respectively). In general, studies have reported relatively higher rates of C5P following posterior approaches, with relatively more delayed presentation. For instance, in the meta-analysis by Wang et al. [55,56], C5P was reported in 6.2% and 5% of patients undergoing posterior and anterior cervical spinal approaches, respectively. Moreover, a study by Lim et al. [49] showed no significant relationship between time to palsy onset (early versus delayed) and the overall duration of recovery. They observed that early- and delayed-onset palsy could indicate different underlying mechanisms. For instance, early-onset palsy could be attributed to a peripheral nerve injury (e.g., brachial plexus injury), whereas delayed palsy could indicate an underlying reperfusion injury.

In contrast, our findings showed that that improvement in neurological outcomes occurred with the passage of time. A majority of the reviewed studies reported recovery rates after 1 year following surgery. We observed a significant improvement in recovery rates among patients undergoing ACDF as the index surgery (recovery rate of 100%). For those undergoing posterior surgical approaches (LP and PDCF), however, the recovery rate approached only around 50% at the end of 1 year. However, considering the retrospective nature of the included studies, selection bias in reporting the recovered C5P cases could not be ruled out among the procedures analyzed. Hence, these results must be interpreted with caution before making any generalizable conclusions.

A previous study by Lim et al. [49] also demonstrated better outcomes following anterior cervical approaches, which they attributed to lower degrees of spinal cord shift, mitigated reperfusion-associated cord damage, and reduced tethering effect on the nerve root (compared to posterior surgeries) [57,58]. In addition, Blizzard et al. [59] observed that excessive restoration of cervical lordosis may be detrimental to C5P given that it could potentially cause greater posterior spinal cord shift and root tethering. Nevertheless, other studies have contradicted this observation and identified inadequate restoration of cervical lordosis or alignment as an inciting factor for C5P [13,39,58,60].

Predicting outcomes following the C5P

A study by Lubelski et al. [8] found that deltoid strength improvement was a key predictor of recovery from C5P. They observed that patients who experienced complete (60% of cases) or partial recovery (29% of cases) demonstrated improvement in motor power by at least one Medical Research Council (MRC) grade at around 6 weeks following the deficit. They emphasized the significance of examination at the 6-week timepoint to predict any meaningful recovery given that grade 4/5 or greater motor power at 6 weeks was predictive of complete recovery. Conversely, patients who demon-

strated a motor power of 3/5 or below in their antigravity muscles alone were bound to only experience partial recovery. In short, the cohort with little or no recovery within 6 weeks following the onset of C5P was unlikely to experience good long-term outcomes. In addition, studies have reported that electrophysiological testing (electromyography) could be used as a means to identify patients unlikely to experience any meaningful recovery following postoperative C5P.

A study by Saadeh et al. [9] found that among the patients with severe C5P (defined based on antigravity strength of MRC grade ≤2) 3 months after surgery, 50% recovered useful strength by 12 months. Moreover, among those with persistently severe C5P at 6 months, only 25% recovered sufficient strength by 12 months. however, among those with motor strength of MRC grades 0 or 1 at 6 months, none had a useful strength at the end of 1 year. The mentioned study showed that while the female gender was associated with good recovery of useful strength, the presence of diabetes mellitus significantly impaired the final outcome.

A study by Lim et al. [49] involving 36 patients who developed C5P following cervical decompression surgery found that 50% of patients (among whom 91.7% recovered between 6 months and 2 years, whereas 8.3% did not recover until 2 years) required longer the 6 months to experience useful neurological recovery. The factors associated with prolonged recovery (>6 months) included motor grade ≤2 (p<0.001), multi-segment paresis involving segments apart from the C5 root (p=0.002), extent of posterior spinal cord shift (p=0.04), and the absence of somatic sensation with pain (p=0.008).

Pennington et al. [5,6] concluded that patients who underwent C4–5 foraminotomy had the greatest likelihood of developing a permanent C5 deficit (p=0.004). Among the other radiological parameters, mean cord-lamina angle (p=0.06) and length of laminectomy (p=0.08) showed a tendency toward significance but ultimately failed to attain the threshold for statistical significance (based on analysis of variance).

Factors underlying delayed or compromised neurological recovery

Hashimoto et al. [53] suggested that underlying asymptomatic damage to the anterior horn cells of the gray matter could promote severe postoperative C5P. It is well acknowledged that severe palsies have been associated with slow and poor neurological recovery. Multilevel, associated paresis has also been purported as a factor for poor C5P outcomes, which may be explained by focal reperfusion injury to the spinal cord following spinal decompression [13]. Similarly, significant sensory involvement (>50% involvement) and the presence of intractable pain can be indicators of serious spinal cord injury or substantial cord ischemia or reperfusion injuries, which in turn have been reported as poor prognostic indicators in patients with C5P.

Interventions for patients with poor spontaneous neurological recovery

Traditionally, patients with poor recovery after C5P have only been treated with supportive care. Alternatively, the use of steroids, C4–5 foraminotomy on the side of the palsy, and prophylactic foraminotomy at the index surgery have been utilized as treatment options [41,47,50,61]. Although some studies have concurred on the beneficial effects of corticosteroids in effectuating quicker recovery from the palsy, certain other studies found no significant relationship between steroid administration and recovery duration. Thus, the role of steroids still remains controversial [62,63].

Nerve transfers have been successfully applied to a growing number of indications, such as pre-ganglionic brachial plexus palsy, post-ganglionic brachial plexus palsy, nerve avulsion injuries, and spinal cord injury [8,50,64]. This procedure involves the use of an intact nerve with a duplicated function to restore the function of the injured nerve [65]. Nerve transfers have also been successfully performed in patients with C5P. However, the nerve transfer must be completed and the muscles reinnervated by the axons (i.e., neurotized) before the phenomenon of muscle fibrosis sets in, which roughly corresponds to 12 to 18 months following denervation [66,67]. Indeed, a study by Saadeh et al. [9] recommended such an intervention in patients who lacked useful motor strength (MRC grade ≤3) at the end of 3 postoperative months. Alternatively, studies have recommended a time window of 3 to 9 months following injury, considering that a period of several weeks to months is required for axons to grow from the site of nerve coaptation to the motor end plate at a typical growth rate of 1 mm/day [68,69].

Thompson et al. [50] has recommended surgical decompression (especially ipsilateral C4–5 foraminotomy) for patients with C5P not responding to conservative measures. However, another study by Lim et al. [49] demonstrated that surgical management was helpful only when definitive indications like fluid or seroma collection or compressive hematoma were identified. Therefore, at this point, no strong recommendation can

be made in favor of surgical decompression for C5P unless a compelling indication suggestive of severe, residual spinal cord or nerve root compression is identified.

Limitations

Our study has some limitations that need to be acknowledged. Although this study has been the most comprehensive among all meta-analyses available on the topic to date, we did exclude non-English publications, which might have limited the inclusion of potentially relevant articles published in other languages. Furthermore, most of the studies included were retrospective in nature, thereby reducing the level of evidence for the conclusions derived from them. However, when analyzing complications arising from surgical interventions, one cannot simply rely on studies of higher quality, such as randomized controlled trials, relevant data are mostly reported and analyzed via retrospective case-control studies. We would like to acknowledge our failure to analyze all risk factors for C5P due to the heterogeneity in the reported risk factor data among the included studies. Furthermore, given the paucity and heterogeneity in reported data among the included studies, we failed to explore further causes of heterogeneity in time to palsy among the included studies apart from procedural categorization. Furthermore, we have excluded studies that reported C5P following procedures for cervical radiculopathies. Hence, caution must be experienced when applying the results of this study to conditions other than myelopathy.

Conclusions

Our analysis showed that the presentation of C5P was delayed, with a mean time to onset of 3 days after surgery, ranging from 2 days for ACDF and 3.6 days for PDCF. Recovery progressively improved with time and varied for different index surgical procedures, with the best recovery rates having been observed following ACDF and the poorest recovery rates after PDCF for cervical myelopathy.

Key Points

- Mean onset of C5 palsy was 3 days postoperatively across studies.
- Anterior cervical discectomy and fusion (ACDF) had the earliest palsy at 2 days, followed by Laminoplasty at 3.2 days, and posterior decompression and fusion at 3.6 days.
- Recovery rates at 1 year varied significantly where ACDF showed 100% recovery while laminoplasty showed 52.9%, and posterior decompression and fusion showed 50% recovery.
- Prognosis improved over time, but recovery differed by technique, favoring ACDF over posterior cervical decompression and fusion in cervical myelopathy cases.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

Data generated in the study will be made available upon reasonable request to the authors

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Conceptualization: SM. Data curation: VKV, GPK, AC, SM. Writing–original draft: VKV, GPK, SM. Writing–review & editing: VKV, AC, SM. Final approval of the manuscript: all authors.

References

1. Bydon M, Macki M, Kaloostian P, et al. Incidence and prognostic factors of c5 palsy: a clinical study of 1001 cases and review of the literature. Neurosurgery 2014;74:595-605.
2. Oh JK, Hong JT, Kang DH, et al. Epidemiology of C5 palsy after cervical spine surgery: a 21-center study. Neurospine 2019;16:558-62.

3. Scoville WB. Cervical spondylosis treated by bilateral facetectomy and laminectomy. J Neurosurg 1961;18:423-8.
4. Simon NG, Spinner RJ, Kline DG, Kliot M. Advances in the neurological and neurosurgical management of peripheral nerve trauma. J Neurol Neurosurg Psychiatry 2016;87:198-208.
5. Pennington Z, Lubelski D, D'Sa A, et al. Preoperative clinical and radiographic variables predict postoperative C5 palsy. World Neurosurg 2019;127:e585-92.
6. Pennington Z, Lubelski D, Westbroek EM, et al. Time to recovery predicted by the severity of postoperative C5 palsy. J Neurosurg Spine 2019;32:191-9.
7. Yoshihara H, Margalit A, Yoneoka D. Incidence of C5 palsy: meta-analysis and potential etiology. World Neurosurg 2019;122:e828-37.
8. Lubelski D, Pennington Z, Planchard RF, et al. Use of electromyography to predict likelihood of recovery following C5 palsy after posterior cervical spine surgery. Spine J 2021;21:387-96.
9. Saadeh YS, Chopra Z, Olsen E, et al. Optimal timing of referral for nerve transfer surgery for postoperative C5 palsy. J Neurosurg Spine 2022;37:563-8.
10. Odate S, Shikata J, Yamamura S, Okahata A, Kawaguchi S, Tanaka C. Insufficient recovery from C5 palsy following anterior cervical decompression and fusion. Spine (Phila Pa 1976) 2022;47:423-9.
11. Higgins JP, Thomas J, Chandler J, et al. Cochrane handbook for systematic reviews of interventions. 2nd ed. Hoboken (NJ): John Wiley & Sons Inc.; 2019.
12. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ 2021;372:n160.
13. Chiba K, Toyama Y, Matsumoto M, Maruiwa H, Watanabe M, Hirabayashi K. Segmental motor paralysis after expansive open-door laminoplasty. Spine (Phila Pa 1976) 2002;27:2108-15.
14. Yonenobu K, Hosono N, Iwasaki M, Asano M, Ono K. Neurologic complications of surgery for cervical compression myelopathy. Spine (Phila Pa 1976) 1991;16:1277-82.
15. Edwards CC, Heller JG, Silcox DH. T-Saw laminoplasty for the management of cervical spondylotic myelopathy: clinical and radiographic outcome. Spine (Phila Pa 1976) 2000;25:1788-94.
16. Ikenaga M, Shikata J, Tanaka C. Radiculopathy of C-5 after anterior decompression for cervical myelopathy. J Neurosurg Spine 2005;3:210-7.
17. Kaneko K, Hashiguchi A, Kato Y, Kojima T, Imajyo Y, Taguchi T. Investigation of motor dominant C5 paralysis after laminoplasty from the results of evoked spinal cord responses. J Spinal Disord Tech 2006;19:358-61.
18. Guo Q, Ni B, Zhou F, et al. Anterior hybrid decompression and segmental fixation for adjacent three-level cervical spondylosis. Arch Orthop Trauma Surg 2011;131:631-6.
19. Zhao X, Xue Y, Pan F, et al. Extensive laminectomy for the treatment of ossification of the posterior longitudinal ligament in the cervical spine. Arch Orthop Trauma Surg 2012;132:203-9.
20. Eskander MS, Balsis SM, Balinger C, et al. The association between preoperative spinal cord rotation and postoperative C5 nerve palsy. J Bone Joint Surg Am 2012;94:1605-9.
21. Chang PY, Chan RC, Tsai YA, et al. Quantitative measures of functional outcomes and quality of life in patients with C5 palsy. J Chin Med Assoc 2013;76:378-84.
22. Wu FL, Sun Y, Pan SF, Zhang L, Liu ZJ. Risk factors associated with upper extremity palsy after expansive open-door laminoplasty for cervical myelopathy. Spine J 2014;14:909-15.
23. Macki M, Alam R, Kerezoudis P, Gokaslan Z, Bydon A, Bydon M. Manual muscle test at C5 palsy onset predicts the likelihood of and time to C5 palsy resolution. J Clin Neurosci 2016;24:112-6.
24. Takenaka S, Hosono N, Mukai Y, Tateishi K, Fuji T. Significant reduction in the incidence of C5 palsy after cervical laminoplasty using chilled irrigation water. Bone Joint J 2016;98-B:117-24.
25. Lee SH, Suk KS, Kang KC, et al. Outcomes and related factors of C5 palsy following cervical laminectomy with instrumented fusion compared with laminoplasty. Spine (Phila Pa 1976) 2016;41:E574-9.
26. Kang KC, Suk KS, Kim HS, et al. Preoperative risk factors of C5 nerve root palsy after laminectomy and fusion in patients with cervical myelopathy: analysis of 70 consecutive patients. Clin Spine Surg 2017;30:419-24.
27. Nori S, Aoyama R, Ninomiya K, et al. Cervical laminectomy of limited width prevents postoperative C5 palsy: a multivariate analysis of 263 muscle-preserving posterior decompression cases. Eur Spine J 2017;26:2393-403.
28. Chen G, Wang Y, Wang Z, Zhu R, Yang H, Luo Z. Analysis of C5 palsy in cervical myelopathy with massive anterior compression following laminoplasty. J Orthop Surg Res 2018;13:26.
29. Sun K, Wang S, Sun J, et al. Surgical outcomes after anterior controllable antedisplacement and fusion compared with single open-door laminoplasty: preliminary analysis of postoperative changes of spinal cord displacements on T2-weighted magnetic resonance imaging. World Neurosurg 2019;127:e288-98.
30. Lubelski D, Derakhshan A, Nowacki AS, et al. Predicting C5 palsy via the use of preoperative anatomic measurements. Spine J 2014;14:1895-901.
31. Pennington Z, Lubelski D, Lakomkin N, et al. Timing of referral to peripheral nerve specialists in patients with postoperative C5 palsy. J Clin Neurosci 2021;92:169-74.
32. Wang H, Tang ZR, Li W, et al. Prediction of the risk of C5 palsy after posterior laminectomy and fusion with cervical myelopathy using a support vector machine: an analysis of 184 consecutive patients. J Orthop Surg Res 2021;16:332.
33. Takano M, Tsuji O, Fujiyoshi K, et al. Clinical application of diffusion tensor tractography to postoperative C5 palsy. Spinal Cord Ser Cases 2021;7:83.
34. Shah AA, Devana SK, Lee C, et al. A risk calculator for the prediction of C5 nerve root palsy after instrumented cervi-

cal fusion. World Neurosurg 2022;166:e703-10.
35. Levi DJ, Brusko GD, Levi AD, Wang MY. Does hinge sidedness influence laterality of C5 palsy after expansile open-door cervical laminoplasty? Neurosurg Focus 2023;55:E6.
36. Kang KC, Im SK, Lee JH, Lee KY, Seo DU, Hwang IU. Impact of lamina-open side on unilateral open door laminoplasty in patients with degenerative cervical myelopathy. Sci Rep 2023;13:2062.
37. Tsuzuki N, Abe R, Saiki K, Zhongshi L. Extradural tethering effect as one mechanism of radiculopathy complicating posterior decompression of the cervical spinal cord. Spine (Phila Pa 1976) 1996;21:203-11.
38. Houten JK, Buksbaum JR, Collins MJ. Patterns of neurological deficits and recovery of postoperative C5 nerve palsy. J Neurosurg Spine 2020;33:742-50.
39. Shiozaki T, Otsuka H, Nakata Y, et al. Spinal cord shift on magnetic resonance imaging at 24 hours after cervical laminoplasty. Spine (Phila Pa 1976) 2009;34:274-9.
40. Hosono N, Miwa T, Mukai Y, Takenaka S, Makino T, Fuji T. Potential risk of thermal damage to cervical nerve roots by a high-speed drill. J Bone Joint Surg Br 2009;91:1541-4.
41. Imagama S, Matsuyama Y, Yukawa Y, et al. C5 palsy after cervical laminoplasty: a multicentre study. J Bone Joint Surg Br 2010;92:393-400.
42. Komagata M, Nishiyama M, Endo K, Ikegami H, Tanaka S, Imakiire A. Prophylaxis of C5 palsy after cervical expansive laminoplasty by bilateral partial foraminotomy. Spine J 2004;4:650-5.
43. 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) 2003;28:2447-51.
44. Hasegawa K, Homma T, Chiba Y. Upper extremity palsy following cervical decompression surgery results from a transient spinal cord lesion. Spine (Phila Pa 1976) 2007;32:E197-202.
45. Pan FM, Wang SJ, Ma B, Wu DS. C5 nerve root palsy after posterior cervical spine surgery. J Orthop Surg (Hong Kong) 2017;25:2309499016684502.
46. Shou F, Li Z, Wang H, Yan C, Liu Q, Xiao C. Prevalence of C5 nerve root palsy after cervical decompressive surgery: a meta-analysis. Eur Spine J 2015;24:2724-34.
47. Nassr A, Eck JC, Ponnappan RK, Zanoun RR, Donaldson WF 3rd, Kang JD. The incidence of C5 palsy after multilevel cervical decompression procedures: a review of 750 consecutive cases. Spine (Phila Pa 1976) 2012;37:174-8.
48. Kratzig T, Mohme M, Mende KC, Eicker SO, Floeth FW. Impact of the surgical strategy on the incidence of C5 nerve root palsy in decompressive cervical surgery. PLoS One 2017;12:e0188338.
49. Lim CH, Roh SW, Rhim SC, Jeon SR. Clinical analysis of C5 palsy after cervical decompression surgery: relationship between recovery duration and clinical and radiological factors. Eur Spine J 2017;26:1101-10.
50. Thompson SE, Smith ZA, Hsu WK, et al. C5 palsy after cervical spine surgery: a multicenter retrospective review of 59 cases. Global Spine J 2017;7(1 Suppl):64S-70S.
51. Traynelis VC, Fontes RB, Kasliwal MK, et al. Risk factors for C5 palsy: a systematic review and multivariate analysis. J Neurosurg Spine 2023;40:216-28.
52. Luo J, Cao K, Huang S, et al. Comparison of anterior approach versus posterior approach for the treatment of multilevel cervical spondylotic myelopathy. Eur Spine J 2015;24:1621-30.
53. Hashimoto M, Mochizuki M, Aiba A, et al. C5 palsy following anterior decompression and spinal fusion for cervical degenerative diseases. Eur Spine J 2010;19:1702-10.
54. Uematsu Y, Tokuhashi Y, Matsuzaki H. Radiculopathy after laminoplasty of the cervical spine. Spine (Phila Pa 1976) 1998;23:2057-62.
55. Wang J, Wo J, Wen J, Zhang L, Xu W, Wang X. Laminoplasty versus laminectomy with fusion for treatment of multilevel cervical compressive myelopathy: an updated meta-analysis. Postgrad Med J 2022;98:680-8.
56. Wang T, Wang H, Liu S, Ding WY. Incidence of C5 nerve root palsy after cervical surgery: a meta-analysis for last decade. Medicine (Baltimore) 2017;96:e8560.
57. Yang L, Gu Y, Shi J, et al. Modified plate-only open-door laminoplasty versus laminectomy and fusion for the treatment of cervical stenotic myelopathy. Orthopedics 2013;36:e79-87.
58. Hatta Y, Shiraishi T, Hase H, et al. Is posterior spinal cord shifting by extensive posterior decompression clinically significant for multisegmental cervical spondylotic myelopathy? Spine (Phila Pa 1976) 2005;30:2414-9.
59. Blizzard DJ, Gallizzi MA, Sheets C, et al. The role of iatrogenic foraminal stenosis from lordotic correction in the development of C5 palsy after posterior laminectomy and fusion. J Orthop Surg Res 2015;10:160.
60. Sodeyama T, Goto S, Mochizuki M, Takahashi J, Moriya H. Effect of decompression enlargement laminoplasty for posterior shifting of the spinal cord. Spine (Phila Pa 1976) 1999;24:1527-32.
61. Nakashima H, Imagama S, Yukawa Y, et al. Multivariate analysis of C-5 palsy incidence after cervical posterior fusion with instrumentation. J Neurosurg Spine 2012;17:103-10.
62. Zhang H, Sun T, Lu S, Li Q, Yadav SK. Comparison of effectiveness between laminoplasty and laminectomy decompression and fusion with internal fixation for cervical spondylotic myelopathy. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi 2012;26:1191-6.
63. Liu T, Zou W, Han Y, Wang Y. Correlative study of nerve root palsy and cervical posterior decompression laminectomy and internal fixation. Orthopedics 2010;33.
64. Midha R, Grochmal J. Surgery for nerve injury: current and future perspectives. J Neurosurg 2019;130:675-85.
65. Bazarek S, Brown JM. The evolution of nerve transfers for spinal cord injury. Exp Neurol 2020;333:113426.
66. Brown JM, Shah MN, Mackinnon SE. Distal nerve transfers: a biology-based rationale. Neurosurg Focus 2009;26:E12.
67. Carlson BM. The biology of long-term denervated skeletal

muscle. Eur J Transl Myol 2014;24:3293.
68. Kato N, Htut M, Taggart M, Carlstedt T, Birch R. The effects of operative delay on the relief of neuropathic pain after injury to the brachial plexus: a review of 148 cases. J Bone Joint Surg Br 2006;88:756-9.
69. Solla DJ, de Oliveira AJ, Riechelmann RS, Martins RS, Siqueira MG. Functional outcome predictors after spinal accessory nerve to suprascapular nerve transfer for restoration of shoulder abduction in traumatic brachial plexus injuries in adults: the effect of time from injury to surgery. Eur J Trauma Emerg Surg 2022;48:1217-23.