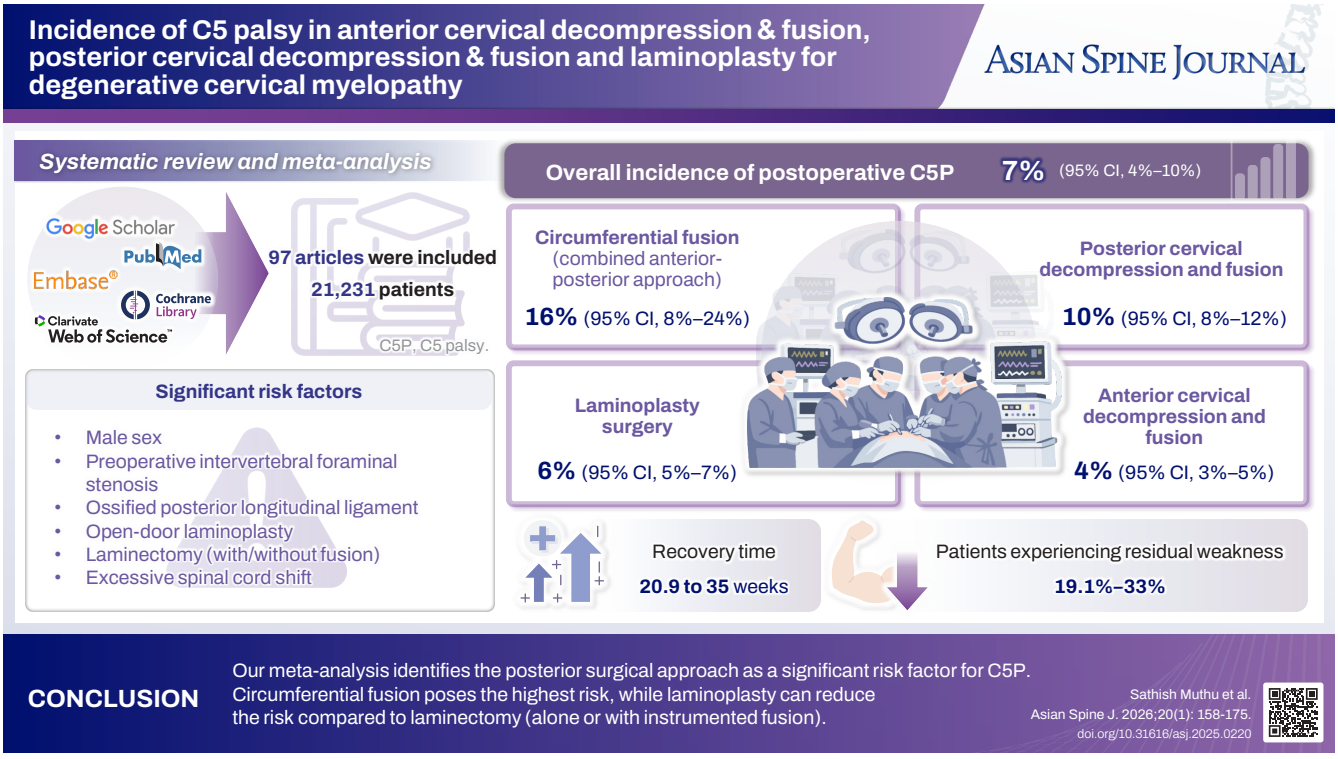
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Incidence of C5 palsy in anterior cervical decompression & fusion, posterior cervical decompression & fusion and laminoplasty for degenerative cervical myelopathy: systematic review and meta-analysis of 21,231 cases

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Incidence of C5 palsy in anterior cervical decompression & fusion, posterior cervical decompression & fusion and laminoplasty for degenerative cervical myelopathy: systematic review and meta-analysis of 21,231 cases

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C5 palsy (C5P) is a common, yet poorly understood complication of cervical decompressive surgery, causing substantial disability and impacting postoperative quality of life. Despite extensive research, the actual incidence and distribution of C5P across different cervical surgical approaches over the past decade remain unclear. A comprehensive literature search was conducted on October 15, 2024, across Google Scholar, Embase, PubMed, Web of Science, and Cochrane Library databases. Studies reporting C5P incidence following surgery for degenerative cervical conditions, published until 2024, were included, excluding reviews, opinions, letters, and non-English manuscripts. Ninety-seven articles were included, encompassing 21,231 patients undergoing decompressive cervical surgery for degenerative cervical myelopathy. The overall incidence of postoperative C5P was 7% (95% confidence interval [CI], 4%–10%). The highest incidence was observed with circumferential fusion (combined anterior-posterior approach) at 16% (95% CI, 8%–24%), while the lowest was with anterior cervical decompression and fusion at 4% (95% CI, 3%–5%). Incidence rates following laminoplasty and laminectomy and fusion were 6% (95% CI, 5%–7%) and 10% (95% CI, 8%–12%), respectively. Recovery time ranged from 20.9 to 35 weeks, with 19.1%–33% of patients experiencing residual weakness. Significant risk factors included male sex, preoperative intervertebral foraminal stenosis, ossified posterior longitudinal ligament, open-door laminoplasty, laminectomy (with/without fusion), and excessive spinal cord shift. The role of C4–5 foraminotomy remains contested. Our meta-analysis identifies the posterior surgical approach as a significant risk factor for C5P. Circumferential fusion poses the highest risk, while laminoplasty can reduce the risk compared to laminectomy (alone or with instrumented fusion).

Keywords: Anterior cervical decompression and fusion; Cervical laminectomy; Cervical laminoplasty; C5 palsy; Cervical myelopathy

Introduction

C5 palsy (C5P) is a recognized complication of cervical spine surgery, with incidence rates ranging from 5% to 10% [1]. Although traditionally associated with posterior cervical surgical approaches, such as laminoplasty (LP) and laminectomy (with or without fusion), C5P has also been reported in anterior cervical decompression and fusion (ACDF) surgeries [2-7]. C5P has broadly been defined as the *de novo* occurrence or worsening of isolated motor weakness involving the C5 myotome (or deterioration in the muscle strength of deltoid or biceps brachii by at least one grade in manual muscle testing [MMT]), without any deterioration in lower extremity function or sensory disturbances [3,8-12]. It primarily manifests as weakness of the deltoid, biceps brachii, and supinator muscles. Although unilateral involvement is typically described, the condition can occur bilaterally [13-15].

Among the C5–T1 nerve roots contributing to the brachial plexus, the C5 root is most frequently associated with post-surgical segmental palsy [16]. Despite unclear etiopathogenesis, several factors have been implicated, including iatrogenic C5 nerve root injury, thermal injury during bone drilling, ischemia of the cervical spinal cord, tethering of the C5 nerve root due to spinal cord shift after decompression, root compression within the neural foramina, and reperfusion-related cord injury [16,17].

Several studies have examined the incidence, etiological factors, and prognosis of C5P. However, the true incidence of this complication following cervical decompressive surgeries, and its variations across different surgical approaches (anterior versus posterior, fusion versus non-fusion) and technical factors (surgical technique and number of segments of decompression), remains unclear [2,4,6,8,12,15,16,18]. This meta-analysis was conducted to synthesize the large body of evidence on C5P and assess its incidence and distribution across diverse cervical decompressive surgical approaches.

Methods

The study was conducted in accordance with the Cochrane Collaboration guidelines for systematic reviews [19] and Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [20].

Literature search

A comprehensive literature search was conducted on October 15, 2024, across five databases (Google Scholar, Embase, PubMed, Web of Science, and Cochrane Library). Studies published through 2024 that reported on the incidence of C5P in patients undergoing cervical decompression were reviewed. The search utilized keywords combined with Boolean operators: (((ACDF) OR (cervical fusion) OR (laminoplasty) OR (circumferential fusion) OR (posterior decompression)) AND (C5 palsy)).

Inclusion and exclusion criteria

Studies reporting on the occurrence, management, or recovery of C5P following decompressive surgery for degenerative cervical myelopathy were considered. Narrative or systematic reviews, opinions, letters to the editor, and non-English publications were excluded. The article selection criteria are summarized in Table 1.

Manuscript selection and data extraction

The search results were downloaded, imported into EndNote (Clarivate, Philadelphia, PA, USA), and deduplicated. Two authors independently screened titles, followed by a separate screening of manuscripts based on the aforementioned criteria. Full-text manuscripts were then reviewed in duplicate, and final article selection was completed. For studies with overlapping patient cohorts from the same center, only the most relevant sample was included. Discrepancies among the authors were resolved through discussion with the senior author.

Quality assessment

The methodological quality of the included studies was assessed using the Newcastle Ottawa Scale for non-randomized studies (Table 2). Only studies with adequate methodological quality were included in the analysis.

Statistical analysis

The meta-analysis was conducted using Stata ver. 16.0 software (Stata Corp., College Station, TX, USA). The reported incidence of C5P was pooled, and the mean incidence was calculated with a 95% confidence interval (CI). A random-effects model was used for data synthesis when heterogeneity was high (I^2>50% and p<0.10). Otherwise, a fixed-effects model was applied. Sensitivity and subgroup analyses were performed when heterogeneity was detected. Publication bias was assessed using Egger's regression test. A p-value less than 0.05 was considered indicative of statistical significance for all statistical analyses

Results

The literature search yielded 3,903 articles. After deduplication and screening, 2,247 manuscripts were assessed. After screening of titles, 244 manuscripts qualified for the next level of screening. Following abstract and full-text review, 97 articles were selected for the systematic review. The study selection process is illustrated in the PRISMA flow diagram (Fig. 1). The general characteristics and outcomes of the included studies are summarized in Table 3. A total of 21,231

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 incidence	-
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

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Table 2. Quality assessment of the included studies

No.	Author	Year	Selection				Comparability	Outcome		
			Representativeness	Non-exposed cohort	Exposure	Outcome at study initiation		Assessment	Follow-up for outcome	Follow-up adequacy
1	K Yonenobu	1991	*	*	*	*	*	*		*
2	N Tsuzuki	1993	*	*	*	*	*	*	*	
3	K Satomi	1994	*	*	*	*	*	*		*
4	Y Uematsu	1998	*	*	*	*	*	*	*	
5	K Hirabayashi	1999	*	*	*	*	*	*		*
6	CC Edwards	2000	*	*	*	*	*	*	*	*
7	E Wada	2001	*	*	*	*	*	*	*	*
8	K Chiba	2002	*	*	*	*	*			*
9	M Ikenaga	2005	*	*	*	*	*	*	*	
10	K Kaneko	2006	*	*	*	*	*	*	*	*
11	Y Liu	2009	*	*	*	*	*	*	*	*
12	M Hashimoto	2010	*	*	*	*	*	*	*	*
13	M Yanase	2010	*	*	*	*	*	*	*	
14	X Guo	2010	*	*	*	*	*	*	*	*
15	XF Lian	2010	*	*	*	*	*	*	*	*
16	K Kotil	2011	*	*	*	*	*	*	*	*
17	X Zhao	2011	*	*	*	*	*	*	*	*
18	JM Highsmith	2011	*	*	*	*	*		*	*
19	Y Chen	2011	*	*	*	*	*	*	*	*
20	Q Lin	2011	*	*	*	*	*	*	*	*
21	PY Chang	2012	*	*	*	*	*	*	*	
22	MS Eskander	2012	*	*	*	*	*	*		*
23	Y Liu	2012	*	*	*	*	*	*	*	*
24	Ya Liu	2012	*	*	*	*	*	*		*
25	D Lubelski	2013	*	*	*	*	*	*		
26	L Yang	2013	*	*	*	*	*	*		*
27	M Ohashi	2014	*	*	*	*	*			*
28	DK Son	2014	*	*	*	*	*			*
29	FL Wu	2014	*	*	*	*	*	*	*	*
30	M Bydon	2014	*	*	*	*	*	*		*
31	T Maeno	2014	*	*	*	*	*	*	*	*
32	KL Tung	2015	*	*	*	*	*		*	*
33	M Macki	2015	*	*	*	*	*	*	*	*
34	DJ Blizzard	2015	*	*	*	*	*	*	*	*
35	H Wang	2015	*	*	*	*	*	*	*	*
36	CH Lim	2016	*	*	*	*	*	*	*	*
37	H Chen	2016	*	*	*	*	*			
38	S Takenaka	2016	*	*	*	*	*	*	*	*
39	SH Lee	2016	*	*	*	*	*	*	*	*
40	DJ Blizzard	2016	*	*	*	*	*	*	*	*
41	M Koda	2016	*	*	*	*	*	*	*	*

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Table 2. Continued

No.	Author	Year	Selection				Comparability	Outcome		
			Representativeness	Non-exposed cohort	Exposure	Outcome at study initiation		Assessment	Follow-up for outcome	Follow-up adequacy
42	M Machino	2016	*	*	*	*	*	*	*	*
43	MG Fehlings	2016	*	*	*	*	*	*		*
44	X Liu	2016	*	*	*	*	*		*	*
45	KC Kang	2017	*	*	*	*	*	*	*	*
46	S Nori	2017	*	*	*	*	*	*	*	*
47	T Kratzig	2017	*	*	*	*	*	*	*	*
48	Z Li	2017	*	*	*	*	*	*	*	*
49	G Chen	2018	*	*	*	*	*	*	*	*
50	H Miyamoto	2018	*	*	*	*	*	*	*	*
51	YJ Zhao	2018	*	*	*	*	*			*
52	HT Wu	2018	*	*	*	*	*		*	*
53	Y Yang	2018	*	*	*	*	*	*	*	
54	K Sun	2019	*	*	*	*	*	*	*	*
55	SC Wagner	2019	*	*	*	*	*	*	*	*
56	Y Kobayashi	2019	*	*	*	*	*			*
57	Z Yu	2019	*	*	*	*	*	*		
58	Z Pennington	2019	*	*	*	*	*	*	*	*
59	Z Pennington	2019	*	*	*	*	*	*	*	
60	Y Ha	2019	*	*	*	*	*	*	*	*
61	SQ Li	2019	*	*	*	*	*	*		*
62	C Zhou	2019	*	*	*	*	*	*	*	*
63	D Lubelski	2020	*		*	*		*	*	*
64	JK Houten	2020	*	*	*	*	*	*	*	*
65	X He	2020	*	*	*	*	*			*
66	FMD Pont	2021	*	*	*	*	*	*	*	
67	H Wang	2021	*	*	*	*	*			
68	RC Hofler	2021	*	*	*	*	*	*	*	*
69	Y Liu	2021	*	*	*	*	*			*
70	Z Pennington	2021	*	*	*			*	*	*
71	M Takano	2021	*	*	*	*	*	*	*	*
72	M Funaba	2021	*	*	*	*	*			
73	S Odate	2021	*	*	*	*	*	*	*	*
74	B Benek	2021	*	*	*	*	*		*	*
75	RC Huang	2022	*	*	*	*	*			*
76	Y Yang	2022	*	*	*	*	*	*	*	*
77	YS Saadeh	2022	*		*			*	*	*
78	L Papavero	2022	*	*	*	*	*	*		
79	A Biczok	2022	*	*	*	*	*	*	*	
80	F Liu	2022	*	*	*	*	*	*		
81	H Nakashima	2022	*	*	*	*	*	*		*
82	AA Shah	2022	*	*	*	*	*	*	*	*

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Table 2. Continued

No.	Author	Year	Selection				Comparability	Outcome		
			Representativeness	Non-exposed cohort	Exposure	Outcome at study initiation		Assessment	Follow-up for outcome	Follow-up adequacy
83	C Li	2022	*	*	*	*	*	*	*	*
84	J Tian	2022	*	*	*	*	*	*		*
85	J Kim	2022	*	*	*	*	*	*		
86	N Nagoshi	2023	*	*	*	*	*			*
87	KC Kang	2023	*	*	*	*	*	*	*	*
88	N Kim	2023	*	*	*	*	*			*
89	DJ Levi	2023	*	*	*	*	*		*	*
90	I Uzunoglu	2023	*	*	*	*	*	*	*	
91	J Liu	2023	*	*	*	*	*	*		*
92	A Aiba	2023	*	*	*	*	*	*		*
93	O Bakr	2023	*	*	*	*	*	*		*
94	H Zhong	2023	*	*	*	*	*			*
95	TH Tu	2024	*	*	*	*	*			*
96	M Hashimoto	2024	*	*	*	*	*			*
97	S Basu	2024	*	*	*	*	*		*	*

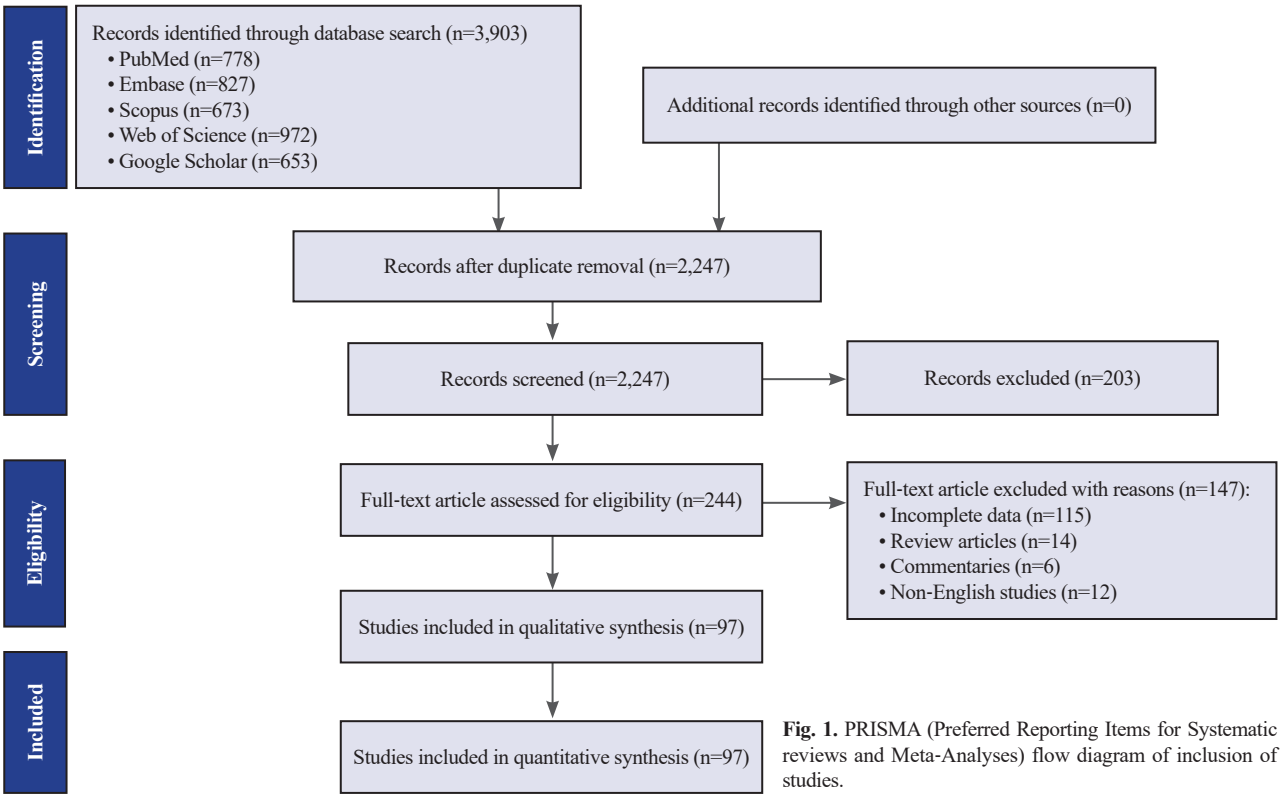


Fig. 1. PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) flow diagram of inclusion of studies.

patients who underwent surgery for cervical myelopathy were analyzed in the included studies. Most studies were retrospective (n=86 [88.7%]). Follow-up periods ranged from 1 month to 12 years (Table 3).

Etiopathogenesis of C5P

Wang et al. [17,21] described C5P as a disorder or insult to the nerve root or segmental spinal cord. Five major

Table 3. General characteristics of studies included in the review

No.	Author	Year	Country	Sample size	Type	Age (yr)	M:F	Palsy incidence	Procedure	Follow-up
1	K Yonenobu	1991	Japan	384	Retrospective cohort study	56.7	298:86	13	ACDF; LP	6.1 yr
2	N Tsuzuki	1993	Japan	198	Retrospective cohort study	59	NA	20	PCDF; LP	54 mo
3	K Satomi	1994	Japan	51	Retrospective cohort study	54.7	44:7	4	LP	7.8 yr
4	Y Uematsu	1998	Japan	365	Retrospective cohort study	NA	NA	20	LP	48 mo
5	K Hirabayashi	1999	Japan	87	Retrospective cohort study	57	76:11	6	LP	7 yr
6	CC Edwards	2000	USA	18	Retrospective cohort study	54	13:5	1	LP	18 mo
7	E Wada	2001	Japan	47	Retrospective cohort study	54.3±9.2	NA	5	ACDF; LP	12 yr
8	K Chiba	2002	Japan	141	Retrospective cohort study	56	NA	11	LP	2 yr
9	M Ikenaga	2005	Japan	549	Retrospective cohort study	NA	NA	18	ACDF; LP	12 mo
10	K Kaneko	2006	Japan	66	Retrospective cohort study	67	38:28	5	LP	2 yr
11	Y Liu	2009	China	28	Retrospective cohort study	53.5	19:09	1	ACDF; LP	17.3 mo
12	M Hashimoto	2010	Japan	199	Retrospective cohort study	NA	NA	17	ACDF; LP	15 mo
13	M Yanase	2010	Japan	153	Retrospective cohort study	59.8	NA	9	LP	12 mo
14	Q Guo	2010	China	53	Retrospective cohort study	53.4±9.5	35:18	1	ACDF	37.3/7 mo
15	XF Lian	2010	China	105	Prospective cohort study	60.3	63:42	2	ACDF	31.5 mo
16	K Kotil	2011	Turkey	25	Retrospective cohort study	60.4	19:6	3	ACDF	3.1 yr
17	X Zhao	2011	China	82	Retrospective cohort study	57.6	47:35	2	PCDF; LP	41.6 mo
18	JM Highsmith	2011	USA	56	Retrospective cohort study	59.5	NA	2	PCDF; LP	41.8 mo
19	Y Chen	2011	China	75	Retrospective cohort study	NA	NA	6	ACDF; PCDF; LP	48 mo
20	Q Lin	2011	China	120	Retrospective cohort study	58.3±9.8	81:39	5	ACDF	24 mo
21	PY Chang	2012	Taiwan	364	Retrospective cohort study	55.9±12	224:140	12	ACDF; LP; Global	12 mo
22	MS Eskander	2012	USA	176	Retrospective cohort study	49.7±11.4	NA	12	ACDF	NA
23	Y Liu	2012	China	286	Retrospective cohort study	53.8±7.2	166:120	22	ACDF	24 mo
24	Ya Liu	2012	China	180	Retrospective cohort study	46.9±6.8	109:71	8	ACDF	26.3 mo
25	D Lubelski	2013	USA	98	Retrospective cohort study	59.5±12	NA	12	ACDF; PCDF; LP	NA
26	L Yang	2013	China	141	Retrospective cohort study	57.9±8.2	106:35	14	LP; Laminectomy	24 mo
27	M Ohashi	2014	Japan	236	Prospective cohort study	63.8±11.2	168:68	10	LP	24 mo
28	DK Son	2014	South Korea	62	Retrospective cohort study	61.5	44:18	1	LP	12 mo
29	FL Wu	2014	China	102	Retrospective cohort study	58.4	76:26	16	LP	16.3 mo
30	M Bydon	2014	USA	41	Retrospective cohort study	64±10.5	24:17	9	PCDF	26.7 mo
31	T Maeno	2014	Japan	100	Retrospective cohort study	69	69:31	5	LP	4.1 yr
32	KL Tung	2015	Hong Kong	29	Retrospective cohort study	64.3	20:09	2	LP	48 mo
33	M Macki	2015	USA	511	Retrospective cohort study	NA	NA	43	PCDF	36 mo/34.5
34	DJ Blizzard	2015	USA	54	Retrospective cohort study	59±9.5	35:19	13	PCDF; LP	6 mo
35	H Wang	2015	China	161	Retrospective cohort study	61.8±9.3	108:53	8	ACDF	3.7/1.3 yr
36	CH Lim	2016	South Korea	710	Retrospective cohort study	59	477:233	36	ACDF; PCDF; LP; Global	25.8 mo
37	H Chen	2016	China	105	Retrospective cohort study	61	84:21	13	LP	
38	S Takenaka	2016	Japan	800	Prospective cohort study	64.5	543:257	54	PCDF	27.4 mo
39	SH Lee	2016	South Korea	190	Retrospective cohort study	59.5±11.8	105:85	30	PCDF; LP	38.5 mo
40	DJ Blizzard	2016	USA	72	Retrospective cohort study	NA	NA	13	PCDF; LP	18.7 mo
41	M Koda	2016	Japan	48	Retrospective cohort study	61	36:12	4	ACDF; PCDF; LP	48.8 mo
42	M Machino	2016	Japan	505	Prospective cohort study	66.6	311:194	7	LP	26.5/12.5 mo

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Table 3. Continued

No.	Author	Year	Country	Sample size	Type	Age (yr)	M:F	Palsy incidence	Procedure	Follow-up
43	MG Fehlings	2016	Canada	266	Prospective cohort study	60.9±11.1	180:86	7	PCDF; LP	24 mo
44	X Liu	2016	China	67	Retrospective cohort study	59.5±9	51:16	2	PCDF; LP	40/11 mo
45	KC Kang	2017	South Korea	70	Retrospective cohort study	60.3	47:23	10	PCDF	12 mo
46	S Nori	2017	Japan	263	Retrospective cohort study	63±10.8	190:73	11	PCDF	12 mo
47	T Kratzig	2017	Germany	1,708	Prospective cohort study	61±11.6	777:931	82	PCDF; Global	36 mo
48	Z Li	2017	China	70	Retrospective cohort study	56.8	49:21	3	ACDF	24 mo
49	G Chen	2018	China	118	Retrospective cohort study	58	94:24	12	LP	36 mo
50	H Miyamoto	2018	Japan	31	Retrospective cohort study	66.7	17:14	10	PCDF; Global	30/10 mo
51	YJ Zhao	2018	China	71	Retrospective cohort study	59±16	39:32	10	PCDF	22.5/6.2 mo
52	HT Wu	2018	China	168	Retrospective cohort study	50.5±17	89:78	9	ACDF	21.5 mo
53	Y Yang	2018	China	100	Retrospective cohort study	49.6±5.3	48:52	11	ACDF	NA
54	K Sun	2019	China	80	Retrospective cohort study	57.2±12	42:38	5	ACDF; LP	12 mo
55	SC Wagner	2019	USA	196	Retrospective cohort study	59	96:100	10	ACDF	7 mo
56	Y Kobayashi	2019	Japan	174	Retrospective cohort study	63.3	83:31	10	PCDF	12.3 mo
57	Z Yu	2019	Taiwan	44	Prospective cohort study	61±10.2	25:19	4	PCDF; LP	19 mo
58	Z Pennington	2019	USA	221	Retrospective cohort study	63	119:102	27	PCDF	12.9 mo
59	Z Pennington	2019	USA	242	Retrospective cohort study	62.4	160:82	42	PCDF	27.9 mo
60	Y Ha	2019	South Korea	91	Retrospective cohort study	60.5	69:22	9	PCDF; LP	38.6 mo
61	SQ Li	2019	China	158	Retrospective cohort study	56.9±8.5	83:75	5	ACDF	21.4/7.6 mo
62	C Zhou	2019	China	52	Retrospective cohort study	55.3	30:22	0	ACDF; LP	15.9 mo
63	D Lubelski	2020	USA	77	Retrospective cohort study	64.5±7.6	61:16	77	PCDF	17.6/23.6 mo
64	JK Houten	2020	USA	642	Retrospective cohort study	65	325:317	18	ACDF; PCDF	20/10.7 mo
65	X He	2020	China	104	Retrospective cohort study	58.5±8.1	51:53	8	PCDF; LP	35.2/10.2 mo
66	FMD Pont	2021	Argentina	20	Retrospective cohort study	58	12:8	1	LP	9 mo
67	H Wang	2021	China	184	Retrospective cohort study	63±11.4	76:108	26	PCDF	12 mo
68	RC Hofler	2021	USA	190	Retrospective cohort study	NA	NA	53	PCDF	19.9 mo
69	Y Liu	2021	China	90	Retrospective cohort study	56.12±12.2	43:47	8	PCDF	16/3.5 mo
70	Z Pennington	2021	USA	77	Retrospective cohort study	64	52:25	77	PCDF	11 mo
71	M Takano	2021	Japan	108	Retrospective cohort study	66.1±11.7	88:20	5	LP	12 mo
72	M Funaba	2021	Japan	1,176	Prospective cohort study	67.6±4.4	663:513	31	ACDF; PCDF; LP; Global	NA
73	S Odate	2021	Japan	839	Retrospective cohort study	59.1±11.6	NA	57	ACDF	55/17 mo
74	B Benek	2021	Turkey	52	Retrospective cohort study	61.9	41:11	3	PCDF; LP	20 mo
75	RC Huang	2022	USA	32	Retrospective cohort study	67.8	24:08	2	PCDF	15.2 mo
76	Y Yang	2022	China	76	Retrospective cohort study	61±8.2	40:36	9	PCDF; LP	18/2.6 mo
77	YS Saadeh	2022	USA	72	Retrospective cohort study	62.5	46:26	72	ACDF; PCDF	12 mo
78	L Papavero	2022	Germany	23	Prospective cohort study	72	17:6	1	Global	12 mo
79	A Biczok	2022	Germany	29	Prospective cohort study	71.5	16:13	1	PCDF	3 mo
80	F Liu	2022	China	98	Retrospective cohort study	62.2±7.7	56:42	9	LP	19.6/5.2 mo
81	H Nakashima	2022	Japan	189	Prospective cohort study	64±11	134:55	15	PCDF; LP	24 mo
82	AA Shah	2022	USA	1,024	Retrospective cohort study	60	588:436	52	ACDF; PCDF	NA
83	C Li	2022	China	17	Retrospective cohort study	57±10.5	12:5	1	PCDF	16/3.3 mo
84	J Tian	2022	China	52	Retrospective cohort study	62±9.2	20:32	5	LP	15 mo

(Continued on the next page)

Table 3. Continued

No.	Author	Year	Country	Sample size	Type	Age (yr)	M:F	Palsy incidence	Procedure	Follow-up
85	J Kim	2022	USA	264	Retrospective cohort study	62±11.5	184:80	14	PCDF; LP	1 mo
86	N Nagoshi	2023	Japan	253	Retrospective cohort study	61±9.2	180:73	19	ACDF; PCDF; LP	24 mo
87	KC Kang	2023	South Korea	193	Retrospective cohort study	59.7±11.9	135:58	12	LP	38.1/15.1 mo
88	N Kim	2023	South Korea	101	Retrospective cohort study	66.2±10	82:19	16	LP	22.3/10.3 mo
89	DJ Levi	2023	USA	272	Retrospective cohort study	59.9	NA	7	PCDF; LP	24 mo
90	I Uzunoglu	2023	Turkey	177	Retrospective cohort study	58.1±11.8	117:60	22	LP	6 mo
91	J Liu	2023	China	122	Retrospective cohort study	60.1±3.8	73:49	9	ACDF; LP	26.8/3.1 mo
92	A Aiba	2023	Japan	801	Retrospective cohort study	64.4±11.9	559:242	42	ACDF	12 mo
93	O Bakr	2023	USA	135	Retrospective cohort study	63	74:61	12	PCDF; LP	24 mo
94	H Zhong	2023	China	116	Retrospective cohort study	57.2±12.1	61:55	9	ACDF; PCDF; LP	38.4/21 mo
95	TH Tu	2024	Taiwan	42	Retrospective cohort study	59.8±10.3	27:15	13	Global	45.8 mo
96	M Hashimoto	2024	Japan	1,434	Retrospective cohort study	62±12.3	575:859	76	ACDF	49/34 mo
97	S Basu	2024	India	60	Retrospective cohort study	52.2±12.1	38:22	9	PCDF; LP	24 mo

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

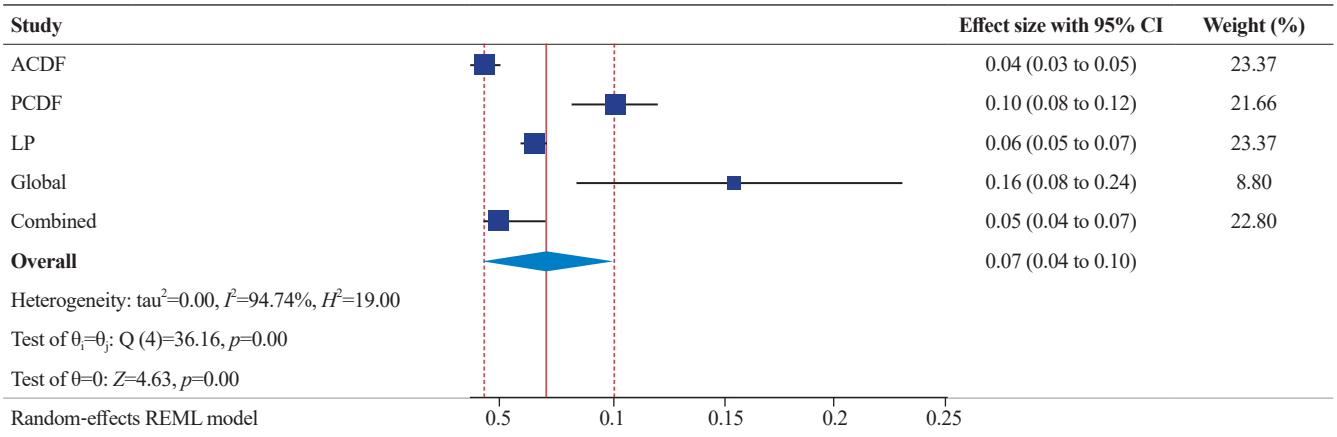


Fig. 2. Forest plot showing the pooled incidence of C5 palsy following surgery for cervical myelopathy. ACDF, anterior cervical decompression and fusion; PCDF, posterior cervical decompression and fusion; LP, laminoplasty; CI, confidence interval; REML, restricted maximum likelihood.

etiopathogenic mechanisms were suggested, namely inadvertent nerve root injury, nerve root traction secondary to cord shift, segmental cord disorder, spinal cord ischemia, and reperfusion cord injury [12,17,21-23]. The main purported hypotheses underlying the higher prevalence of C5P in posterior decompressive surgeries include the "tethering phenomenon" (or posterior shift of spinal cord leading to C5 nerve root traction) and spinal cord expansion secondary to acute canal decompression [17,24].

The C5 nerve roots are particularly vulnerable due to their short length, relatively less laxity, location at the apex of cervical lordosis (which exposes them to the highest strain during spinal cord shift), proximity to the C5 superior articular process (which is more anteriorly protruded), and horizontal orientation [4,25]. These factors increase their risk of injury from traction or stretch compared to the other subaxial roots [10,13,26-29]. Bydon et al. [10] found a 3-fold higher posterior cord shift at C4–5 level in patients with C5P, limiting the nerve root's accommodation to the shift. Pennington et al. [13] demonstrated an axonotmesis-like nerve injury in these palsies, which explains the mean 6- to 12-month recovery period for weakness.

Incidence of C5P

The pooled incidence of C5P from 97 studies (21,231 patients) was 7% (95% CI, 4%–10%) (Fig. 2), analyzed using a random-effects model due to heterogeneity across studies.

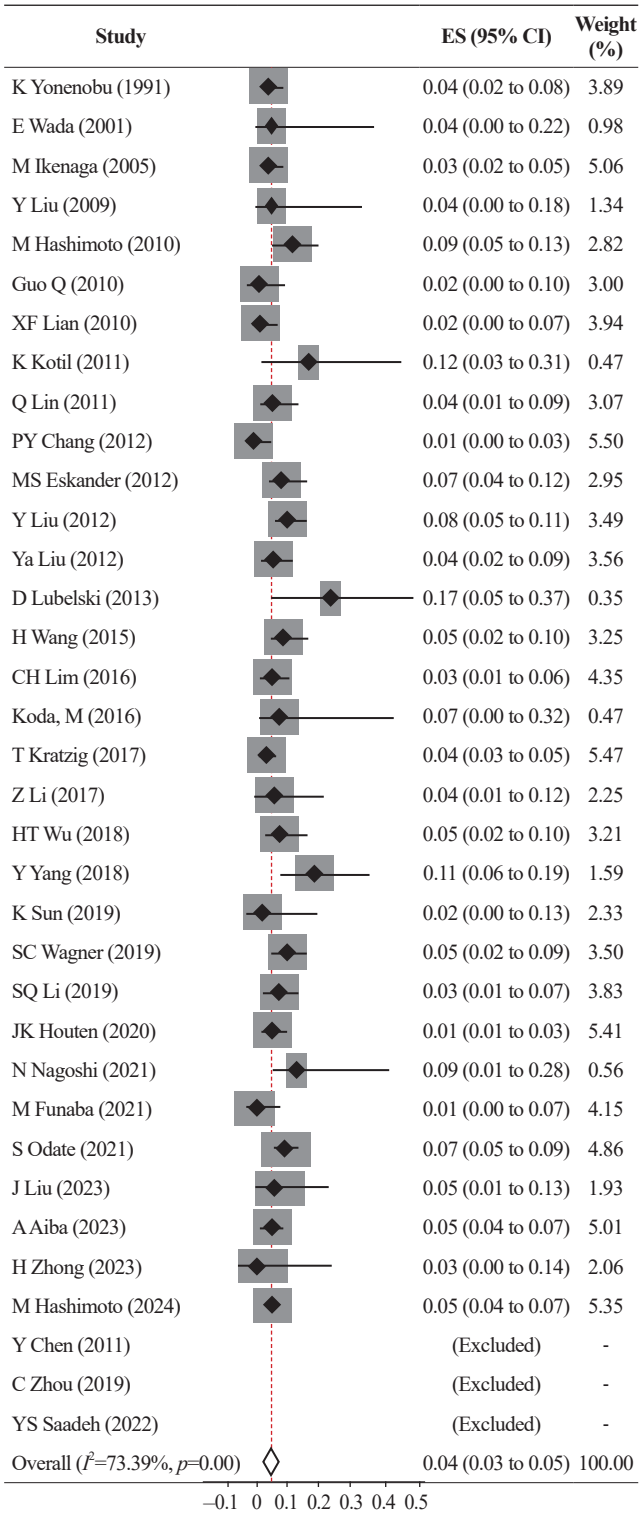


Fig. 3. Forest plot showing the incidence of C5 palsy following anterior cervical decompression and fusion surgery for cervical myelopathy. ES, effect size; CI, confidence interval.

Subgroup analysis

A subgroup analysis was performed based on the surgical procedure, including ACDF, posterior cervical decompression and fusion (PCDF), LP, and combined anterior and posterior fusion (circumferential fusion). Upon subgroup analysis, the incidence rates were 4% (95% CI, 3%–5%) for ACDF (Fig. 3), 6% (95% CI, 5%–7%) with LP (Fig. 4), 10% (95% CI, 8%–12%) for PCDF (or laminectomy and fusion [LF]) (Fig. 5), and 16% (95% CI, 8%–24%) for circumferential fusion (Fig. 6).

Risk factors for C5P

Various studies have examined the risk factors for C5P in patients undergoing cervical spinal surgeries [16,30,31]. Pennington et al. [13] found that mean foraminal diameter (p<0.001) and gait disturbance at the initial consultation (p=0.008) were significant predictors of postoperative C5P. A preoperative foraminal diameter <2 mm was associated with a twofold higher incidence of C5P. In addition, preoperative symptoms such as tingling or numbness (p=0.08) and inadvertent dropping of objects (p=0.09) tended toward significance, but were not statistically significant in multivariate analysis. In the study by Wang et al. [17,21], the C5P rate was substantially higher in males (5.9% vs. 4.1%). They also found unilateral involvement to be substantially more common.

Several radiological parameters have been purported to predict C5P with a high specificity and sensitivity, including reduced anteroposterior canal dimension, decreased intervertebral foraminal size, and high cervical lordosis angle (open angle of lamina) [32-34]. Lubelski et al. [35] studied 98 patients undergoing anterior or posterior decompression at the C4–5 level and found a significant impact of the severity of preoperative C4–5 foraminal stenosis on the occurrence of postsurgical C5P. Notably, each 1 mm increase in foraminal size reduced the risk of developing palsy by 50-fold.

Other potential risk factors include inadequate restoration of cervical lordosis or alignment, severity of myelopathy (measured by Japanese Orthopaedic Association scores) and high-intensity spinal cord signal on T2-weighted image. However, the impact of these factors remains debated [36-39]. Egger's regression test showed no significant publication bias among the included studies (p=0.521).

Discussion

C5P was first described by Scoville [40] in the 1960s as a complication of cervical decompressive surgery. It can present immediately following surgery (typically at or after 24 hours) or even up to 2 months postopera-

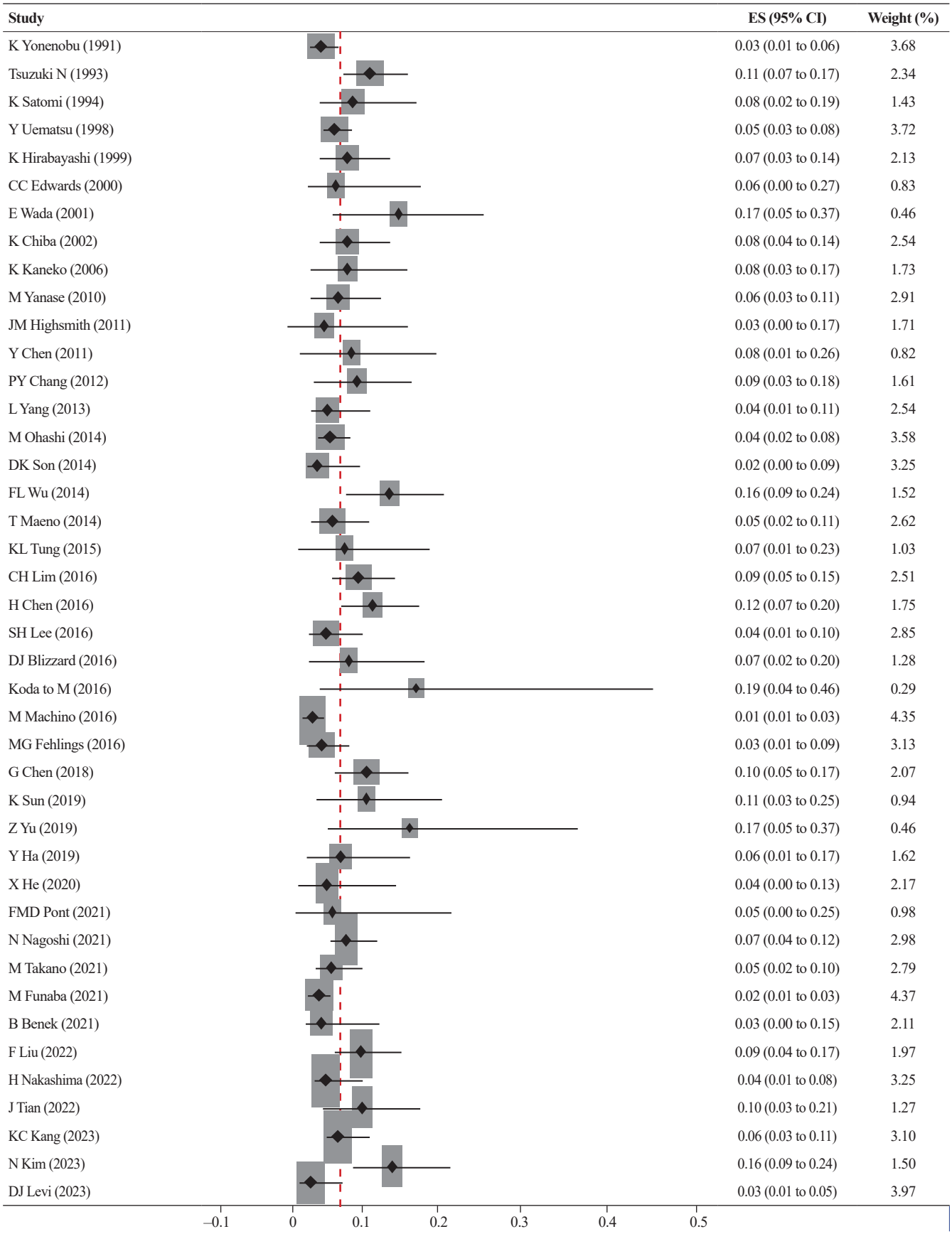


Fig. 4. Forest plot showing the incidence of C5 palsy following laminoplasty surgery for cervical myelopathy. ES, effect size; CI, confidence interval. (Continued on the next page.)

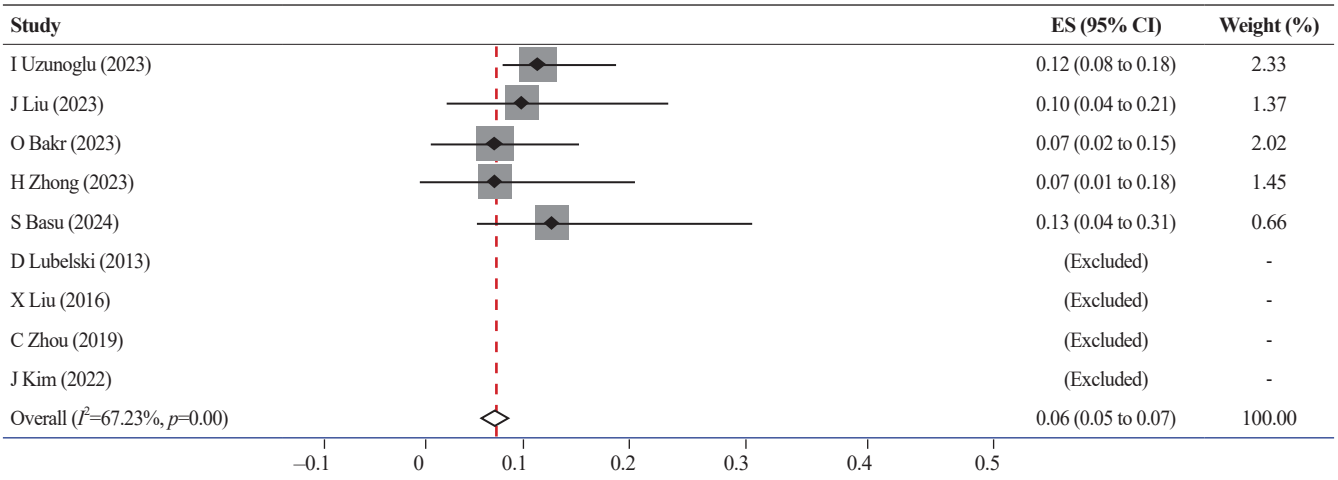


Fig. 4. (Continued; caption shown on previous page).

tively. While the prognosis is usually good, the recovery time can substantially vary depending on the severity of the neurodeficit [15,41]. In the short term, C5P significantly impairs the quality of life, decreases patient satisfaction, and increases the overall healthcare-related expenditure. Conservative treatment strategies for C5P include rest, muscle rehabilitation, drug therapy (such as high-dose corticosteroids), dehydration therapy, and hyperbaric oxygen therapy [8,11,15,21,26,42]. This systematic review aimed to comprehensively review recent literature and analyze the incidence rate of this adverse event across various surgical approaches.

Definitions of C5P

There is a significant variation in the definitions for C5P across studies, which can potentially impact the reported incidence rates. Imagama et al. [4] defined C5P as a postoperative deltoid muscle strength of 0–2 on the MMT, with or without weakness of biceps brachii, while other muscles remain unaffected. Nakashima et al. [43] defined it as a ≥1 grade deterioration in deltoid muscle on MMT, with or without biceps brachii involvement. Nassr et al. [14] described C5P as loss of motor power in the deltoid and/or biceps, sensory impairment in the C5 dermatome, and increased pain in the C5 distribution. Nakamae et al. [44] defined C5P as a palsy in the deltoid and biceps musculature with a ≥1 grade decrease in MMT without sensory impairment.

Incidence of C5P

In the study by Shou et al. [45], the mean incidence of C5P was 5.3% (95% CI, 4.6%–6.0%), while the incidence varied between 0 and 30% in the study by Sakaura et al. [12] In the meta-analysis by Wang et al. [17], the pooled mean incidence of C5P was 6.3% (95% CI, 5.7%–7.9%), with the mean rate ranging between 1% and 29% across the reviewed studies. The meta-analysis by Wang et al. [17,21] found C5P incidence rates of 6.2% for posterior cervical approaches and 5% for anterior cervical spinal approaches. Most studies suggest a relatively higher incidence of C5P with posterior cervical procedures. In the increasing order of frequency, the reported incidence of C5P in patients undergoing LP, ACDF, anterior cervical corpectomy with discectomy and fusion (ACCDF)–hybrid procedure, anterior cervical corpectomy and fusion (ACCF), and LF were 4.4%, 5.5%, 6%, 7.5% and 13%, respectively. In our meta-analysis, the overall pooled mean incidence of C5P was 7% (95% CI, 4%–10%).

Underlying pathological diagnosis and C5F

Wang et al. [17,21] compared the incidence of C5P across diverse cervical degenerative pathologies. They found a significantly higher incidence of C5P in patients with ossified posterior longitudinal ligament (OPLL) at 8.1%, compared to those with cervical spondylomyelopathy (CSM) at 4.8%. In their study, patients with OPLL had higher C5P rates than those with CSM when undergoing ACDF (5.5% vs. 4.7%) and LP (8.1% vs. 3.1%), but similar rates when undergoing LF (13% vs. 13.1%) [17,25]. The higher incidence of C5P in OPLL patients has been attributed to the greater spinal cord shifting, resulting in a stronger tethering effect on the nerve roots [16]. A meta-analysis by Shou et al. [45] involving 13,621 patients from 79 studies, identified male sex and LF as key risk factors for C5P. Another meta-analysis identified male sex, preoperative inter-

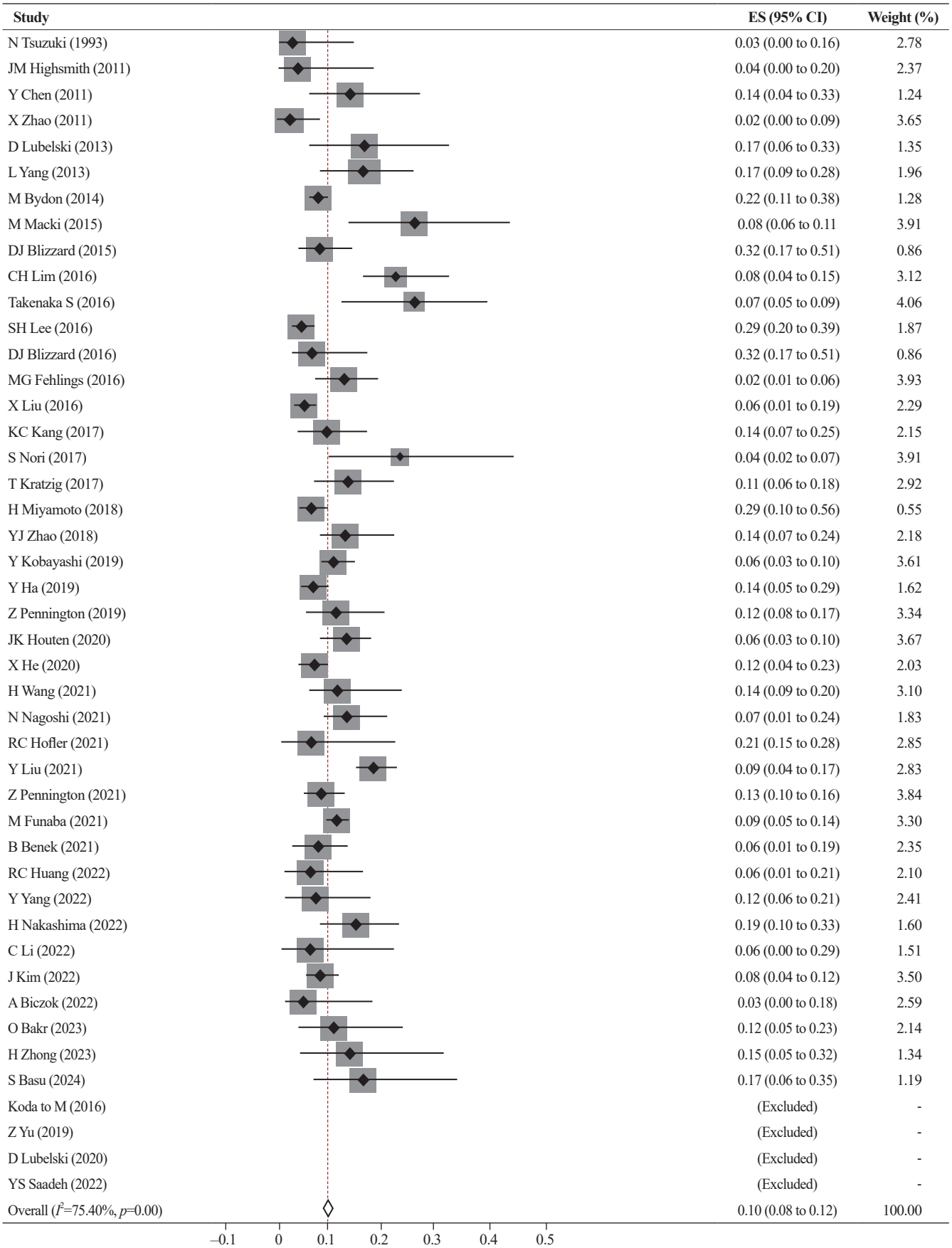


Fig. 5. Forest plot showing the incidence of C5 palsy following posterior decompression and fusion surgery for cervical myelopathy. ES, effect size; CI, confidence interval.

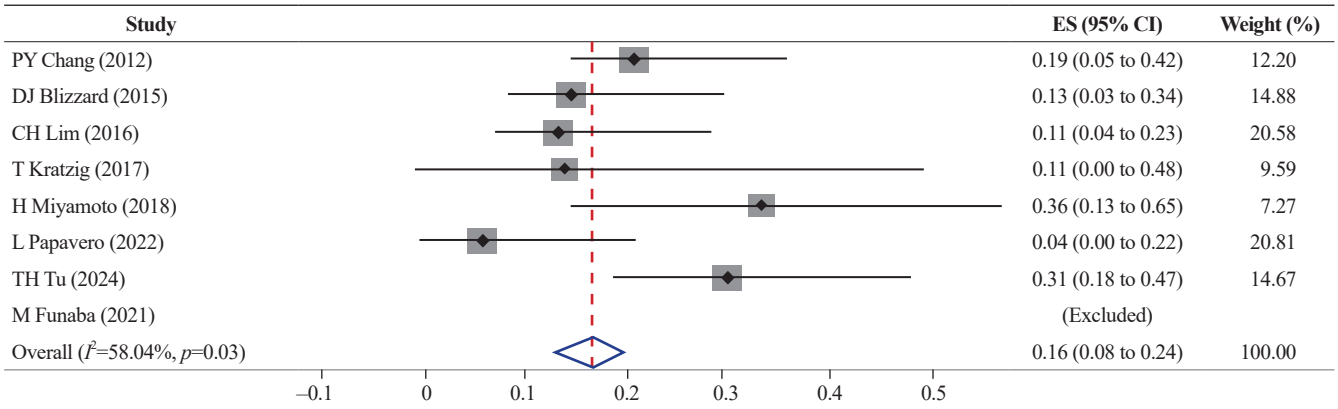


Fig. 6. Forest plot showing the incidence of C5 palsy following global decompression and fusion surgery for cervical myelopathy. ES, effect size; CI, confidence interval.

vertebral foraminal stenosis, underlying OPLL, laminectomy, and excessive spinal cord shift as significant risk factors for C5P in patients undergoing posterior cervical procedures [25].

Surgical approaches and C5P

The multicenter, prospective, randomized phase-3 CSM-protect trial found that the posterior approach was independently associated with at least 4-fold greater risk of developing postoperative C5P compared to the anterior approach [24]. In our study, subgroup analysis showed ACDF had the lowest incidence of C5P (4%; 95% CI, 3%–5%), while circumferential fusion (combined anterior-posterior) carried the highest risk for C5P (16%; 95% CI, 8%–24%]). In a meta-analysis by Takase et al. [8,11] involving patients who underwent 3 to 6 level anterior cervical decompression, the incidence of late C5P was 4.2%. The incidence rates following ACDF, ACCDF-hybrid, and ACCF procedures were 2.3%, 3.9%, and 6.4%, respectively. Based on network meta-analysis, they concluded that ACCF was associated with a substantially higher risk of C5P compared to ACDF, recommending ACDF as the preferred option for long-segment cervical fusions when feasible. Broadly, our study also demonstrated relatively higher rates of C5P following posterior decompressive surgeries, compared to anterior approaches.

The meta-analysis by Wang et al. [17,21] found that LF was associated with a significantly higher incidence of C5P (p=0.004) and higher Neck Disability Index (p<0.001) compared to LP. Based on a single-surgeon experience, Kim et al. [3] concluded that LP was associated with a significantly lower incidence of C5P compared to LF (p=0.01) [7]. However, analysis of data from the National Registry showed no significant difference between LP and LF in this respect, suggesting that surgeon experience and training may impact complication rates [46]. Our study also found relatively higher rates of C5P following LF or PDCF, in comparison with LP (6% [95% CI, 5%–7%] for LP vs. 10% [95% CI, 8%–12%] for PDCF or LF).

The types of LP described include cervical expansile open-door LP (EOLP), Hirabayashi, Z-type, double-door, and spinous-process splitting-type LP. A large-scale study by Levy et al. [47] on EOLP found C5P to be the most common complication, occurring in 2.6% of patients. Notably, C5P in LP was more common on the open-door side of the lamina compared to the hinge side, likely due to the potentially greater tethering effect on the open side. They recommended creating the hinge on the patient's dominant arm side to minimize the risk of loss of dominant arm function. A systematic review by Gu et al. [25] found that open-door LP had a higher incidence of C5P, compared to double-door LP, likely due to cord rotation from asymmetric spinal decompression, resulting in greater tethering on the open side [4,5,25,48]. On the contrary, a large-scale, multicenter study by Imagama et al. [4] found no significant difference in C5P rates between open-door and double-door LP.

C4–5 foraminotomy and its role in C5P

Sasai et al. [49] identified the presence of preoperative C5 radiculopathy (which may correlate with the degree of C4–5 foraminal stenosis) as a crucial predictor of palsy. In this context, the impact of C4–5 foraminotomy on postoperative C5P has been widely debated. Studies by Katsumi et al. [50], Komagata et al. [51], and Sasai et al. [49] supported the role of prophylactic C4–5 foraminotomy in reducing the risk of C5P, attributing the

benefit to the reduction in the nerve root anchorage at the site of intervertebral foramen. However, other studies have demonstrated significantly increased C5P rates after intraoperative manipulation of the nerve root and C4–5 foraminotomy. Pennington et al. [13] suggested that the C5 nerve root's susceptibility to injury during decompression may be due to the small size of the C4–5 foramen and the horizontal orientation of the C5 nerve root, which can put it in line with the long axis of the Kerrison's rongeur during decompression, increasing the risk of impingement by the instrument [52].

Predicting the outcome following C5P

In the study by Lubelski et al. [53], deltoid strength improvement was found to predict recovery from C5P. They observed that patients who experienced complete (overall 60%) or partial recovery (29% of cases) demonstrated improvement in motor power by at least one Medical Research Council (MRC) grade at approximately 6 weeks following the deficit. They underlined the significance of examination at 6 weeks' time point to predict any meaningful recovery, since the motor power of grade 4/5 or greater at 6 weeks was predictive of complete recovery. On the other hand, patients who gained strength of 3/5 or below in the antigravity muscles alone exhibited only partial recovery. In short, the cohort with little or no recovery within 6 weeks of the onset of C5P was unlikely to experience good long-term outcomes. In addition, electrophysiological testing, such as electromyography, can help identify patients with postoperative C5P who are unlikely to experience meaningful recovery.

A study by Saadeh et al. [54] found that among patients with severe C5P (defined by antigravity strength of MRC grade ≤2) at 3 months postoperatively, 50% regained useful strength by 12 months. However, for those with persistently severe C5P at 6 months, only 25% recovered sufficient strength by 12 months. Patients with MRC grades 0 or 1 at 6 months did not regain useful strength by 1 year. In their series, female sex was associated with good recovery, while those with diabetes mellitus had significantly poorer outcomes.

Lim et al. [2] investigated 36 patients who developed C5P following cervical decompression surgery. They found that 50% of patients (among whom, 91.7% recovered between 6 months and 2 years, while 8.3% did not recover until 2 years) required longer than 6 months to experience useful neurological recovery. The factors associated with longer recovery (>6 months) included motor grade ≤2 (p<0.001), multi-segment paresis involving segments apart from 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. [13,55] found that patients who underwent C4–5 foraminotomy were more likely to develop permanent C5 deficit (p=0.004). Other radiological parameters, such as mean cord-lamina angle and length of laminectomy, showed trends toward significance (p=0.06 and p=0.08, respectively) but did not reach statistical significance.

Factors underlying delayed or compromised neurological recovery

Hashimoto et al. [56] suggested that pre-existing, asymptomatic damage to the anterior horn cells in the spinal cord gray matter may contribute to the development of severe postoperative C5P. Severe C5 palsies are known to have slower and poorer neurological recovery. Additionally, multilevel paresis has been associated with poor outcomes, potentially due to focal reperfusion injury to the spinal cord following spinal decompression [38]. Similarly, significant sensory involvement (>50%) and intractable pain may indicate severe spinal cord injury or ischemia/reperfusion injury, which are associated with poor prognosis in patients with C5P.

Limitations

Our study has limitations, including the exclusion of non-English publications, which may have led to missed relevant articles. Additionally, the predominantly retrospective nature of the included studies reduces the level of evidence. However, given the focus on complications from surgical interventions, retrospective case-control studies are often the primary source of data, limiting the availability of higher-quality evidence from randomized controlled trials. The study's results may be influenced by the overlapping nature of some of the reviewed parameters, such as circumferential fusion being usually performed on patients with more severe pathologies. Additionally, certain factors like aggressive shoulder retraction or shoulder taping during positioning, which could impact outcomes, were beyond the purview of this review.

Conclusions

Our meta-analysis found that the posterior surgical approach is a significant risk factor for C5P. Circumferential (or combined anteroposterior) fusion carries the

greatest risk of developing the palsy. Among posterior approaches, LP may reduce the risk of C5P compared to laminectomy, with or without instrumented fusion.

Key Points

- C5 palsy occurred in 7% of cases overall, with the highest rates seen in circumferential fusion (16%) and posterior approaches (10%), compared to 4% in anterior cervical decompression and fusion.
- Male sex, severe foraminal stenosis (<2 mm), ossified posterior longitudinal ligament, and excessive spinal cord shift were consistently associated with higher C5 palsy risk.
- Reduced canal diameter and steep cervical lordosis angle emerged as significant imaging markers for vulnerability.
- Mean recovery time ranged from 21 to 35 weeks, and up to one-third of patients had persistent weakness, especially if deltoid strength was poor at 6 weeks.
- While some evidence supports prophylactic C4–5 foraminotomy, others caution against it due to potential intraoperative nerve manipulation.

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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