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Review Article

Outcomes of posterior cervical fusion and decompression: a systematic review and meta-analysis

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Abstract

BACKGROUND CONTEXT: Posterior cervical fusion (PCF) with decompression is a treatment option for patients with conditions such as spondylosis, spinal stenosis, and degenerative disc disorders that result in myelopathy or radiculopathy. The annual rate, number, and cost of PCF in the United States has increased. Far fewer studies have been published on PCF outcomes than on anterior cervical fusion (ACF) outcomes, most likely because far fewer PCFs than ACFs are performed.

PURPOSE: To evaluate the patient-reported and clinical outcomes of adult patients who underwent subaxial posterior cervical fusion with decompression.

STUDY DESIGN/SETTING: Systematic review and meta-analysis.

PATIENT SAMPLE: The total number of patients in the 31 articles reviewed and included in the meta-analysis was 1,238 (range 7−166).

OUTCOME MEASURES: Preoperative to postoperative change in patient-reported outcomes (visual analog scales for arm pain and neck pain, Neck Disability Index, Japanese Orthopaedic Association [JOA] score, modified JOA score, and Nurick pain scale) and rates of fusion, revision, and complications or adverse events.

METHODS: This study was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and a preapproved protocol. PubMed and Embase databases were searched for articles published from January 2001 through July 2018. Statistical analyses for patient-reported outcomes were performed on the outcomes' raw mean differences, calculated as postoperative value minus preoperative value from each study. Pooled rates of successful fusion, revision surgery, and complications or adverse events, and their 95% confidence

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intervals, were also calculated. Two subgroup analyses were performed: one for studies in which only myelopathy or radiculopathy (or both) were stated as surgical indications and the other for studies in which only myelopathy or ossification of the posterior longitudinal ligament (or both) were stated as surgical indications. This study was funded by Providence Medical Technology, Inc. ($32,000).

RESULTS: Thirty-three articles were included in the systematic review, and 31 articles were included in the meta-analysis. For all surgical indications and for the 2 subgroup analyses, every cumulative change in patient-reported outcome improved. Many of the reported changes in patient-reported outcome also exceeded the minimal clinically important differences. Pooled outcome rates with all surgical indications were 98.25% for successful fusion, 1.09% for revision, and 9.02% for complications or adverse events. Commonly reported complications or adverse events were axial pain, C5 palsy, transient neurological worsening, and wound infection.

CONCLUSIONS: Posterior cervical fusion with decompression resulted in significant clinical improvement, as indicated by the changes in patient-reported outcomes. Additionally, high fusion rates and low rates of revision and of complications and adverse events were found.

Keywords: Clinical outcomes; Fusion rate; Meta-analysis; Myelopathy; Ossification of the posterior longitudinal ligament (OPLL); Patient-reported outcomes; Posterior cervical fusion; Radiculopathy; Subaxial; Systematic review

Introduction

Posterior cervical fusion (PCF) with decompression is a treatment option for patients with conditions such as spondylosis, spinal stenosis, and degenerative disc disorders that result in myelopathy or radiculopathy [1]. Adding PCF to laminectomy has become the standard of care, as isolated cervical laminectomy is no longer considered best practice for the treatment of myelopathy [2] or radiculopathy [3]. As compared with patients who undergo anterior cervical fusion (ACF), patients who undergo PCF are more likely to be male [1,4]; are more likely to have myelopathy than radiculopathy as a clinical indication for surgery [1]; and on average are older [4,5], have more comorbidities [1,5], and have more levels operated [5,6].

The annual rate of PCFs undergone by adults in the United States increased 2.7-fold from 2001 to 2013 for a preoperative diagnosis of degenerative disease [4], and the annual number of PCFs increased 2.9-fold from 2003 to 2013 for a preoperative diagnosis of cervical spondylotic myelopathy (CSM) [5]. Increases in the annual rate of cervical spinal fusion surgery have been attributed to an aging population; a greater awareness of quality of life issues within that aging population; a greater number of fellowship-trained spine surgeons; and advances in anesthesia, surgical instrumentation and technique, and postsurgical care that allow this surgery to be safely performed in patients who are older, less healthy, or earlier along the disease process [1,5]. Inflation-adjusted charges for PCF also increased over time, by 1.9-fold from 2003 to 2013, for a preoperative diagnosis of CSM [5]. With these increases in the rate, number, and cost of PCF comes an increase in the importance of assessing the safety and effectiveness of this procedure.

Far fewer studies have been published on PCF outcomes than on ACF outcomes (especially anterior cervical discectomy and fusion outcomes), most likely because far fewer PCFs than ACFs are performed [1,4−6]. Posterior cervical fusion patient-reported outcomes, as well as complication and reoperation rates, have been assembled mostly in review articles from studies that compared PCF (laminectomy and fusion) with laminoplasty [7−12] or PCF with ACF [13]. A systematic review, published in 2009, of 11 studies on cervical laminectomy and fusion reported on patients' improvement in neurologic function and in Japanese Orthopaedic Association (JOA) score [14]. Posterior cervical fusion clinical outcomes such as short-term complication rate [1,15−17], short-term readmission rate [15], and revision rate [6,15] are available from large administrative databases such as the National Inpatient Sample database, but such studies do not include patient-reported outcomes. The purpose of this systematic review and meta-analysis was therefore to evaluate the patient-reported and clinical outcomes of adult patients who underwent subaxial PCF with decompression.

Material and methods

Literature search

The systematic review was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [18] (Fig. 1) and a preapproved protocol. PubMed and Embase databases were searched for articles published from January 2001 through July 2018 with the search terms of "posterior cervical fusion" OR (posterior AND cervical AND (fusion OR fixation) AND (myelopathy OR radiculopathy OR spondylosis OR disease OR "degenerative disc disease" OR "degenerative disease" OR "cervical degenerative disease") NOT trauma NOT fracture NOT atlantoaxial). Duplicate articles were

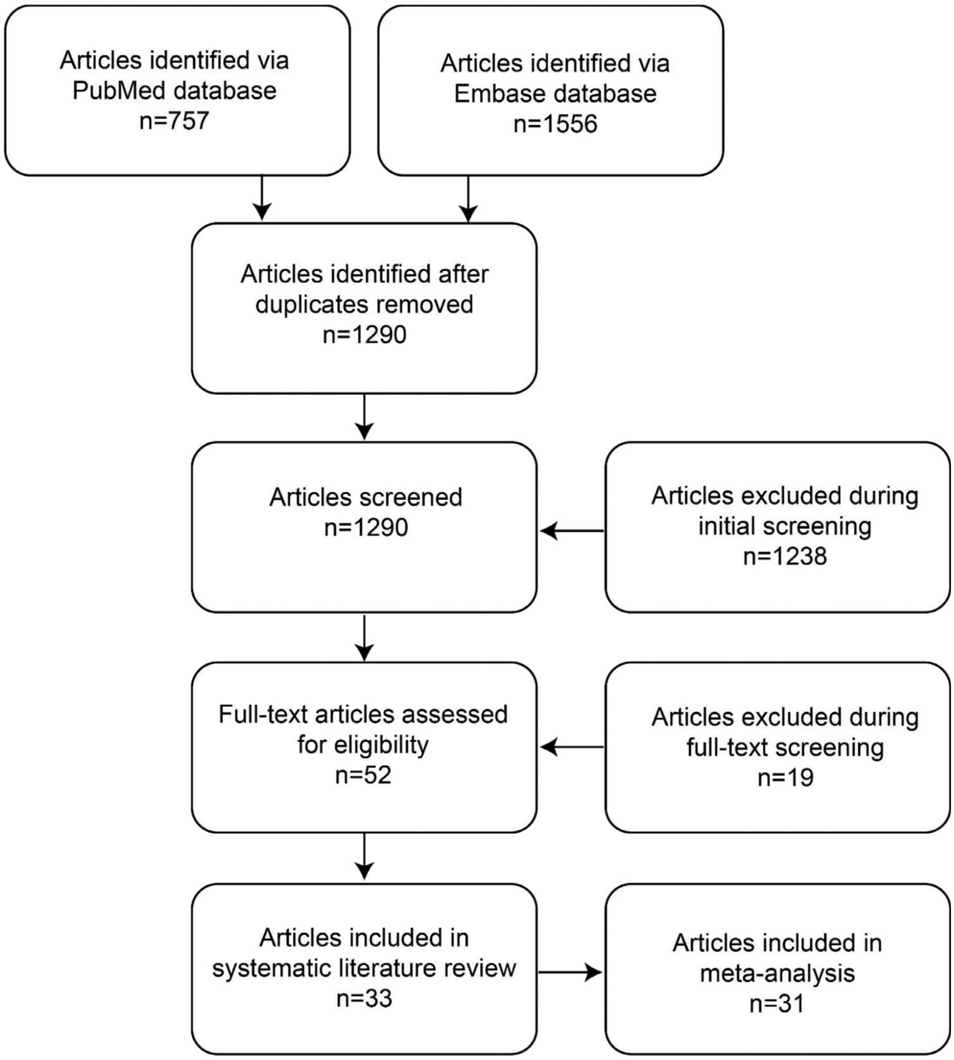


Fig. 1. The PRISMA flow diagram for systematic review and meta-analysis of posterior cervical fusion outcomes.

removed on the bases of the publication title, PubMed ID, and Embase ID.

Article assessment

The titles and abstracts of the articles identified during the literature search were reviewed to see if they fulfilled the following inclusion criteria: written in English; peer-reviewed; had a level of evidence of I, II, or III; included human subjects; involved PCF with implantable devices; and included postoperative patient-reported outcomes. The articles that remained were assessed in full against exclusion criteria of no patient-reported outcome data reported, any anterior procedures performed, patients with congenital diseases such as cerebral palsy included, and less than 12 months' follow-up reported. Articles included in the systematic review but excluded from meta-analysis were those that had another article published of the same study but at a later time point.

Data extraction

Study, demographic, surgical procedure, and outcome data were extracted from the articles selected for systematic review. Study data collected were study design, number of patients, and length of follow-up. Demographic data collected were patient age, patient sex (% female), and surgical indications (myelopathy, radiculopathy, ossification of the posterior longitudinal ligament [OPLL], or other). Surgical procedure data collected were number of levels treated, range of treated vertebrae, decompression procedure performed, and fusion instrumentation. Patient-reported outcome data were collected preoperatively and at the final postoperative time point. Additional outcome data collected were the percentages of successful fusion, revision, and complications or adverse events; the fusion assessment modality; and the 3 most common complications or adverse events. Data were extracted from the text of the articles where available, tables where available, and by using a digitizing program (DigitizeIt, Germany) to digitize figures when exact numbers were not reported in text or tables.

Quality assessment

Risk of bias in each study selected for systematic review was assessed with the Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS) guidelines for systematic review of nonrandomized studies [19] and the Cochrane guidelines for systematic review of randomized studies [20].

Statistical analysis

Patient-reported outcome data analyzed included visual analog scales for arm pain (VAS-arm) and neck pain (VAS-neck), Neck Disability Index (NDI), JOA score, modified JOA (mJOA) score, and Nurick pain scale [21]. The VAS-arm and VAS-neck data reported on a 100-point scale were converted to a 10-point scale. Modified JOA scores reported on an 18-point scale were converted to a 17-point scale. The JOA and mJOA score data were combined and reported as JOA/mJOA score data. Changes in patient-reported outcome measures reported in less than 4 articles did not undergo meta-analysis.

Table 1
Risk of bias assessment using (a) Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS) guidelines for systematic review of nonrandomized studies [19] and (b) Cochrane guidelines for systematic review of randomized studies [20]. Italic rows indicate articles that were included in the systematic review but not in the meta-analysis, as each of those articles had another article published of the same study but at a later time point

a.

Article	Selection of participants	Confounding variables	Exposure	Blinding of outcome assessments	Incomplete outcome data
Blume et al., 2018 (n=49)	Low	Low	Low	Low	Low
Chen et al., 2012 (n=32)	Low	Low	Low	Low	Low
Denaro et al., 2015 (n=40)	Low	Low	Low	Low	Low
Epstein & Epstein, 2006 (n=14)	Low	Low	Low	Low	Low
Epstein, 2008 (n=35)	Low	Low	Low	Low	Low
Epstein, 2011 (n=53)	Low	Low	Low	Low	Low
Epstein, 2017 (n=32)	Low	Low	Low	Low	Low
Fehlings et al., 2017 (n=166)	High	Low	Low	Low	High
Heller et al., 2001 (n=13)	Low	Low	Low	Low	Low
Highsmith et al., 2011 (n=26)	Low	High	Low	Low	Low
Huang et al., 2003 (n=32)	Low	Low	Low	Low	Low
Hyun et al., 2016 (n=38)	*Low*	*Low*	*Low*	*Low*	*Low*
Hyun et al., 2017 (n=31)	Low	Low	Low	Low	Low
Kasliwal et al., 2015 (n=19)	Low	Low	Low	Low	Low
Koda et al., 2016 (n=17)	Low	Low	Low	Low	Low
Koda et al., 2018 (n=38)	Low	Low	Low	Low	Low
Lau et al., 2017 (n=44)	Low	Low	Low	Low	Low
Lee et al., 2016 (n=21)	Low	Low	Low	Low	Low
Lee et al., 2017 (n=56)	Low	High	Low	Low	Low
Liu et al., 2013 (n=146)	Low	Low	Low	Low	Low
McCormack et al., 2013 (n=60)	*Low*	*Low*	*Low*	*Low*	*Low*
Onari et al., 2001 (n=12)	Low	Low	Low	Low	Low
Saito et al., 2016 (n=27)	Low	Low	Low	Low	Low
Scheufler et al., 2007 (n=11)	Low	Low	Low	Low	Low
Sielatycki et al., 2016 (n=45)	Low	Low	Low	Low	Low
Siemionow et al., 2016 (n=51)	Low	Low	Low	Low	Low
Su et al., 2016 (n=49)	Low	Low	Low	Low	Low
Tang et al., 2016 (n=20)	Low	Low	Low	Low	Low
Tashjian et al., 2009 (n=28)	Low	Low	Low	Low	Low
Yang et al., 2013 (n=66)	Low	Low	Low	Low	Low
Yuan et al., 2015 (n=18)	Low	High	Low	Low	Low

b.

Article	Random-ization	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Lenzi et al., 2017 (n=40)	Low	Uncertain	Low	Low	Low	Low	Low
Manzano et al., 2012 (n=7)	Uncertain	Low	Low	Low	Low	Low	Low

Table 2
Study, demographic, and operative data from the systematic review of posterior cervical fusion outcomes. Italic rows indicate articles that were included in the systematic review but not in the meta-analysis, as each of those articles had another article published of the same study but at a later time point

Article	Study design	# patients	Follow-up, months (SD or range)	Mean age, years (SD or range)	Sex (% female)	Surgical indications	Mean # levels treated (SD or range)	Range of treated vertebrae	Decompression	Fusion instrumentation
Blume et al., 2018	Retrospective	49	26.3 (15.6)	68.1 (12.3)	45.8%	Myelopathy	Median: 3 (1−7)	—	Laminectomy	Lateral mass rod/screw
Chen et al., 2012	Retrospective	32	48−72	52.6 (1.7)	40.6%	Myelopathy, OPLL	4.2 (0.1)	—	Laminectomy	Lateral mass rod/screw
Denaro et al., 2015	Retrospective	40	68.4 (12−132)	64.3 (35−90)	30.0%	Myelopathy	4.18 (2−5)	—	Laminectomy	Lateral mass rod/screw
Epstein & Epstein, 2006	Prospective	14	16.8 (12−27.6)	64 (44−81)	28.6%	Myelopathy, radiculopathy	6.4 (4−9)	C2−T2[*]	“Focal” (1-2 level) laminectomy	Rod/eyelet system, braided titanium cables
Epstein, 2008	Prospective clinical trial	35	12	65 (10.4)	37.1%	Myelopathy, OPLL	7.11 (1.4)	C2−T2	Laminectomy	Split fibula strut allografts applied bilaterally, 2-mirror image, contoured rods with eyelets applied bilaterally, braided titanium cables
Epstein, 2011	Prospective clinical trial	53	43 (22−63)	65.3 (47−82)	39.6%	Myelopathy, OPLL	7.5 (1.2, 5−9)	—	Laminectomy	Vertex/Rod/Eyelet System utilizing braided titanium cables
Epstein, 2017	Prospective	32	32.6 (12−48)	63 (43−76)	40.6%	Myelopathy, radiculopathy, OPLL	7.8 (5−8)[†]	C2−T2	Laminectomy	Vertex/Rod/Eyelet System utilizing braided titanium cables
Fehlings et al., 2017	Retrospective	166	24	61.4 (10.6)	31.9%	Myelopathy	5.0 (0.9)	—	Laminectomy	Not specified
Heller et al., 2001	Retrospective	13	25.5 (9−62)	55 (39−78)	15.4%	Myelopathy, OPLL	5 (3−6)	C3−T1	Laminectomy	Lateral mass screw/plate
Highsmith et al., 2011	Retrospective	26	41.3	58 (42−81)	—	Myelopathy, OPLL	5.3 (3−8)	—	Laminectomy	Lateral mass rod/screw
Huang et al., 2003	Retrospective	32	15.2	67.8 (50−79)	25.0%	Myelopathy, radiculopathy, OPLL	3.1 (1−6)	—	Laminectomy	Lateral mass screw/plate
Hyun et al., 2016	*Retrospective*	*38*	*6.2 (0.5)*	*61 (10)*	*34.2%*	*Myelopathy, radiculopathy, OPLL*	*3.4 (0.8)*	—	*Laminectomy*	*Not specified*
Hyun et al., 2017	Retrospective	31	61.7	53.7 (4.0)	25.8%	Myelopathy, radiculopathy, OPLL, other	3.7 (0.6)	—	Laminectomy (per Hyun et al., 2016)	Not specified
Kasliwal et al., 2015	Retrospective	19	20 (12−56)	54 (31−65)	68.4%	Radiculopathy, other	—	—	Indirect	Cervical interfacet spacers
Koda et al., 2016	Retrospective	17	42 (12−103)	65 (35−82)	17.6%	OPLL	—	C2−T1	Laminoplasty	Not specified
Koda et al., 2018	Retrospective	38	50 (12−146)	67.9 (49−84)	18.4%	OPLL	—	C2−T1	Laminoplasty	Lateral mass rod/screw

Table 2 (*Continued*)

Article	Study design	# patients	Follow-up, months (SD or range)	Mean age, years (SD or range)	Sex (% female)	Surgical indications	Mean # levels treated (SD or range)	Range of treated vertebrae	Decompression	Fusion instrumentation
Lau et al., 2017	Retrospective	44	16.8	60.9 (9.0)	52.3%	Myelopathy	5.3 (1.7)	C2−T1‡	Laminectomy	Lateral mass rod/screw
Lee et al., 2016	Retrospective	21	24	63.7 (7.7)	17.5%	Myelopathy, OPLL	—	—	Laminectomy	Lateral mass rod/screw
Lee et al., 2017	Prospective	56	15.5	59.8 (29−83)	12.5%	Myelopathy, OPLL, other	2.0 (1.1)	C2−C7	Laminectomy (in 37 cases)	Pedicle screw
Lenzi et al., 2017	RCT	40	12	46.1 (12.52)	47.5%	Radiculopathy	1	C3−C7	Indirect	Posterior cervical cage and synthetic bone
Liu et al., 2013	Retrospective	146	46.8 (24−60)	62 (39−75)	28.0%	Myelopathy, OPLL	4	C2−C7	Hemilaminectomy	Lateral mass rod/screw
Manzano et al., 2012	RCT	7	20	55	71.4%	Myelopathy, radiculopathy	≥4	C2−T1	Laminectomy	Lateral mass and pedicle screws and rods
McCormack et al., 2013	*Prospective clinical trial*	*60*	*12*	*52.8*	*61.7%*	*Radiculopathy*	*1*	*C3−C7*	*Indirect*	*Posterior cervical cage*
Onari et al., 2001	Prospective	12	66 (25.2−121.2)	76.3 (5.4, 70−86)	75.0%	Myelopathy	3.9 (1.3)	C2−T1	Indirect	Wave-shaped rods
Saito et al., 2016	Retrospective	27	61.8 (39)	67.1 (8.2)	14.8%	OPLL	—	C2−C7	Laminoplasty	Pedicle screw in C2, C7, and T1, and lateral mass screw in C3−C6
Scheufler et al., 2007	Prospective	11	14.6	72.8 (6.3)	45.5%	Myelopathy, radiculopathy	3.7 (0.8)	C2−C7	Laminectomy and foraminotomy	Lateral mass and pedicle screws and rods
Sielatycki et al., 2016	Retrospective	45	12	63 (10.5)	38.0%	Myelopathy	3.7 (1.3)	—	Laminectomy	Lateral mass rod/screw
Siemionow et al., 2016	Prospective	51	24	24	—	Radiculopathy	1	C3−C7	Indirect	Posterior cervical cage
Su et al., 2016	Retrospective	49	53.1 (19.0)	59.4 (10.5)	24.5%	Myelopathy	3.2 (0.6)	C3−C7	Extensive open-door laminoplasty	Lateral mass rod/screw
Tang et al., 2016	Retrospective	20	36	66.7 (8.4)	50.0%	Myelopathy	1.4 (0.5)	—	Laminoplasty	Lateral mass screw/plate
Tashjian et al., 2009	Retrospective	28	20.1 (12−48)	63.8 (47−84)	53.6%	Myelopathy	4.7 (3−7)	—	Laminectomy	Lateral mass rod/screw
Yang et al., 2013	Retrospective	66	24	57.0 (8.3)	25.8%	Myelopathy	4.5 (0.7)	—	Laminectomy	Lateral mass rod/screw
Yuan et al., 2015	Prospective	18	12	62 (13.1)	38.9%	Myelopathy, OPLL	4	C3−C7	Laminectomy	Lateral mass rod/screw

* Range not specified in text, but all figures show C2 through T2 fused.
† Data recorded as written, but most likely are # vertebrae instead of # levels.
‡ Range not specified in text, but Fig. 2 shows C2 through T1 fused.
SD, standard deviation; OPLL, ossification of the posterior longitudinal ligament; RCT, randomized controlled trial.

Table 3
Clinical outcome data from the systematic review of posterior cervical fusion outcomes. Italic rows indicate articles that were included in the systematic review but not in the meta-analysis, as each of those articles had another article published of the same study but at a later time point

Article	Fusion assessment modality	% successful fusion	% revision surgery	% complications/ adverse events	Three most frequent complications/adverse events (count)
Blume et al., 2018	—	—	12.24%	48.98%	Transient neurological worsening (10), wound infection (5), permanent neurologic worsening (3)
Chen et al., 2012	—	—	0%	37.5%	C5 palsy (8), axial pain (4)
Denaro et al., 2015	XR-S	100%	0%	5%	Eyelid edema (1), surgical infection (1)
Epstein & Epstein, 2006	XR-D, CT	100%	—	—	—
Epstein, 2008	XR-D, CT	86%	5.71%	14.29%	C5 palsy (2), wound infection (2), DVT/pulmonary embolism (1)
Epstein, 2011	XR-D, CT	86.8%	0%	1.89%	Wound breakdown (4), wound infection (2), C5 palsy (1)
Epstein, 2017	XR-D, CT	97%	3.13%	9.38%	C5 palsy (1), pseudoarthrosis (1)
Fehlings et al., 2017	—	—	1.20%	28.31%	Dural tear (5), surgical infection (5), postoperative kyphosis (5)
Heller et al., 2001	—	—	7.69%	—	Pseudoarthrosis (5), progression of myelopathy (2), hardware breakage (2)
Highsmith et al., 2011	XR-S, XR-D	92%	26.92%	30.77%	Wound infection (4), wound seromas (2), hardware malposition (2)
Huang et al., 2003	XR-S	100%	3.13%	3.13%	Wound infection (3), axial pain (2), postoperative confusion (2)
Hyun et al., 2016	—	—	—	—	—
Hyun et al., 2017	—	—	—	—	—
Kasliwal et al., 2015	XR-S	100%	0%	0%	None
Koda et al., 2016	—	—	0%	11.76%	C5 palsy (2)
Koda et al., 2018	XR-S	100%	0%	10.42%	C5 palsy (3), drop-finger (2)
Lau et al., 2017	—	—	6.82%	6.82%	Wound infection (2), pseudarthrosis (1)
Lee et al., 2016	—	—	4.76%	4.76%	C5 palsy (2), screw malposition (1)
Lee et al., 2017	XR-D, CT	98.2%	—	—	—
Lenzi et al., 2017	XR-S	89.5%	2.5%	1.25%	Radicular pain (1), hardware dislocation caused by trauma (1), hardware malposition (1)
Liu et al., 2013	XR-S, CT	100%	0%	0.68%	Posterior hematoma (1)
Manzano et al., 2012	XR-S	100%	0%	0%	None
McCormack et al., 2013	*XR-S, CT*	*93%*	*0%*	*6.67%*	*Facet fracture during implantation (2), arm weakness (1), thoracolumbar infection (1)*
Onari et al., 2001	XR-S	100%	0%	0%	None
Saito et al., 2016	—	—	0%	11%	C5 palsy (3)
Scheufler et al., 2007	CT	90.91%	0%	18.18%	Transient axial pain (2)
Sielatycki et al., 2016	—	—	2.22%	6.67%	Urinary tract infection (2), superficial wound infection (2), worsening myelopathy (1)
Siemionow et al., 2016	XR-S, CT	98.1%	0%	3.37%	—
Su et al., 2016	XR, MRI	100%	0%	12.24%	Neck/shoulder pain (5), epidural hematoma (1)
Tang et al., 2016	—	—	0%	0%	None
Tashjian et al., 2009	—	—	—	—	—
Yang et al., 2013	CT	96.97%	0%	21.21%	Axial pain (23), C5 palsy (11), CSF leakage (3)
Yuan et al., 2015	—	—	—	33%	Axial pain (4), C5 palsy (2)

XR-S, X-ray, static; XR-D, X-ray, dynamic; CT, computerized tomography; XR, X-ray (unspecified); MRI, magnetic resonance imaging.

Statistical analyses were performed by using R (R Foundation for Statistical Computing, Vienna, Austria). For each variable, heterogeneity between studies was assessed by calculating the I^2 value. Statistical analyses for patient-reported outcomes were performed on the outcomes' raw mean differences (RMDs), calculated as postoperative value minus preoperative value from each study, with the null hypothesis of RMD=0 and with α=0.05. Cumulative RMDs in patient-reported outcomes were determined with mixed random-effects models by using the "metafor" package and a custom script in R. Minimal clinically important differences (MCIDs) for cervical spine surgery were obtained from the literature for reference: 2.5 for VAS-arm and VAS-neck and 7.5 for NDI, as determined in a study of patients who underwent cervical spine fusion surgery for degenerative disorders and had a minimum 1-year follow-up [22], and 1.11 for JOA/mJOA, as determined in a study of patients who underwent surgical decompression for degenerative cervical myelopathy and had a minimum 1-year follow-up [23]. Pooled rates of successful fusion, revision surgery, and complications or adverse events, and their 95% confidence intervals, were calculated by using the "meta" package in R.

Two subgroup analyses were performed: one for studies in which only myelopathy or radiculopathy (or both) were stated as surgical indications (myelopathy/radiculopathy) and the other for studies in which only myelopathy or OPLL (or both) were stated as surgical indications (myelopathy/OPLL). These subgroups thus eliminated variability resulting from other surgical indications, primarily by excluding OPLL from the myelopathy/radiculopathy subgroup and by excluding radiculopathy from the myelopathy/OPLL subgroup. Additionally, the myelopathy/OPLL subgroup could be compared with 2 earlier systematic reviews that reported on those surgical indications [14,24].

Results

The literature search of PubMed and Embase yielded 1,290 articles after duplicate publications were removed (Fig. 1). After the initial screening of the titles and abstracts, applying the inclusion criteria specified earlier, 52 articles remained. Upon full-text screening of those 52 articles, 19 more articles were excluded, leaving 33 articles for data extraction (Tables 2 and 3; Supplemental Table A). For meta-analysis, 2 more articles were excluded [25,26], leaving 31 articles [27−57]. Study designs reported were randomized controlled trial (2 articles), prospective clinical trial (3 articles, with 1 excluded from the meta-analysis), prospective (7 articles), and retrospective (21 articles, with 1 excluded from the meta-analysis) (Table 2).

Risk of bias within the studies was almost always low (Table 1). One nonrandomized study had high risk of bias regarding selection of participants (significantly different proportions of patients from study site regions [Asia Pacific, Europe, Latin America, North America] between the PCF and laminoplasty groups) and incomplete outcome data (approximately 10% of missing PCF outcome scores at 24 months' follow-up were imputed) [34]. Three nonrandomized studies had high risk of bias regarding confounding variables between study groups, with those confounding variables not accounted for during analysis—for 2 studies, confounding variables were significantly different between the PCF and laminoplasty groups [36,57]; and for another study, confounding variables were significantly different between the patients who received local bone only, allograft only, or local bone plus allograft [44]. Of the 2 randomized studies, 1 could not be evaluated regarding allocation concealment [45] and the other could not be evaluated regarding randomization [47].

Demographics

The total number of patients in the 31 articles selected for meta-analysis was 1,238 (range 7−166) (Table 2). Average age of the patients at surgery ranged from 46.1 to 76.3 years (reported in all 31 articles) and the average percentage of female patients ranged from 12.5% to 75.0% (reported in 29 articles).

The number of articles selected for meta-analysis that included the following surgical indications were myelopathy alone, 10 (32.3%); radiculopathy alone, 2 (6.5%); OPLL alone, 3 (9.7%); myelopathy/radiculopathy, 15 (48.4%); and myelopathy/OPLL, 21 (67.7%) (Table 2).

Surgical procedure

The number of levels treated was reported in 26 of the articles selected for meta-analysis and ranged from 1 to 9 levels (Table 2). The range of treated vertebrae was reported in 17 of the articles selected for meta-analysis; the

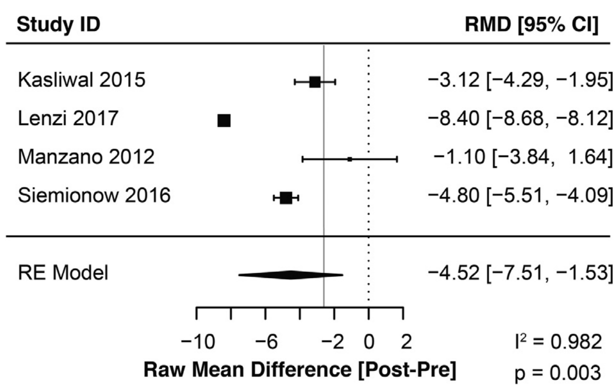


Fig. 2. Forest plot of changes in visual analog scale for arm pain (VAS-arm) after posterior cervical fusion with decompression, for only myelopathy or radiculopathy (or both) as surgical indications in a study (no data for other surgical indications). The VAS-arm is on a 10-point scale; a negative difference indicates improvement. Dotted vertical line indicates no change in patient-reported outcome; solid vertical line indicates minimal clinically important difference of 2.5 [22].

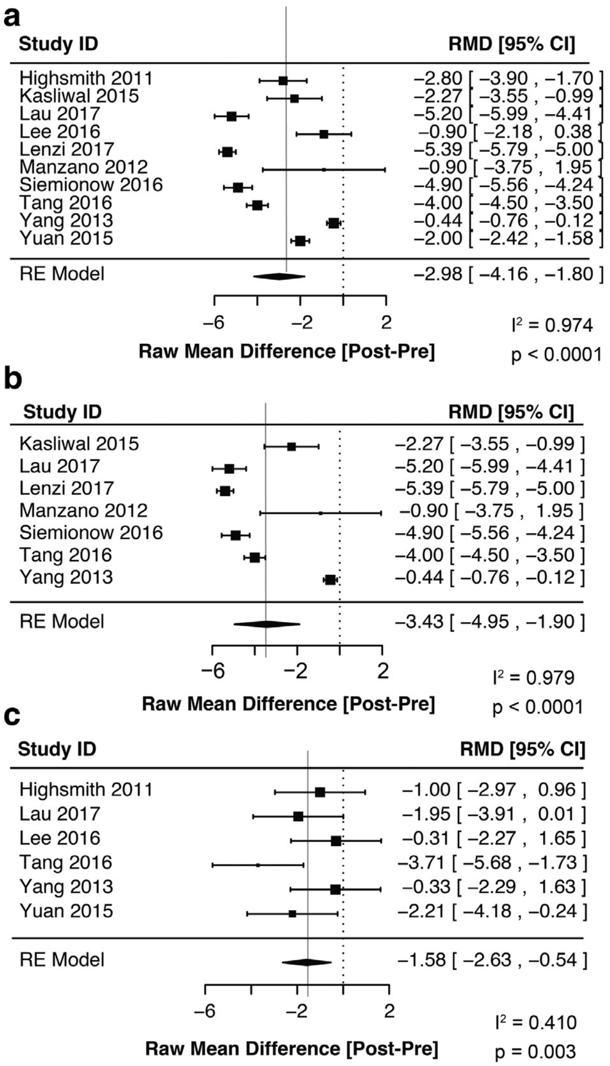


Fig. 3. Forest plots of changes in visual analog scale for neck pain (VAS-neck) after posterior cervical fusion with decompression, for (a) all surgical indications, (b) only myelopathy or radiculopathy (or both) as surgical indications in a study, and (c) only myelopathy or ossification of the posterior longitudinal ligament (or both) as surgical indications in a study. The VAS-neck is on a 10-point scale; a negative difference indicates improvement. Dotted vertical line indicates no change in patient-reported outcome; solid vertical line indicates minimal clinically important difference of 2.5 [22].

most cranial vertebra treated within a study was C2 or C3, and the most caudal vertebra treated within a study was C7, T1, or T2. Articles were not excluded if the number of levels treated or the range of treated levels signified any multilevel cervical fusions' extending caudally into the thoracic spine. Decompression reported in the articles selected for meta-analysis was laminectomy, hemilaminectomy, or laminectomy plus foraminotomy in 22 (71.0%) articles; laminoplasty in 5 (16.1%) articles; and indirect in 4 (12.9%) articles. The most commonly reported fusion instrumentation in the articles selected for meta-analysis was lateral mass rods/screws (13 out of 28 articles selected for meta-analysis in which instrumentation was reported).

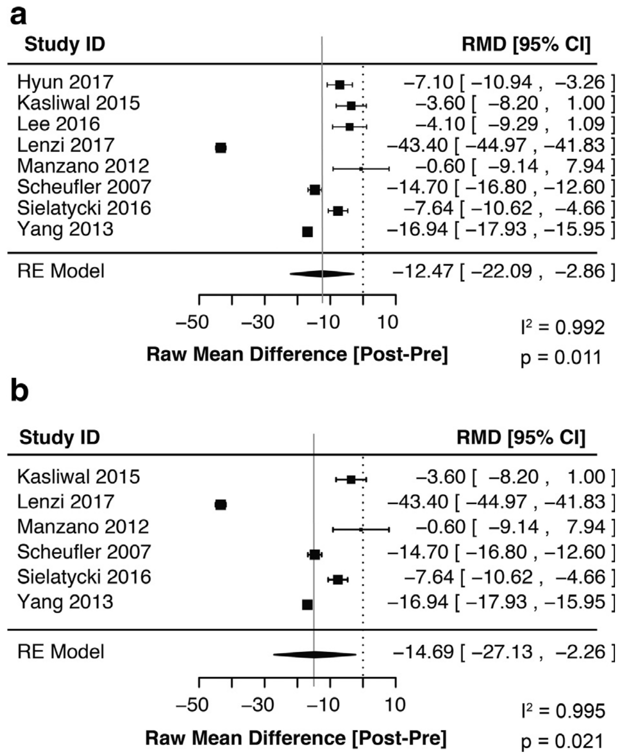


Fig. 4. Forest plots of changes in Neck Disability Index (NDI) after posterior cervical fusion with decompression, for (a) all surgical indications and (b) only myelopathy or radiculopathy (or both) as surgical indications in a study. The NDI is on a 50-point scale; a negative difference indicates improvement. Dotted vertical line indicates no change in patient-reported outcome; solid vertical line indicates minimal clinically important difference of 7.5 [22].

Patient-reported outcomes

For all surgical indications and for the 2 subgroup analyses, every cumulative change in patient-reported outcome calculated was significantly different from zero ($p \leq .0205$), in the direction of improvement (Supplemental Table A, Figs. 2−6). For myelopathy/OPLL, meta-analysis was not performed for VAS-arm or NDI. Patient-reported outcome variables had high heterogeneity ($I^2>0.87$) except for VAS-neck ($I^2=0.41$) and Nurick pain scale ($I^2=0.18$) in the myelopathy/OPLL subgroup.

Clinical outcomes

The pooled rate of successful fusion was 98.25% for all surgical indications, 98.90% for myelopathy/radiculopathy, and 97.07% for myelopathy/OPLL (Fig. 7a). The pooled revision rate was 1.09% for all surgical indications, 0.81% for myelopathy/radiculopathy, and 1.41% for myelopathy/OPLL (Fig. 7b). The pooled rate of complications or adverse events was 9.02% for all surgical indications, 7.07% for myelopathy/radiculopathy, and 13.18% for myelopathy/OPLL (Fig. 7c). Commonly reported complications or adverse events were axial pain, C5 palsy, transient neurological worsening, and wound infection (Table 3).

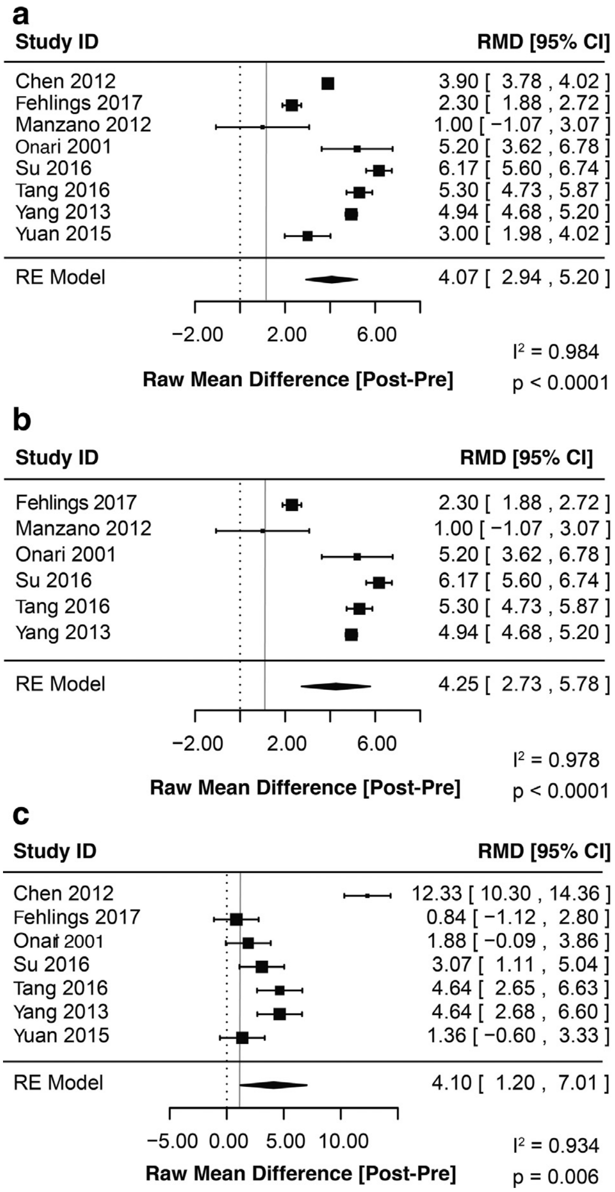


Fig. 5. Forest plots of changes in Japanese Orthopaedic Association score and modified Japanese Orthopaedic Association score (JOA/mJOA) after posterior cervical fusion with decompression, for (a) all surgical indications, (b) only myelopathy or radiculopathy (or both) as surgical indications in a study, and (c) only myelopathy or ossification of the posterior longitudinal ligament (or both) as surgical indications in a study. The JOA/mJOA is on a 17-point scale; a positive difference indicates improvement. Dotted vertical line indicates no change in patient-reported outcome; solid vertical line indicates minimal clinically important difference of 1.11 [23].

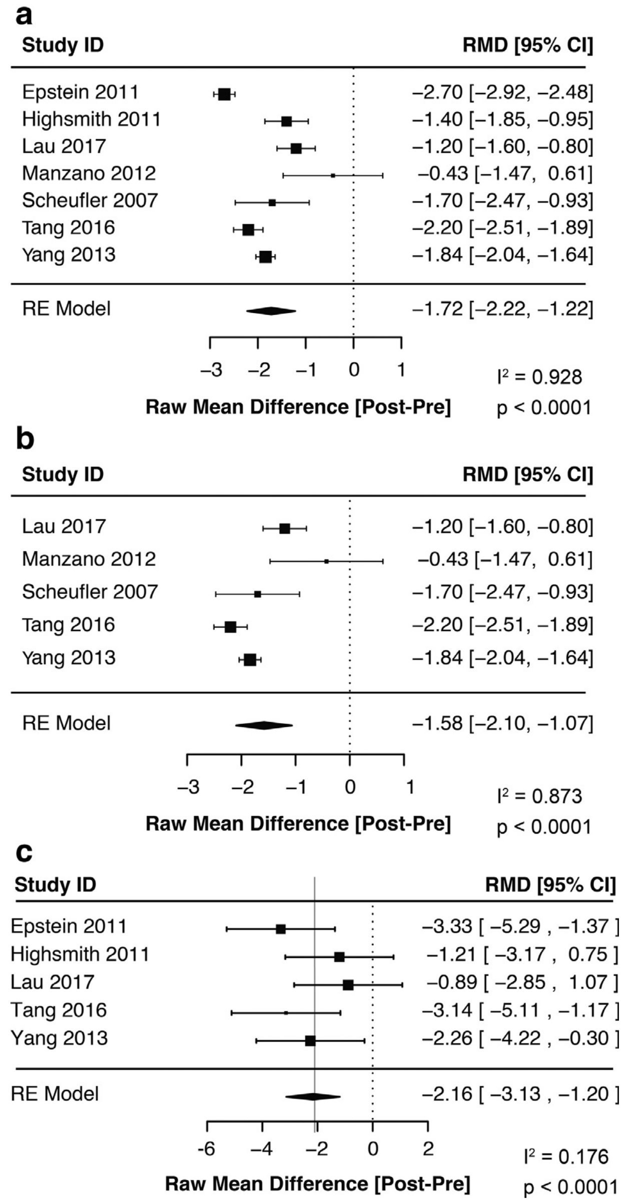


Fig. 6. Forest plots of changes in Nurick pain scale after posterior cervical fusion with decompression, for (a) all surgical indications, (b) only myelopathy or radiculopathy (or both) as surgical indications in a study, and (c) only myelopathy or ossification of the posterior longitudinal ligament (or both) as surgical indications in a study. The Nurick pain scale is on a 5-point scale; a negative difference indicates improvement. Dotted vertical line indicates no change in patient-reported outcome; no minimal clinically important difference was available for this measure.

Heterogeneity for each clinical outcome variable was moderate or high (I^2=0.47−0.90).

Discussion

The purpose of this systematic review and meta-analysis was to evaluate the patient-reported and clinical outcomes of adult patients who underwent subaxial PCF with decompression. Far fewer studies have been published on PCF outcomes than on ACF outcomes. In this meta-analysis, with a minimum 12 months' follow-up, cumulative changes in patient-reported outcomes improved. Many of the reported changes in patient-reported outcome also exceeded the outcomes' MCIDs, especially for JOA/mJOA scores.

Although heterogeneity was too high to draw any definite conclusions, the myelopathy/radiculopathy subgroup generally had slightly better results than did the pooled group and the myelopathy/OPLL subgroup. The myelopathy/radiculopathy subgroup had the greatest improvement in VAS-neck, NDI, and JOA/mJOA and the highest fusion rate, lowest revision rate, and lowest rate of complications or adverse events. This could be the result of excluding OPLL from the myelopathy/radiculopathy subgroup. This might also have resulted from this meta-analysis's including 2 articles with a clinical indication of single level radiculopathy.

A systematic review, published in 2009, of 11 studies on cervical laminectomy and fusion reported that neurologic function improved in 70% to 95% of patients operated on for CSM or OPLL and that the patients recovered around 50% of their deficit in JOA score [14]. Similarly, in the present meta-analysis, PCF with decompression for myelopathy/OPLL improved JOA/mJOA score, by a RMD of 4.1, which well exceeded the MCID of 1.11 [23]. A more recent systematic review and meta-analysis, published in 2017, evaluated changes in patient-reported outcomes for CSM or cervical myelopathy caused by OPLL, after surgical decompression with or without fusion (results not separated by type of surgery) [24]. That study reported postoperative improvement in patient-reported outcomes, especially for JOA/mJOA, as did the present meta-analysis of PCF with decompression.

The pooled rates of revision and of complications or adverse events for subaxial PCF with decompression were lower in this meta-analysis than those rates calculated from large administrative databases. Revision rates for subaxial PCF surgery as reported from large administrative databases were 7.4% with a median follow-up interval of 70 months [6] and 18.1% with an unspecified non-time-restricted follow-up interval (preoperative diagnosis of multilevel [≥3 levels] degenerative cervical disease) [15]. The lower pooled revision rate (1.09%) reported in this current meta-analysis for all surgical indications could be attributed to shorter follow-up intervals reported in the meta-analysis articles (Table 2). Short-term complication rates for subaxial PCF as reported from large administrative databases were 10.5% (in-hospital rate) [1], 18.6% (30-day rate, preoperative diagnosis of multilevel [≥3 levels]

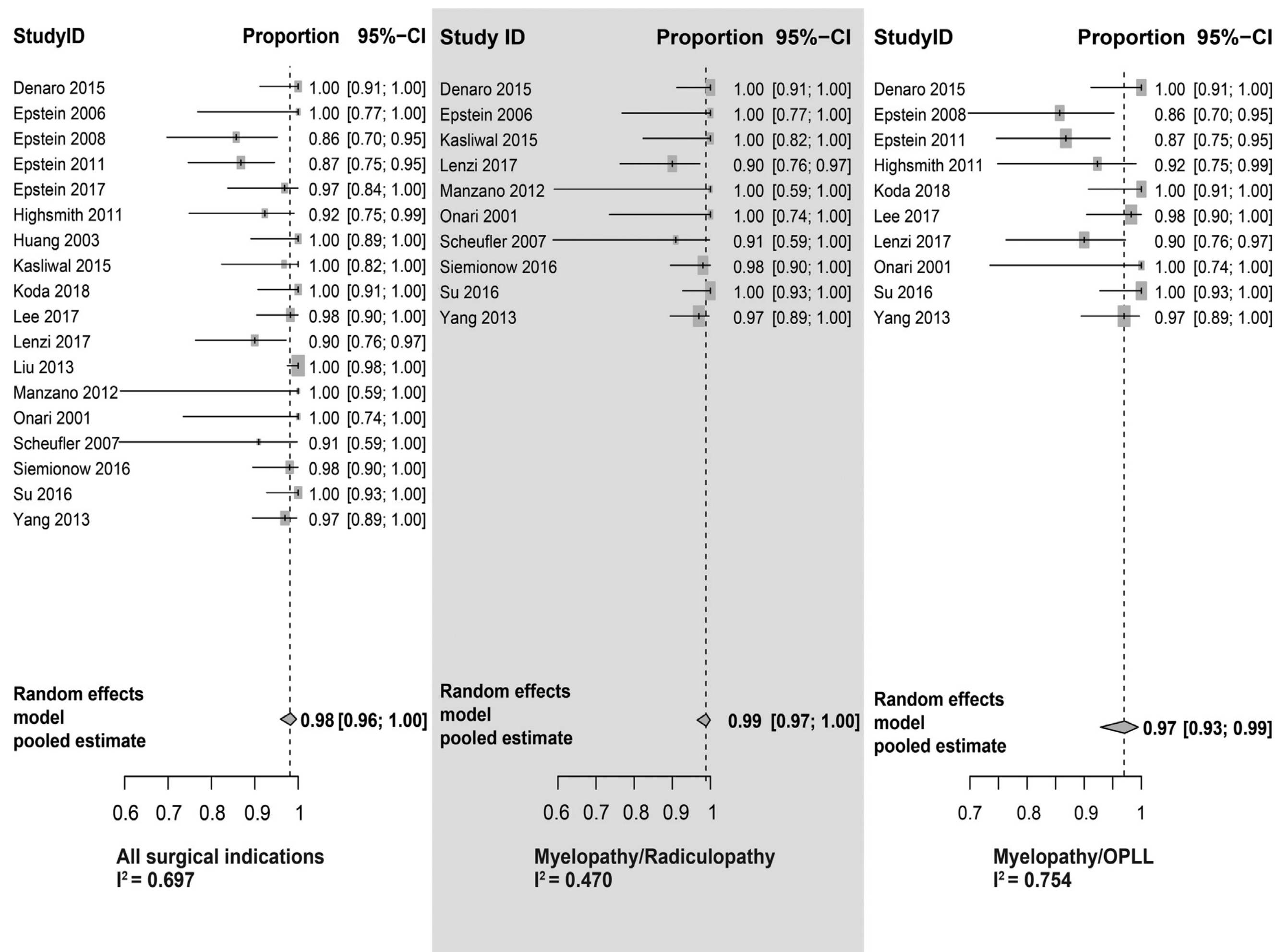
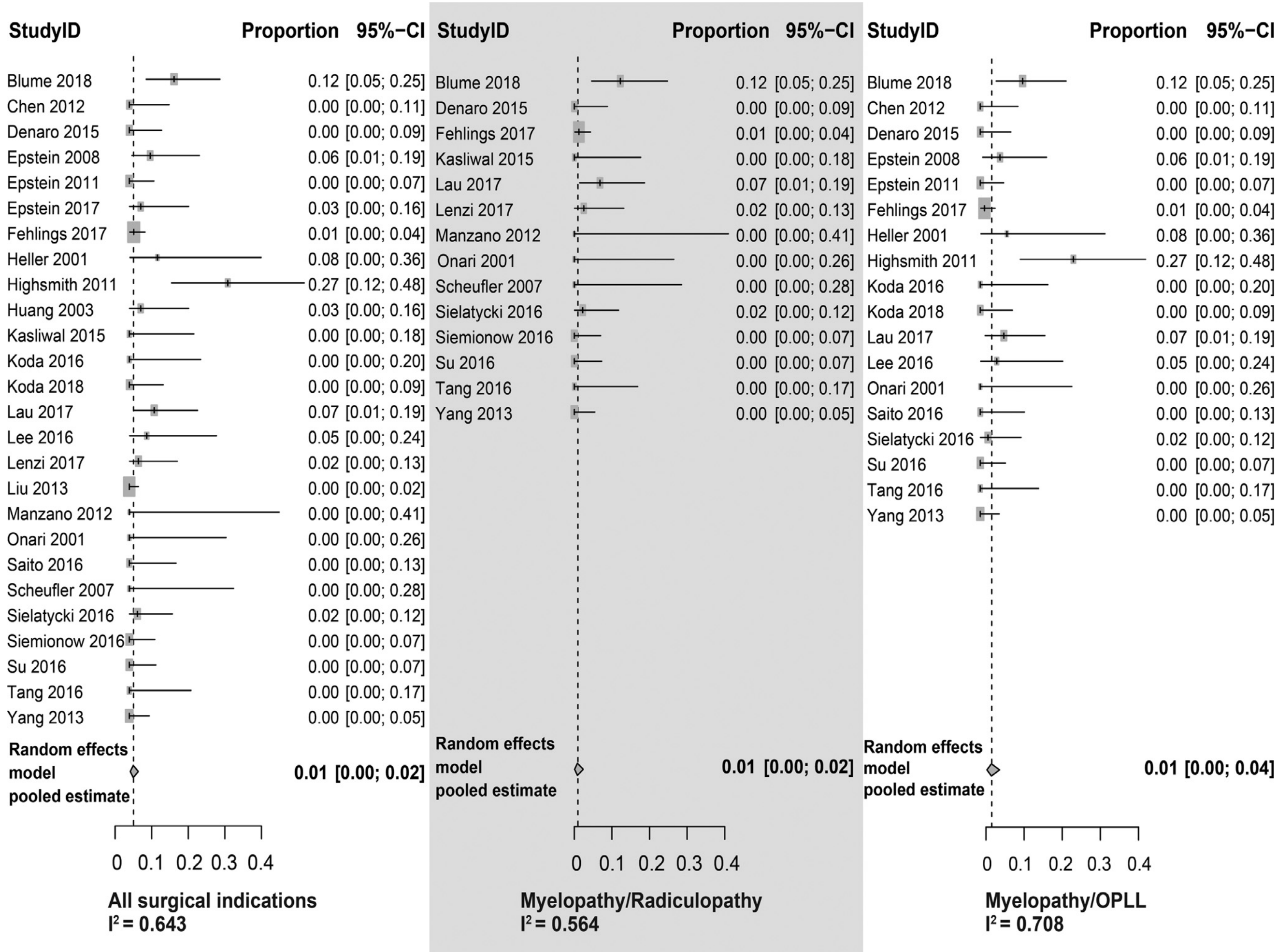


Fig. 7. Forest plots of clinical outcomes of posterior cervical fusion with decompression; for all surgical indications, for only myelopathy or radiculopathy (or both) as surgical indications in a study (myelopathy/radiculopathy), and for only myelopathy or ossification of the posterior longitudinal ligament (or both) as surgical indications in a study (myelopathy/OPLL). (a) Successful fusion rate, (b) revision rate, and (c) complication or adverse event rate.



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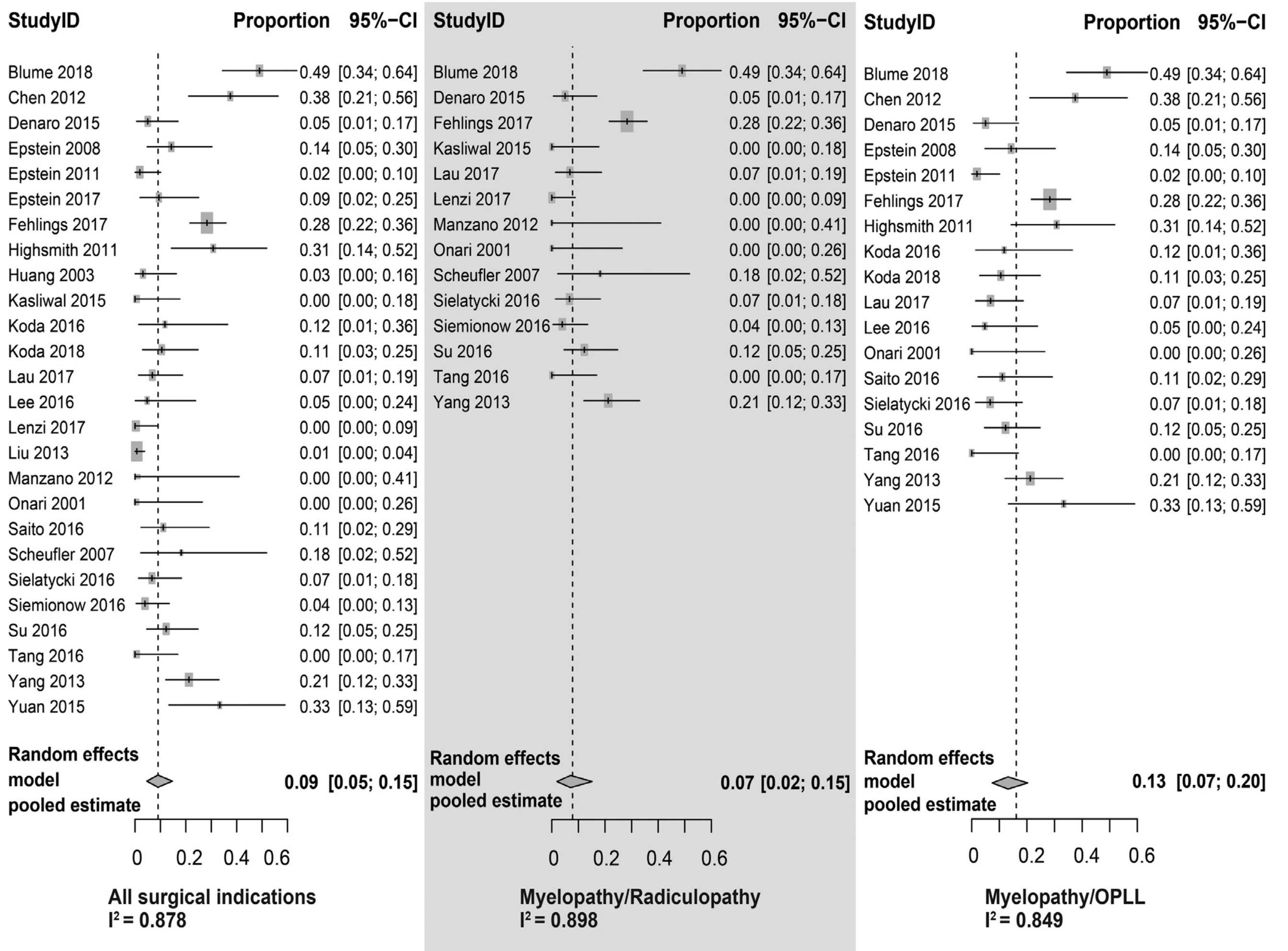
degenerative cervical disease) [15], and 29.2% (30-day rate, preoperative diagnosis of CSM) [17]. The pooled rate of complications or adverse events from this current meta-analysis for all surgical indications was 9.02%; this lower rate might have resulted from stricter inclusion/exclusion criteria in the meta-analysis studies than in the large administrative database studies.

A prospective observational study of 95 patients receiving a posterior decompressive/reconstructive surgical approach (either laminectomy and fusion or laminoplasty) versus 169 patients receiving an anterior approach (discectomy/corpectomy with instrumented fusion) for CSM reported that the posterior versus anterior approaches had equivalent efficacy after controlling for patient and disease factors—the patients receiving an anterior approach were younger, had more focal cervical pathology, and better preoperative patient-reported outcomes than did the patients receiving a posterior approach [2]. Keeping in mind the differences between patients receiving PCF or ACF [1,4−6], whereas in the current meta-analysis the revision rate was 1.09%, in large administrative databases the revision rate was reported as 7.4% for PCF and 13.4% for ACF [6] and as 18.1% for PCF and 12.8% for ACF (preoperative diagnosis of multilevel [≥3 levels] degenerative cervical disease) [15]; in meta-analyses of anterior cervical discectomy and fusion (ACDF) the revision rate was reported as 1.8% to 16.8% [58−61]. Also, whereas in the current meta-analysis the complication or adverse event rate was 9.02%, in large administrative databases the complication or adverse event rate was reported as 10.5% for PCF and 3.0% for ACF (in-hospital rate) [1], 18.6% for PCF and 16.7% for ACF (preoperative diagnosis of multilevel [≥3 levels] degenerative cervical disease) [15], and 29.2% for PCF and 15.6% for ACDF (30-day rate, preoperative diagnosis of CSM) [17]; in meta-analyses of ACDF the complication or adverse event rate was reported as 4.5% to 29.6% [58,59,62,63].

Postoperative complications of axial pain and infection may be expected after the extensive muscle detachment and retraction required during PCF surgery. Postoperative C5 palsy may result from stretching of the C5 spinal nerves in their respective foramina during spinal cord repositioning subsequent to laminectomy [64]. Transient neurologic



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worsening is a postoperative complication that surgeons might not have discussed with patients who are potential candidates for PCF with decompression surgery.

This study had some limitations. Most of the meta-analysis articles were of retrospective studies (20 out of 31). A few of the articles were assessed as having elements with a high risk of bias (the study with the highest number of patients had 2 elements with a high risk of bias [34]); however, the majority of the risk of bias assessments were low (Table 1). The myelopathy/radiculopathy subgroup excluded articles that stated surgical indications that might be expected to cause myelopathy or radiculopathy but did not explicitly state myelopathy or radiculopathy as surgical indications. The VAS-arm was measured only within studies that included radiculopathy as a surgical indication, so no VAS-arm measurements were available for the myelopathy/OPLL subgroup. Although 5 articles in the myelopathy/OPLL subgroup measured NDI (Supplemental Table A), meta-analysis was not performed as only 3 articles included sufficient data. Heterogeneity for almost all variables was moderate or high, which led to the use of the mixed random-effects models for statistical analysis. The JOA and mJOA scores were combined for this meta-analysis; although these 2 scores should not be used interchangeably, they correlate well with each other for assessing cervical myelopathy [65]. The MCID data for a patient population should properly be reported as the proportion of that population that achieves the MCID, not as the average change in MCID for that population [66]. In this study, the MCIDs for cervical spine surgery were included for reference and were not involved in any statistical analyses. This study was industry funded but followed a preapproved protocol conducted by outside researchers and involved no original data collection.

The number of studies assessing the safety and efficacy of PCF is fewer than for ACF, but this systematic review identified 33 studies, 31 of which were included in the meta-analysis. Most of those studies (22 out of 31) involved PCF as a supplement to laminectomy, hemilaminectomy, or laminectomy plus foraminotomy (Table 2), thus supporting earlier studies that demonstrated the inadequacy of isolated cervical laminectomy [2,3]. This meta-analysis calculated improved patient-reported outcomes, a high fusion rate, and low rates of revision and of complications and adverse events across the pooled subjects for all indications and for the subgroups of myelopathy/radiculopathy and myelopathy/OPLL. These findings suggest that PCF with decompression should be considered as a surgical option in selected patients. Given the trends in demographics and in the cost and use of PCF, additional studies are needed.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.spinee.2019.04.019.

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