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Original Article

Decompression with fusion in the treatment of lumbar spinal stenosis: a meta-analysis

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Abstract: The present study investigated whether spinal fusion with decompression has a better effect than decompression alone in the treatment of patients with lumbar spinal stenosis (LSS). The surgical methods of degenerative LSS include spinal decompression with or without spinal fusion. The treatment of spinal stenosis by surgery has increased rapidly in the past two decades; however, its efficacy is yet controversial. PubMed, Embase, and Cochrane library databases were searched for randomized controlled trials and cohort studies published up to October 31, 2016. The meta-analysis was performed using random or fixed effects model. A total of 29 studies were identified with data assimilated from 27380 patients. The pooled results showed that decompression plus fusion was similar to the decompression on dural tear rate [risk ratios (RR) = 1.05, 95% confidence interval (CI): 0.70-1.55], clinical outcome (RR = 0.93, 95% CI: 0.85-1.01), reoperation rate (RR = 0.94, 95% CI: 0.87-1.02), wound infection rate (RR = 0.56, 95% CI: 0.29-1.07), Oswestry disability index [weighted mean differences (WMD) = -2.22, 95% CI: -2.84-1.59], and European quality of life-5 dimensions score (WMD = -0.00, 95% CI: -0.02-0.02); the former was inferior to the latter in terms of surgery duration (WMD = -95.63, 95% CI: -128.75-62.51), blood loss (WMD = -413.02, 95% CI: -562.80-263.23), and hospital stay (WMD = -2.22, 95% CI: -2.84-1.59). Thus, decompression with fusion was found to have fewer benefits than decompression alone for the treatment of LSS.

Keywords: Lumbar spinal stenosis, decompression, spinal fusion, meta-analysis

Introduction

Lumbar spinal stenosis (LSS) is the narrowing of the spinal canal by surrounding soft tissues and bone, which compromises of neural structures [1]. Radiographic findings of spinal stenosis revealed typically long-term symptoms of intermittent neurogenic claudication (radicular pain during walking and/or standing that resolves with lumbar flexion) in a majority of the patients [2]. Consequently, patients are commonly referred for surgery if their condition is refractory to conservative treatment. As a result, the number of surgical procedures conducted for LSS has increased steadily over the years, costing approximately 2 billion annually [3, 4]. However, the surgical techniques selected by surgeons are yet indeterminate, although no clear superiority of one technique over the others has been recommended yet.

The current evidence suggests that surgery for LSS is more effective than common conservative treatment when the latter has failed for up to 3 months [5, 6]. For example, the Spine Patient Outcomes Research Trial (SPORT) patients treated surgically exhibited lower pain levels than those assigned to a nonsurgical treatment [7]. The standard surgical approach for LSS is bony decompression via laminectomy [8, 9]. However, as spinal instability is a frequent consequence following bony decompression, and surgical fusion has been recommended in addition to decompression of the spinal canal for the treatment of some patients with spinal stenosis [10]. Several studies have demonstrated that the addition of fusion is advisable for patients, as this procedure yields acceptable surgical results [11, 12]. The method of spinal fusion is now gaining prevalence; a previous study reported that the rate of fusion

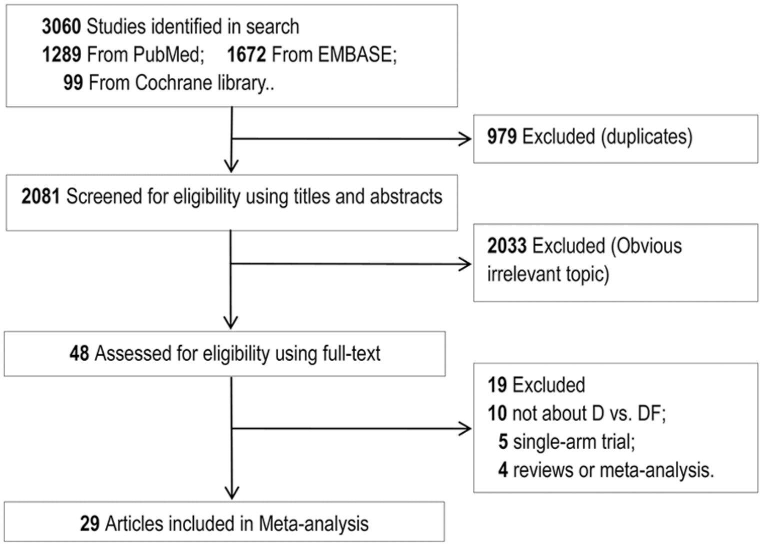


Figure 1. Schematic representation of the study selection process.

surgery increased by 220% from 1990 to 2001 for the treatment of LSS [4].

Although both surgical techniques are effective in treating LSS, lack of evidence supporting this rapid evolution of surgical techniques usually render the clinicians to rely on their personal experiences. A previous meta-analysis estimated the effect of fusion-added decompression for LSS and found a superior clinical outcome but a higher reoperation rate for spinal fusion than decompression alone [13]. However, the analysis evaluated only two outcomes (clinical outcome and reoperation rate). Therefore, we conducted a meta-analysis to compare the surgical and prognostic outcomes of LSS quantitatively between decompression and decompression plus fusion.

Materials and methods

Search strategy

Relevant randomized controlled trials (RCTs) and cohort studies were identified. Briefly, we searched the PubMed, Embase, and Cochrane library for studies published up to October 31, 2016 using the following search terms: "(LSS OR [spinal stenosis]) AND Fusion AND (Laminectomy OR decompression)" without restrictions (further details of the search strategy are available in Supplementary 1). All abstracts, studies, and citations were reviewed irrespective of the language. Also, we included unpublished studies in the gray literature (theses and technical reports).

All analyses were based on previously published studies, and thus, no ethical approvals and patient consents were required.

Study selection

Studies were included in this meta-analysis if they fulfilled the following criteria: (1) Study design: RCT or cohort study; (2) Participants: adult patients (≥ 18-year-old) with primary LSS; (3) Treatment: decompression for the trial group (D group) and decompression plus fusion for the control group (D+F group); (4) Outcomes: surgical outcomes, including operating time, loss of blood, hospital stay, and dural tear rate and prognostic outcomes, including clinical outcome, reoperation rate, wound infection rate, Oswestry disability index (ODI), and European quality of life-5 dimensions (EQ-5D) score. The exclusion criteria were as follows : (1) Participants with a history of spinal surgery due to LSS; (2) Follow-up time of <1 year; (3) Without available data for analysis.

Data extraction and quality assessment

The following data were extracted independently by two authors (ZFX and YY) from each study: first author's name, year of publication, study design, study location, intervention, sample size, age, sex, follow-up period, and outcomes. Any disagreements were resolved by a consensus. We evaluated the quality of the RCTs using the Cochrane Collaboration tool for assessing the risk of bias. In addition, a 9-star system using the Newcastle-Ottawa scale (NOS) was employed for assessing the quality of the cohort studies [14].

Statistical analysis

Risk ratios (RRs) or weighted mean differences (WMDs) with 95% confidence intervals (CIs) were calculated as effect sizes. Dichotomous variables were estimated for the RRs and continuous variables for the WMD. The operation duration, loss of blood, length of hospital stay, dural tear rate, clinical outcome, reoperation rate, wound infection rate, ODI, and EQ-5D score between the D and D+F groups were eval-

Table 1. Characteristics of each included study

Study	Country	Design	Intervention	Follow-up	n	M/F*	Age (years)	Outcomes
Athiviraham, A 2007	Canada	PCS	D	2 years	49	32/17	63	d, e, f, g
			D+F		39	14/25	70	
Austevoll, IM 2016	Norway	PCS	D	1 year	260	72/188	66.7 (10.0)	d, e, h
			D+F		260	65/195	66.3 (9.6)	
Bridwell, KH 1993	USA	RCT	D	3 years	9	2/7	66.2	e
			D+F		34	8/26	66.2	
Brodke, DS 2013	USA	RCS	D	63 months	24	16/8	69 (9.2)	e, f, g
			D+F		45	16/29	70 (9.3)	
Chen, YM 2010	China	RCS	D	67 months	31	20/11	61.5 (34-75)	a, b, c, e, f, g
			D+F		39	14/25	59.9 (32-79)	
Cornefjord, M 2000	Sweden	RCS	D	7.1 years	37	NR	64.4 (29-87)	e
			D+F		59	NR	64.4 (29-87)	
Fokter, SK 2006	USA	RCS	D	27 months	38	17/21	64.6 (8.9)	a, b, c, b, e
			D+F		20	4/16	69.1 (6.1)	
Forsth, P 2013	Sweden	RCS	D	2 years	4259	2020/2239	70 (50-91)	f, h, i
			D+F		1131	315/818	67 (50-90)	
Forsth, P 2016	Sweden	RCT	D	2 years	120	35/95	66.6 (7.4)	a, b, c, d, e, f, g, h, i
			D+F		113	43/70	67.2 (7.9)	
Fox, MW 1996	USA	RCS	D	5.8 years	92	NR	67.5 (34-83)	e
			D+F		32	NR	67.5 (34-83)	
Ghogawala, Z 2004	USA	PCS	D	1 year	20	NR	68.8 (8.0)	f, g
			D+F		14	NR	68.8 (8.0)	
Ghogawala, Z 2016	USA	RCT	D	4 years	35	8/27	66.5 (8.0)	a, b, c, h
			D+F		31	5/26	66.7 (7.2)	
Grob, D 1995	Sweden	RCT	D	28 months	15	6/9	66 (48-72)	a, b, d, e, f
			D+F		30	15/15	71 (56-87)	
Hallett, A 2007	Scotland	RCT	D	5 years	14	9/5	57 (10)	a, b, f
			D+F		30	15/15	56.3 (9.2)	
Herkowitz, HN 1991	USA	PCS	D	3 years	25	9/16	65 (53-83)	e
			D+F		25	5/20	63.5 (52-84)	
Katz, JN 1997	USA	PCS	D	2 years	194	91/103	70 (8.1)	e, f
			D+F		78	20/58	65 (8.9)	
Lad, SP 2014	USA	RCS	D	>2 years	9400	NR	NR	c, f
			D+F		3257	NR	NR	
Lee, CH 2013	South Korea	RCS	D	3.9 years	25	15/10	79.2 (75-90)	f
			D+F		25	15/10	79.7 (75-93)	
Li, Z 2015	China	RCS	D	1 year	15	NR	72 (5.2)	a, b, d, e, g
			D+F		24	NR	72 (5.2)	
Matsudaira, K 2005	Japan	RCS	D	2 years	18	8/10	68 (7)	e
			D+F		19	7/11	67 (7)	
Modhia, U 2013	USA	RCS	D	2 years	4164	2166/1998	NR	f
			D+F		629	289/340	NR	
Munting, E 2015	Belgium	PCS	D	1 year	1068	516/552	67.6 (29.9)	d, g
			D+F		108	35/73	66.3 (41-98)	
Rampersaud, YR 2014	Canada	RCS	D	2 years	46	19/27	67.80 (8.66)	e
			D+F		133	35/98	62.47 (10.83)	
Rompe, JD 1999	German	RCS	D	8 years	90	44/46	60.7 (7.2)	e, f
			D+F		27	24/23	64 (8.8)	
Sigmundsson, FG 2015	Sweden	PCS	D	2 years	245	69/176	73.5 (9.9)	h, i
			D+F		594	122/472	69.0 (8.9)	

Son, S 2013	South Korea	RCS	D	5.5 years	31	16/15	72.8 (6.8)	a, b, c, e, g, i
			D+F		29	11/18	69.4 (3.8)	
Wu, YJ 2008	China	RCS	D	51 months	96	NR	58.3 (29-87)	e
			D+F		85	NR	58.3 (29-87)	
Yone, K 1996	Japan	RCS	D	3 years	7	3/4	69 (61-79)	e
			D+F		10	4/6	68 (60-89)	
Yone, K 1999	Japan	RCS	D	40 months	14	10/4	63 (45-79)	e
			D+F		19	12/7	61 (55-79)	

M, male; F*, female; a, operating time; b, loss of blood; c, hospital stay; d, dural tear rate; e, clinical outcome; f, reoperation rate; g, wound infection rate; h, ODI (Oswestry disability index); i, EQ-5D (European quality of life-5 dimensions); n, sample size; D, decompression; F, fusion; NR, not reported; PCS, prospective cohort study; RCS, retrospective cohort study; RCT, randomized controlled trial.

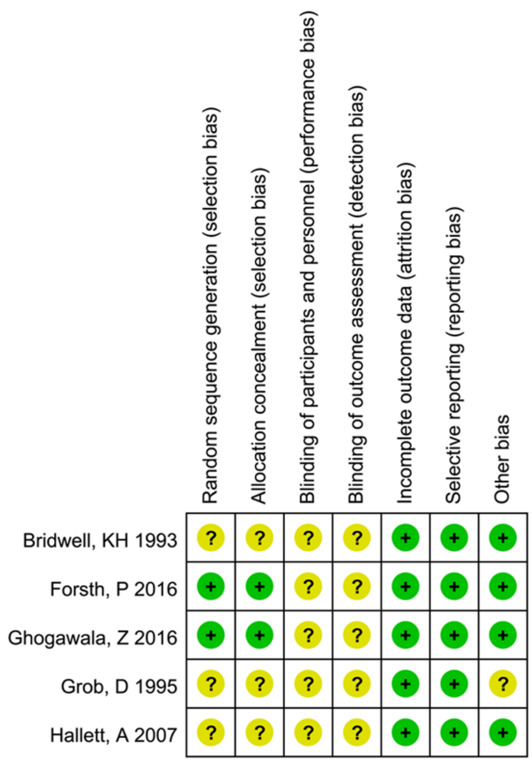


Figure 2. Risk of bias summary: a review of the authors' judgments about the risk of bias item for each included study.

uated. The potential heterogeneity across the studies was examined using the Cochran's Q-statistic [15] and I^2 statistics [16]. If the *P*-value for heterogeneity was <0.05 or I^2 was >50%, the random-effects model was used for the analysis; otherwise, the summary effect was computed using the fixed-effect model. Publication bias was evaluated using the Egger's test [17], where P<0.05 indicated a statistically significant publication bias. In order to explore the potential association among the different study designs, a subgroup analysis was conducted to assess the estimated effect based on the study designs, such as RCT or cohort. All the analyses were conducted using the Review Manager Software (version 5.2, Nordic Cochrane Center, Copenhagen, Denmark).

Results

Literature search and study selection

The study selection process was illustrated in **Figure 1**. A total of 3060 relevant articles were retrieved (PubMed: 1289, Embase: 1672, and Cochrane library: 99), of which, 979 were excluded owing to duplication. Subsequently, 2081 articles were identified and screening based on the title and/or abstract. Of these, 2033 articles were not related to the topic, and hence, excluded. After assessing the eligibility of the full-text articles, 19 were excluded. Finally, 29 articles that fulfilled all the inclusion criteria were included in the meta-analysis [12, 18-45].

Study characteristics

Selected details of the individual studies are listed in **Table 1**. These studies, including 5 RCTs [20, 26, 29-31], 17 retrospective cohort studies [12, 21-25, 27, 34-38, 40, 41, 43-45], and 7 prospective cohort studies [18, 19, 28, 32, 33, 39, 42], were published before October 2016. Of these, 12 studies were conducted in the USA [18, 20, 21, 24, 27-29, 32-34, 38, 40], 9 in Europe [19, 23, 25, 26, 30, 31, 39, 41, 42], and 8 in Asia [12, 22, 35-37, 43-45]. The length of the follow-up period ranged from 1-7 years. The number of patients involved in the studies ranged from 37-5390. All the included studies presented moderate and high qualities with acceptable and moderate risks of bias (**Figure 2**, **Table 2**).

Table 2. Methodological quality of cohort studies included in the meta-analysis[1]

First author	Representativeness of the exposed cohort	Selection of the unexposed cohort	Ascertainment of exposure	Outcome of interest not present at start of study	Control for important factor or additional factor	Outcome assessment	Follow-up duration sufficient for outcomes to occur[2]	Adequacy of follow-up of cohorts	Total quality scores
Athiviraham, A 2007	☆	☆	☆	☆	☆	☆	-	☆	7
Austevoll, IM 2016	☆	☆	☆	☆	☆☆	-	-	☆	7
Brodke, DS 2013	☆	☆	☆	-	☆	☆	☆	☆	7
Chen, YM 2010	☆	☆	☆	-	☆	☆	☆	☆	7
Cornefjord, M 2000	☆	☆	☆	-	☆	-	☆	☆	6
Fokter, SK 2006	☆	☆	☆	-	☆	☆	-	☆	6
Forsth, P 2013	☆	☆	☆	-	☆	☆	-	☆	6
Fox, MW 1996	☆	☆	☆	-	☆	-	☆	☆	6
Ghogawala, Z 2004	☆	☆	☆	☆	☆	☆	-	☆	7
Herkowitz, HN 1991	☆	☆	☆	☆	☆	☆	-	☆	7
Katz, JN 1997	☆	☆	☆	☆	☆	☆	-	☆	7
Lad, SP 2014	☆	☆	☆	-	☆	☆	-	☆	6
Lee, CH 2013	☆	☆	☆	-	☆☆	☆	-	☆	7
Li, Z 2015	☆	☆	☆	-	☆	☆	-	☆	6
Matsudaira, K 2005	☆	☆	☆	-	☆☆	-	-	☆	6
Modhia, U 2013	☆	☆	☆	-	☆	☆	-	☆	6
Munting, E 2015	☆	☆	☆	☆	☆	☆	-	☆	7
Rampersaud, YR 2014	☆	☆	☆	-	☆	☆	-	☆	6
Rompe, JD 1999	☆	☆	☆	-	☆	☆	☆	☆	7
Sigmundsson, FG 2015	☆	☆	☆	☆	☆	☆	-	☆	7
Son, S 2013	☆	☆	☆	-	☆	☆	☆	☆	7
Wu, YJ 2008	☆	☆	☆	-	☆	☆	-	☆	6
Yone, K 1996	☆	☆	☆	-	☆	☆	-	☆	6
Yone, K 1999	☆	☆	☆	-	☆☆	☆	-	☆	7

[1]A study could be awarded a maximum of one star for each item except for the item control for important factor or additional factor. [2]Follow-up time ≥ 5 years.

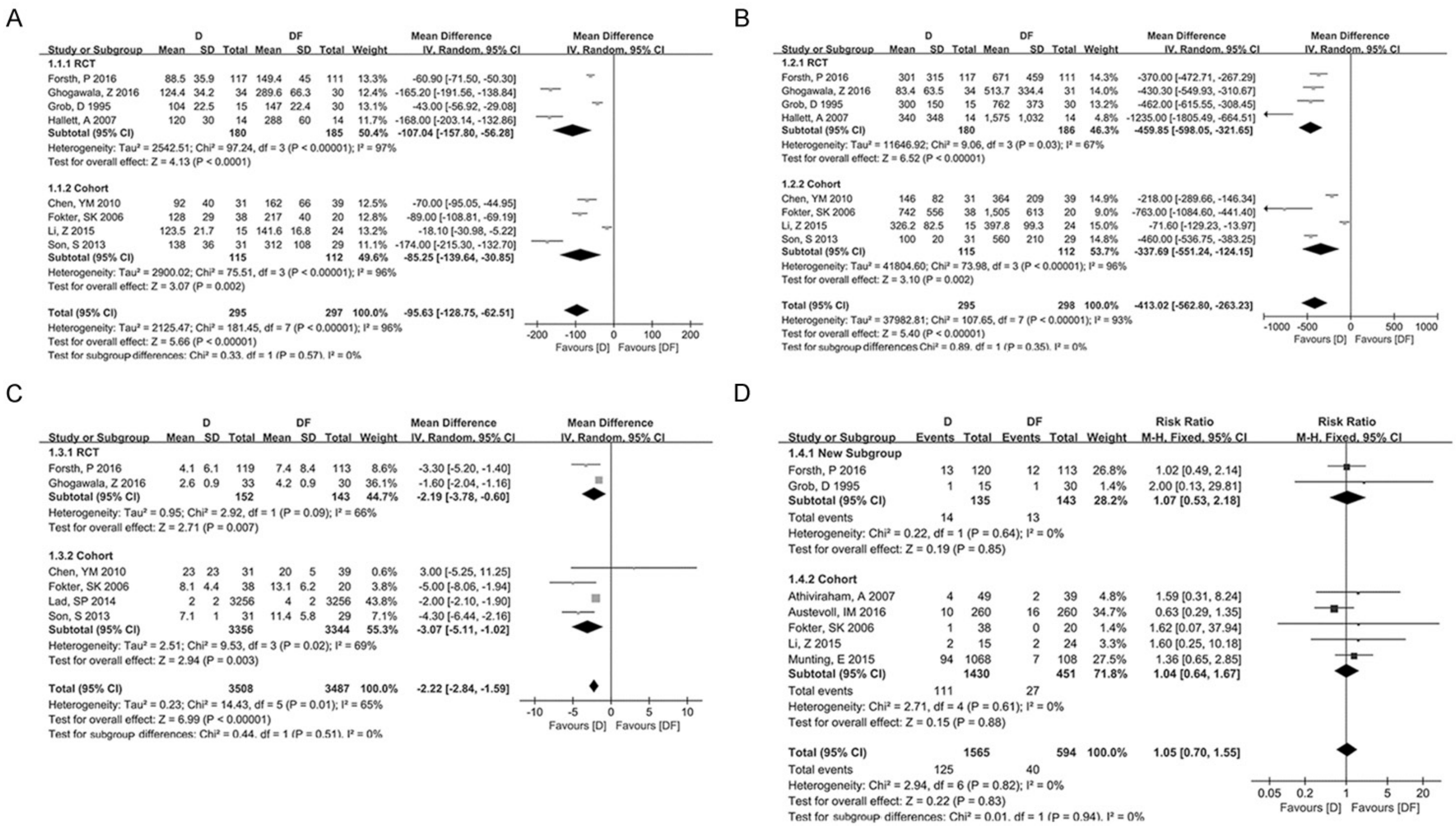


Figure 3. A. Forest plot of the operation time. Each study is shown by the point estimate of the WMD and 95% CI (extending lines). B. Forest plot of the blood loss. Each study is shown by the point estimate of the WMD and 95% CI (extending lines). C. Forest plot of the hospital stay. Each study is shown by the point estimate of the MD and 95% CI (extending lines). D. Forest plot of the dural tear. Each study is shown by the point estimate of the RR and 95% CI for the RR (extending lines). WMD, weighted mean difference; CI, confidence interval; RR, risk ratio; CI, confidence interval.

Main analysis

Operating time: Eight studies reported the mean operating time and standard deviation and revealed that the operating time of the D+F group was longer than that of the D group (**Figure 3A**); the WMD was statistically significant (WMD = -95.63, 95% CI: -128.75 - -62.51, P<0.00001). To explore the potential association among the study designs, a stratified analysis was conducted to assess the effect estimated in the subgroups defined by the study design. The results of the stratified analysis were similar to that of the total result.

Blood loss: Eight studies reported the mean blood loss and the standard deviation and revealed that the blood loss of the D+F group was greater than that of the D group (**Figure 3B**); the WMD was statistically significant (WMD = -413.02, 95% CI: -562.80 - -263.23, P<0.00001). In addition, a stratified analysis was performed to assess the effect estimated in the subgroups defined by the study design, and the results were similar to that of the total result.

Hospital stay: Six studies reported the mean hospital stay and the standard deviation and revealed that the length of the hospital stay of the D+F group was longer than that of the D group (**Figure 3C**); the WMD was statistically significant (WMD = -2.22, 95% CI: -2.84 - -1.59, P<0.00001). The stratified analysis defined by the study design also suggested that the length of the hospital stay of the D+F group was longer than that of the D group.

Dural tear rate: Seven studies provided the rate of dural tear after various surgical procedures. The overall estimations revealed that the D+F group did not show a statistically significant altered dural tear rate as compared to the D group (RR = 1.05, 95% CI: 0.70 - 1.55, P = 0.83) (**Figure 3D**). A stratified analysis defined by the study design showed results similar to the total result.

Clinical outcome: Twenty-three studies provided the rate of clinical outcome after different surgical procedures. The overall estimates did not show a statistically significant altered clinical outcome in the D+F group as compared to the D group (RR = 0.93, 95% CI: 0.85 - 1.01, P = 0.07) (**Figure 4A**). A stratified analysis defined by the study design showed results similar to the total result.

Reoperation rate: Thirteen studies provided the reoperation rate after various surgical procedures. The overall estimates revealed that the reoperation rate did not alter significantly in the D+F as compared to the D group (RR = 0.94, 95% CI: 0.87 - 1.02, P = 0.15) (**Figure 4B**). A stratified analysis defined by the study design showed results similar to the total result.

Wound infection rate: Thirteen studies provided the wound infection rate after different surgical procedures. The overall estimates revealed that the D+F group did not demonstrate any statistically significant change in the rate of wound infection as compared to the D group (RR = 0.56, 95% CI: 0.29 - 1.07, P = 0.08) (**Figure 4C**). A stratified analysis defined by the study design also showed results similar to the total result.

ODI: The ODI data were available in 6 studies, and the total results did not reveal any difference between the two groups (WMD = -2.22, 95% CI: -2.84 - -1.59, P = 0.35) (**Figure 4D**). Moreover, the stratified analysis defined by the study design displayed results similar to the total result.

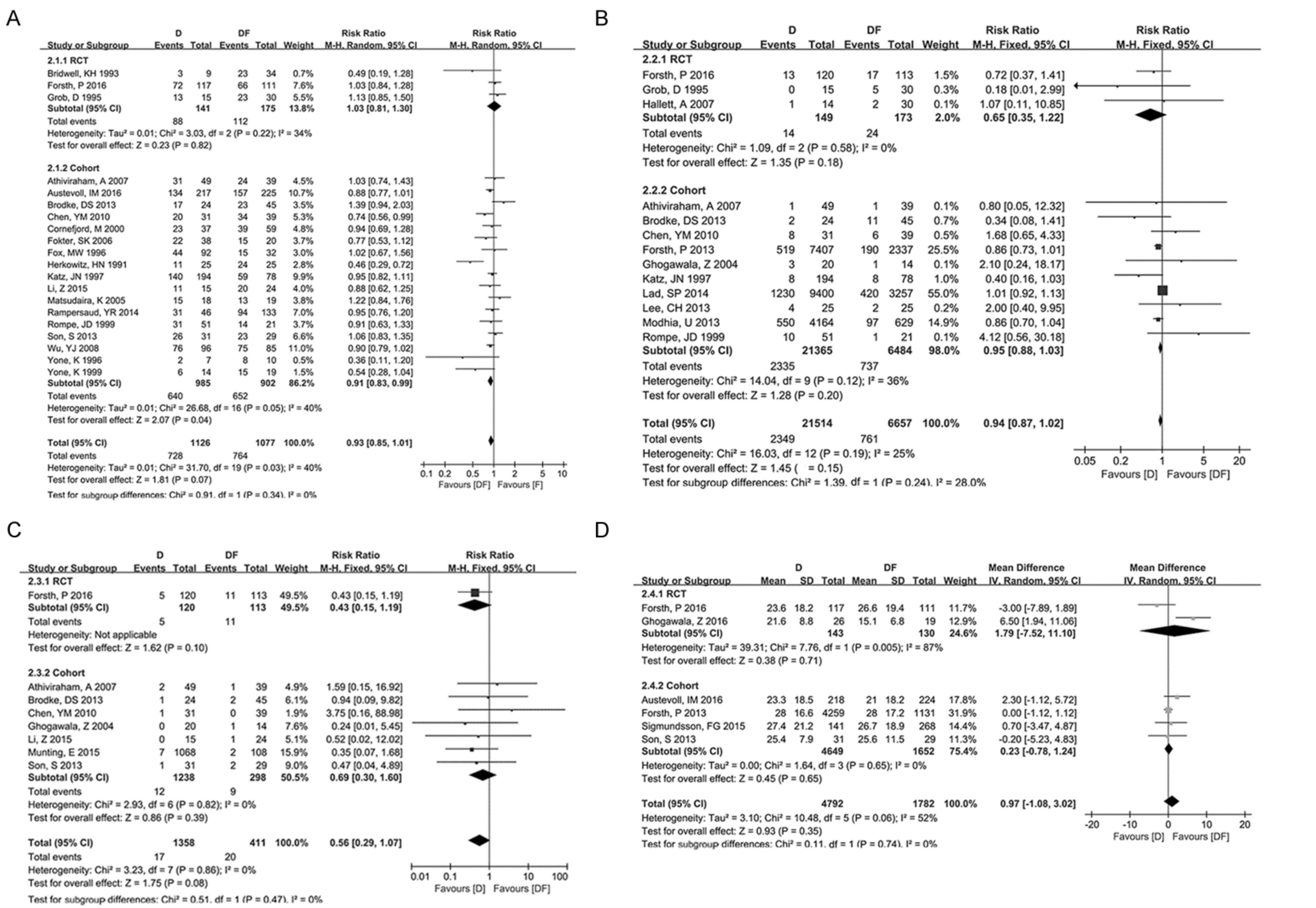
EQ-5D: Data regarding the EQ-5D were available in 3 studies. The total results revealed that no significant difference was observed between the two groups (WMD = -0.00, 95% CI: -0.02 - -0.02, P = 0.99) (**Figure 4E**). The stratified analysis defined by the study design also showed results similar to the total result.

Publication bias

Publication bias was evaluated by comparing the clinical outcomes using the Egger's test; no publication bias was evident (P = 0.289).

Discussion

The current meta-analysis encompassing 29 studies included 27380 participants and showed that decompression plus fusion was similar to decompression with respect to satisfaction degree, complications, reoperation rate, and quality of life; the former was inferior to the latter regarding the surgery duration, blood loss, and length of hospital stay. The stratified


A
Study or Subgroup | D Events | D Total | DF Events | DF Total | Weight | Risk Ratio M-H, Random, 95% CI | Risk Ratio M-H, Random, 95% CI
2.1.1 RCT
Bridwell, KH 1993 3 9 23 34 0.7% 0.49 [0.19, 1.28]
Forsth, P 2016 72 117 66 111 7.6% 1.03 [0.84, 1.28]
Grob, D 1995 13 15 23 30 5.5% 1.13 [0.85, 1.50]
Subtotal (95% CI) 141 175 13.8% 1.03 [0.81, 1.30]
Total events 88 112
Heterogeneity: Tau² = 0.01; Chi² = 3.03, df = 2 (P = 0.22); I² = 34%
Test for overall effect: Z = 0.23 (P = 0.82)
2.1.2 Cohort
Athiviraham, A 2007 31 49 24 39 4.5% 1.03 [0.74, 1.43]
Austevoll, IM 2016 134 217 157 225 10.7% 0.88 [0.77, 1.01]
Brodke, DS 2013 17 24 23 45 3.5% 1.39 [0.94, 2.03]
Chen, YM 2010 20 31 34 39 5.3% 0.74 [0.56, 0.99]
Cornefjord, M 2000 23 37 39 59 4.8% 0.94 [0.69, 1.28]
Fokter, SK 2006 22 38 15 20 3.7% 0.77 [0.53, 1.12]
Fox, MW 1996 44 92 15 32 3.0% 1.02 [0.67, 1.56]
Herkowitz, HN 1991 11 25 24 25 2.8% 0.46 [0.29, 0.72]
Katz, JN 1997 140 194 59 78 9.9% 0.95 [0.82, 1.11]
Li, Z 2015 11 15 20 24 4.0% 0.88 [0.62, 1.25]
Matsudaira, K 2005 15 18 13 19 3.8% 1.22 [0.84, 1.76]
Rampersaud, YR 2014 31 46 94 133 7.0% 0.95 [0.76, 1.20]
Rompe, JD 1999 31 51 14 21 3.7% 0.91 [0.63, 1.33]
Son, S 2013 26 31 23 29 6.6% 1.06 [0.83, 1.35]
Wu, YJ 2008 76 96 75 85 11.0% 0.90 [0.79, 1.02]
Yone, K 1996 2 7 8 10 0.5% 0.36 [0.11, 1.20]
Yone, K 1999 6 14 15 19 1.5% 0.54 [0.28, 1.04]
Subtotal (95% CI) 985 902 86.2% 0.91 [0.83, 0.99]
Total events 640 652
Heterogeneity: Tau² = 0.01; Chi² = 26.68, df = 16 (P = 0.05); I² = 40%
Test for overall effect: Z = 2.07 (P = 0.04)
Total (95% CI) 1126 1077 100.0% 0.93 [0.85, 1.01]
Total events 728 764
Heterogeneity: Tau² = 0.01; Chi² = 31.70, df = 19 (P = 0.03); I² = 40%
Test for overall effect: Z = 1.81 (P = 0.07)
Test for subgroup differences: Chi² = 0.91, df = 1 (P = 0.34), I² = 0%
0.1 0.2 0.5 1 2 5 10
Favours [DF] Favours [F]
B
Study or Subgroup | D Events | D Total | DF Events | DF Total | Weight | Risk Ratio M-H, Fixed, 95% CI | Risk Ratio M-H, Fixed, 95% CI
2.2.1 RCT
Forsth, P 2016 13 120 17 113 1.5% 0.72 [0.37, 1.41]
Grob, D 1995 0 15 5 30 0.3% 0.18 [0.01, 2.99]
Hallett, A 2007 1 14 2 30 0.1% 1.07 [0.11, 10.85]
Subtotal (95% CI) 149 173 2.0% 0.65 [0.35, 1.22]
Total events 14 24
Heterogeneity: Chi² = 1.09, df = 2 (P = 0.58); I² = 0%
Test for overall effect: Z = 1.35 (P = 0.18)
2.2.2 Cohort
Athiviraham, A 2007 1 49 1 39 0.1% 0.80 [0.05, 12.32]
Brodke, DS 2013 2 24 11 45 0.7% 0.34 [0.08, 1.41]
Chen, YM 2010 8 31 6 39 0.5% 1.68 [0.65, 4.33]
Forsth, P 2013 519 7407 190 2337 25.5% 0.86 [0.73, 1.01]
Ghogawala, Z 2004 3 20 1 14 0.1% 2.10 [0.24, 18.17]
Katz, JN 1997 8 194 8 78 1.0% 0.40 [0.16, 1.03]
Lad, SP 2014 1230 9400 420 3257 55.0% 1.01 [0.92, 1.13]
Lee, CH 2013 4 25 2 25 0.2% 2.00 [0.40, 9.95]
Modhia, U 2013 550 4164 97 629 14.9% 0.86 [0.70, 1.04]
Rompe, JD 1999 10 51 1 21 0.1% 4.12 [0.56, 30.18]
Subtotal (95% CI) 21365 6484 98.0% 0.95 [0.88, 1.03]
Total events 2335 737
Heterogeneity: Chi² = 14.04, df = 9 (P = 0.12); I² = 36%
Test for overall effect: Z = 1.28 (P = 0.20)
Total (95% CI) 21514 6657 100.0% 0.94 [0.87, 1.02]
Total events 2349 761
Heterogeneity: Chi² = 16.03, df = 12 (P = 0.19); I² = 25%
Test for overall effect: Z = 1.45 (= 0.15)
Test for subgroup differences: Chi² = 1.39, df = 1 (P = 0.24), I² = 28.0%
0.05 0.2 1 5 20
Favours [D] Favours [DF]
C
Study or Subgroup | D Events | D Total | DF Events | DF Total | Weight | Risk Ratio M-H, Fixed, 95% CI | Risk Ratio M-H, Fixed, 95% CI
2.3.1 RCT
Forsth, P 2016 5 120 11 113 49.5% 0.43 [0.15, 1.19]
Subtotal (95% CI) 120 113 49.5% 0.43 [0.15, 1.19]
Total events 5 11
Heterogeneity: Not applicable
Test for overall effect: Z = 1.62 (P = 0.10)
2.3.2 Cohort
Athiviraham, A 2007 2 49 1 39 4.9% 1.59 [0.15, 16.92]
Brodke, DS 2013 1 24 2 45 6.1% 0.94 [0.09, 9.82]
Chen, YM 2010 1 31 0 39 1.9% 3.75 [0.16, 88.98]
Ghogawala, Z 2004 0 20 1 14 7.6% 0.24 [0.01, 5.45]
Li, Z 2015 0 15 1 24 5.1% 0.52 [0.02, 12.02]
Munting, E 2015 7 1068 2 108 15.9% 0.35 [0.07, 1.68]
Son, S 2013 1 31 2 29 9.0% 0.47 [0.04, 4.89]
Subtotal (95% CI) 1238 298 50.5% 0.69 [0.30, 1.60]
Total events 12 9
Heterogeneity: Chi² = 2.93, df = 6 (P = 0.82); I² = 0%
Test for overall effect: Z = 0.86 (P = 0.39)
Total (95% CI) 1358 411 100.0% 0.56 [0.29, 1.07]
Total events 17 20
Heterogeneity: Chi² = 3.23, df = 7 (P = 0.86); I² = 0%
Test for overall effect: Z = 1.75 (P = 0.08)
Test for subgroup differences: Chi² = 0.51, df = 1 (P = 0.47), I² = 0%
0.01 0.1 1 10 100
Favours [D] Favours [DF]
D
Study or Subgroup | D Mean | D SD | D Total | DF Mean | DF SD | DF Total | Weight | Mean Difference IV, Random, 95% CI | Mean Difference IV, Random, 95% CI
2.4.1 RCT
Forsth, P 2016 23.6 18.2 117 26.6 19.4 111 11.7% -3.00 [-7.89, 1.89]
Ghogawala, Z 2016 21.6 8.8 26 15.1 6.8 19 12.9% 6.50 [1.94, 11.06]
Subtotal (95% CI) 143 130 24.6% 1.79 [-7.52, 11.10]
Heterogeneity: Tau² = 39.31; Chi² = 7.76, df = 1 (P = 0.005); I² = 87%
Test for overall effect: Z = 0.38 (P = 0.71)
2.4.2 Cohort
Austevoll, IM 2016 23.3 18.5 218 21 18.2 224 17.8% 2.30 [-1.12, 5.72]
Forsth, P 2013 28 16.6 4259 28 17.2 1131 31.9% 0.00 [-1.12, 1.12]
Sigmundsson, FG 2015 27.4 21.2 141 26.7 18.9 268 14.4% 0.70 [-3.47, 4.87]
Son, S 2013 25.4 7.9 31 25.6 11.5 29 11.3% -0.20 [-5.23, 4.83]
Subtotal (95% CI) 4649 1652 75.4% 0.23 [-0.78, 1.24]
Heterogeneity: Tau² = 0.00; Chi² = 1.64, df = 3 (P = 0.65); I² = 0%
Test for overall effect: Z = 0.45 (P = 0.65)
Total (95% CI) 4792 1782 100.0% 0.97 [-1.08, 3.02]
Heterogeneity: Tau² = 3.10; Chi² = 10.48, df = 5 (P = 0.06); I² = 52%
Test for overall effect: Z = 0.93 (P = 0.35)
Test for subgroup differences: Chi² = 0.11, df = 1 (P = 0.74), I² = 0%
-20 -10 0 10 20
Favours [D] Favours [DF]

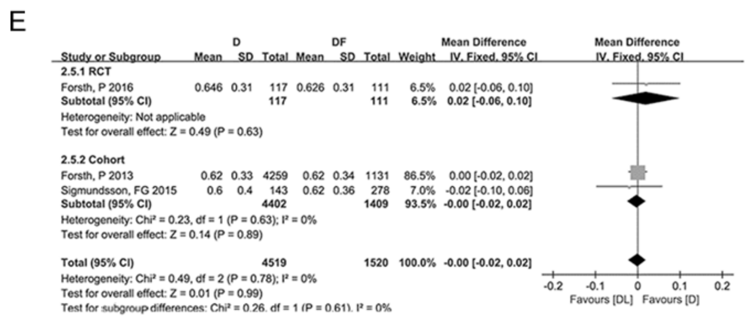


Figure 4. A. Forest plot of the clinical outcome. Each study is shown by the point estimate of the RR and 95% CI (extending lines). B. Forest plot of the reoperation rate. Each study is shown by the point estimate of the RR and 95% CI (extending lines). C. Forest plot of the wound infection rate. Each study is shown by the point estimate of the RR and 95% CI (extending lines). D. Forest plot of the ODI. Each study is shown by the point estimate of the WMD and 95% CI (extending lines). E. Forest plot of the EQ-5D. Each study is shown by the point estimate of the MD and 95% CI (extending lines). RR = risk ratio; CI = confidence interval; ODI = Oswestry disability index; WMD = weighted mean difference; EQ-5D = European quality of life-5 dimensions.

analysis defined by the study design displayed results similar to the total results.

These results were predominantly consistent with those from previous studies, wherein the addition of fusion to conventional decompression for the management of LSS was not beneficial in terms of both clinical outcome and prognosis [27, 34, 37]. Clinically, the coupling of fusion with traditional decompression was superior to decompression for the surgical management of LSS as supported by a systematic review by Martin et al. Historically, superior outcomes of fusion plus decompression vs. decompression alone are reported in terms of postoperative increase in listhesis (instability), patient-reported outcomes, and reoperation rates [46]. Herein, we performed a study design-specific evaluation to conduct a stratified analysis for an accurate conclusion. In contrast to the study by Liang et al. [13], the current study neither suggested any difference in the reoperation rate nor the clinical outcome between the D+F and Ds group. However, some differences were noted between the present analysis and other meta-analyses. First, the included studies were updated, and additional studies with high quality were included in the current meta-analysis. Second, publication bias and quality of the included articles were assessed. Third, comparison between the operating time, loss of blood, hospital stay, dural tear rate, wound infection rate, ODI, and EQ-5D score was performed for the first time, which were not conducted in previous meta-analyses due to less related studies.

Degenerative LSS results from changes in the spine that appear with aging, including loss of intervertebral disc height, facet joint hypertrophy, osteophyte formation, disc bulging, and hypertrophy of the ligamentum flavum [2]. The characteristics of LSS consist of lower limb pain, neurogenic claudication, and neurological symptoms exacerbated by walking [4]. The symptoms are commonly intermittent and posture-dependent that appear with standing and lumbar extension, exacerbated by walking and relieved by rest in a flexed or seated position. Surgery can increase the amount of space in the spinal canal via removal of portions of the posterior spinal elements. This phenomenon is referred to as "decompression". The removal of these pathological compressive structures may exacerbate the existing instabilities or create de novo instabilities following decompression. Thus, occasionally, spinal fusion is added to the decompression procedure for modification of this instability. Alternatively, spinal instrumentation in the form of posterior spacers may be installed to alter the spinal alignment without fusion in order to achieve a position of empirical pain relief. In most of the patients, this position is characterized by a relative flexion and posterior decompression of the stenotic segment, which is achieved without disruption of the normal anatomical structures [1]. Thus, the goal of surgery is to create a relative flexion that opens the foramina without altering the anatomy at the stenotic level. Several studies have compared the difference between decompression with fusion and conventional decompression alone in various clinical and prognostic measurements [30, 34, 37]; albeit, the results are inconclusive and inconsistent. Owing to the small sample sizes and different outcomes, the results of the studies cannot be replicated. A combination of all the available published data led to the hypothesis that the current meta-analysis with an increased statistical power might identify an effective and reliable method.

Nevertheless, a few limitations of this meta-analysis should be noted. First, a number of confounding factors may be correlated to increased risks of LSS, such as age, sex, and living status. However, we could not obtain this information to conduct an appropriate stratified analysis owing to the limited data available in the included articles. In addition, the number of subjects included in the studies was relatively small. Second, the difference in the sample size, patient age, duration of follow-up, evaluation of end-points, methods of decompression, numbers of fused levels, and other factors among the studies may be responsible for the heterogeneity, which might not provide sufficient statistical power for reliable results. Third, several included articles reported that the cases of LSS occurred as acquired degenerative stenosis, resulting from aging of the spine or surgery or infection; however, other studies did not demonstrate the specific etiology. Thus, the comparison between these two surgical methods necessitates confirmation by additional studies.

In summary, the pooled results showed that decompression plus fusion was similar to decompression with respect to satisfaction degree, complications, reoperation rate, and quality of life; the former was inferior to the latter regarding the surgery duration, blood loss, and length of hospital stay. Taken together, this meta-analysis suggested that decompression plus fusion has fewer benefits than decompression alone for the treatment of LSS. However, an additional number of studies with superior original study designs should be enrolled.

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Disclosure of conflict of interest

None.

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Supplementary 1. Detailed search strategy of databases

1. Search strategy using PubMed	
Search	Query
#1	Search "spinal stenosis" [MeSH Terms] OR ("spinal" [All Fields] AND "stenosis" [All Fields]) OR "spinal stenosis" [All Fields]
#2	Search LSS [All Fields]
#3	Search #1 OR #2
#4	Search "fusion" [All Fields]
#5	Search ("laminectomy" [MeSH Terms] OR "laminectomy" [All Fields]) OR
#6	Search ("decompression" [MeSH Terms] OR "decompression" [All Fields])
#7	Search #5 OR #6
#8	Search #3 AND #4 AND #7
2. Search strategy using Embase	
Search	Query
#1	Search spinal stenosis
#2	Search LSS
#3	Search #1 OR #2
#4	Search fusion
#5	Search laminectomy
#6	Search decompression
#7	Search #5 OR #6
#8	Search #3 AND #4 AND #7
3. Search strategy using Cochrane library	
Search	Query
#1	Search spinal stenosis: ti, ab, kw (Word variations have been searched)
#2	Search LSS: ti, ab, kw (Word variations have been searched)
#3	Search #1 OR #2
#4	Search fusion: ti, ab, kw (Word variations have been searched)
#5	Search laminectomy: ti, ab, kw (Word variations have been searched)
#6	Search decompression: ti, ab, kw (Word variations have been searched)
#7	Search #5 OR #6
#8	Search #3 AND #4 AND #7