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REVIEW ARTICLE

Effectiveness of posterior decompression techniques compared with conventional laminectomy for lumbar stenosis

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Abstract

Purpose To compare the effectiveness of techniques of posterior decompression that limit the extent of bony decompression or to avoid removal of posterior midline structures of the lumbar spine versus conventional facet-preserving laminectomy for the treatment of patients with degenerative lumbar stenosis.

Methods A comprehensive electronic search of the Cochrane Central Register of Controlled Trials, MEDLINE, EMBASE, Web of Science, and the clinical trials registries ClinicalTrials.gov and World Health Organization International Clinical Trials Registry Platform was conducted for relevant literature up to June 2014.

Results A total of four high-quality RCTs and six low-quality RCTs met the search criteria of this review. These studies included a total of 733 participants. Three different techniques that avoid removal of posterior midline structures are compared to conventional laminectomy; unilateral laminotomy for bilateral decompression, bilateral laminotomy and split-spinous process laminotomy. Evidence of low or very low quality suggests that different techniques of posterior decompression and conventional laminectomy have similar effects on functional disability and leg pain. Only perceived recovery at final follow-up was better in patients that underwent bilateral laminotomy compared with conventional laminectomy. Unilateral laminotomy for bilateral decompression and bilateral laminotomy resulted in numerically fewer cases of iatrogenic instability, although in both cases, the incidence of instability was low. The difference in severity of postoperative low back pain following bilateral laminotomy and split-spinous process laminotomy was significantly less, but was too small to be clinically important. We found no evidence to show that the incidence of complications, length of the procedure, length of hospital stay and postoperative walking distance differed between techniques of posterior decompression.

Conclusion The evidence provided by this systematic review for the effects of unilateral laminotomy for bilateral decompression, bilateral laminotomy and split-spinous process laminotomy compared with conventional laminectomy on functional disability, perceived recovery and leg pain is of low or very low quality. Therefore, further research is necessary to establish whether these techniques provide a safe and effective alternative for conventional laminectomy. Proposed advantages of these techniques regarding the incidence of iatrogenic instability and postoperative back pain are plausible, but definitive conclusions are limited by poor methodology and poor reporting of outcome measures among included studies.

Keywords Lumbar stenosis · Surgery · Decompression · Laminectomy · Laminotomy · Systematic review

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Introduction

The gold standard treatment for symptomatic lumbar stenosis refractory to conservative management is a facet-preserving laminectomy [1]. This procedure requires a midline lumbar incision, after which the paraspinous muscles are detached from the spinous processes and vertebral arches and are retracted laterally. It has been suggested that extensive resection of the posterior bone, posterior ligaments and muscular structures leads to increases in postoperative pain, perioperative blood loss, complications and length of hospital stay [2–4]. Controversy continues about the extent of bony decompression required to effectively decompress the spinal canal [5]. As narrowing of the spinal canal occurs predominantly at the interlaminar region involving the arthrosis of the facet joints and bulging of the intervertebral disc and the ligamentum flavum, resection of the whole vertebral arch may not be necessary. Alternatively, an interlaminar or undercutting laminectomy can be performed to decompress the spinal canal [6, 7].

More recently, various authors have recommended surgical techniques that preserve posterior midline structures [2–4, 8]. Extensive paraspinal muscle detachment from the midline osseous structures can cause weakness secondary to muscle denervation [9, 10]. In addition, removal of the midline structures (i.e. spinous processes, vertebral arches, interspinous and supraspinous ligaments) may contribute to instability after surgery [8, 11, 12]. Laminotomy is the most commonly described decompressive procedure that preserves the posterior midline structures. Other techniques that are designed to preserve the posterior midline structures include endoscopic laminotomy and spinous process osteotomies. The amount of decompression achieved with these techniques has been shown to be approximately equal to that attained with laminectomy [13, 14]. However, these techniques are technically demanding because of the limited working space for decompression and may result in a higher rate of surgical complications [3]. Furthermore, the relevance of preservation of the posterior midline structures is still unclear. As most translational and rotational spinal stability is provided by the vertebral disc and the zygapophyseal joints [15, 16], and the momentum generated by the posterior ligaments during flexion is small compared with the force exerted by back muscles [17], spinal stability is possibly minimally affected by a conventional laminectomy performed with resection of the posterior midline structures.

Various studies have reported the results of techniques designed to limit the extent of bony decompression or to preserve posterior midline structures. Some studies claim reduced back pain, perioperative blood loss and decreased length of hospital stay. However, the actual (long-term) efficacy of these techniques compared with facet-preserving laminectomy is unclear. Moreover, reducing impairment of the spinal integrity is hypothesised to reduce surgically induced instability. Surgically induced instability, as noted radiographically or by the need for revision surgery with concomitant instrumented fusion, is an important outcome measure when various surgical techniques are considered for the treatment of lumbar stenosis. As surgically induced instability is a serious but infrequent complication, definitive conclusions require a systematic review of available evidence.

The objective of this systematic review was to compare the effectiveness of techniques of posterior decompression that limit the extent of bony decompression or avoid removal of posterior midline structures of the lumbar spine versus conventional facet-preserving laminectomy for the treatment of patients with degenerative lumbar stenosis. Furthermore, conclusions relevant to current clinical practice are summarised.

Criteria for considering studies for this review

Types of studies

We included all types of prospective, controlled studies (randomised controlled trials (RCTs) and cohort studies).

Types of participants

The population consists of adult patients with symptomatic degenerative lumbar stenosis. We excluded studies that included cases of congenital lumbar stenosis (e.g. achondroplasia) or acquired lumbar stenosis due to trauma, infection or abnormal bone metabolism (e.g. Paget's disease). We made no exclusions for age or gender of the population, or type, location or duration of symptoms.

Types of interventions

We included all prospective studies comparing a posterior decompressive technique that avoids removal of posterior midline structures (spinous processes, vertebral arches, interspinous and supraspinous ligaments) or a technique involving only partial resection of the vertebral arch with conventional facet-preserving laminectomy. We also included studies that describe cases requiring decompression of more than one stenotic level or a concomitant discectomy or foraminotomy. We excluded studies involving cases of decompression through interspinous process devices or concomitant (instrumented) fusion procedures.

Types of outcome measures

Eligible studies evaluate at least one of the main clinically relevant outcome measures using a valid instrument. Furthermore, predefined secondary outcome measures are compared, as mentioned below. The minimal duration of follow-up for studies considered for inclusion is 6 months. Long-term follow-up is defined as a minimum of 2 years of follow-up.

Primary outcomes

- Functional disability (e.g. Roland Disability Questionnaire, Oswestry Disability Index).
- Perceived recovery.
- Leg pain.

Secondary outcomes

- Length of hospital stay.
- Complication incidence.
- Surgically induced spinal instability.
- Paraspinal muscle denervation/atrophy.
- Muscle cell injury (creatine kinase level).
- Walking distance.
- Back pain.
- Length of surgical procedure.
- Perioperative blood loss.
- Postoperative use of analgesics.

Methods

Search methods for identification of studies

An experienced librarian conducted a comprehensive electronic search for relevant literature in the Cochrane Central Register of Controlled trials, Medline, Embase and Web of Science up to June 2014. The trials registries ClinicalTrials.gov and World Health Organization International Clinical Trials Registry Platform (WHO ICTRP) were searched for ongoing and unpublished trials up to 5 June 2014. Additionally, we reviewed the reference sections and citation tracking results of all included studies for articles not found during the systematic search.

Two review authors (GO, WJ) independently examined titles and abstracts from the electronic search to identify eligible studies. We obtained full-text articles if necessary. We consulted a third review author (WP) if consensus was not reached. We listed unpublished, ongoing and excluded studies in the results and used no language restrictions to minimise publication bias.

Assessment of risk of bias in included studies

Two independent review authors (CVL, CT) assessed risk of bias using the criteria advised by the Cochrane Back Review Group (CBRG) for evaluation of RCTs [18], listed in Table 2.

The list consists of 12 items, which are scored low, unclear or high. In accordance with the recommendations of the CBRG, review authors rated studies as having low risk of bias if at least six of the criteria were met and the study had no serious flaws (e.g. more than 20 % loss to follow-up).

The review authors discussed differences in scoring of the risk of bias assessment during a consensus meeting and consulted a third review author (RG) if necessary. Among other degenerative spinal conditions, all review authors involved in the risk of bias assessment are experts in the field of lumbar stenosis.

Data extraction and management

We recorded data describing study characteristics such as study design, characteristics and numbers of participants, surgical techniques and co-interventions, primary and secondary outcomes, follow-up time and study sponsorship. Data were entered into the statistical software of The Cochrane Collaboration, Review Manager 2011 [19].

Measures of treatment effect

We defined treatment effect as the differences between treatment groups on relevant outcome measures. We presented comparisons of continuous data as mean differences (MDs) with corresponding 95 % confidence intervals (CIs). For dichotomous outcomes (e.g. perceived recovery among treatment groups), we calculated odds ratios (ORs) and corresponding 95 % CIs. We compared continuous data directly or through calculation of standardised mean differences (SMDs) if outcome measures were not directly comparable (e.g. different measurement scales used). We analysed outcomes of included studies using a random-effects model.

We adopted the definition of a minimal clinically important difference [20]. We defined the minimal clinically important difference of the primary outcome measures (i.e. functional disability, perceived recovery, leg pain) as 30 % improvement from baseline. This corresponds to a mean difference of 1.5 for the visual analogue scale (VAS) (0–10), 2 for the numerical rating scale (0–10), 5 for the Roland Disability Questionnaire (0–24), 10 for the Oswestry Disability Questionnaire (0–100) and 20 for the Quebec Back Pain Disability Questionnaire (0–100). These thresholds represent a minimum important change from baseline for a patient. However, there is no generally accepted minimal clinically important difference between treatments.

Assessment of heterogeneity

We assessed the heterogeneity of RCTs first clinically, then statistically. We evaluated clinical heterogeneity for variability in participant characteristics (baseline symptom severity, duration of symptoms, number of stenotic levels involved, age and gender) and treatment characteristics (comparison of techniques, concomitant interventions and length of follow-up time). When we judged studies to be clinically homogeneous, we tested statistical homogeneity with an I^2 test.

Data synthesis

We pooled results from individual studies if the studies were judged to be sufficiently homogeneous (clinically and statistically). We evaluated the quality of evidence for all primary outcome parameters, regardless of quantitative analysis, using the GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach [21, 22]. In short, we judged the quality of evidence using the following criteria:

- 75 % of studies have low risk of bias (six or more items met, including valid randomisation and treatment allocation techniques).
- Included studies have consistent findings.
- Included population adequately reflects selection criteria of the review.
- Results are based on direct comparison.
- Estimate of effect is sufficiently precise (confidence interval is narrow and conclusive).
- Analysis is free of publication bias (more than 75 % of studies contributed to the analysis).

Depending on how many domains were met, we judged the quality of evidence as 'high', 'moderate', 'low' or 'very low' based on the following descriptions.

- High-quality evidence: All domains were met; further research is very unlikely to change our confidence in the estimate of effect.
- Moderate-quality evidence: All but one domain were met; further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
- Low-quality evidence: All but two domains were met; further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
- Very low-quality evidence: All but three domains were met; there is great uncertainty about the estimate of effect.
- No evidence: No RCTs were identified that addressed this outcome.

We considered important outcomes for which there are no trials to have 'no evidence'. We automatically graded an outcome with only one trial as low quality, and if it also had high risk of bias, we graded the evidence as very low quality.

Results

Results of the search

The literature search up to June 2014 yielded 5924 articles. We identified 10 studies that compared a posterior decompressive technique that avoids removal of posterior midline structures versus conventional laminectomy. All studies were randomised controlled trials. We found no eligible prospective cohort studies, and we identified no study that compared a technique involving only partial resection of the vertebral arch (with removal of posterior midline structures) or laminoplasty versus conventional laminectomy. Citation tracking and review of the reference sections of included articles yielded no additional articles eligible for inclusion. We identified one published study protocol of an ongoing study [23]. Review of trial registries revealed no other ongoing or unpublished trials. We subdivided studies evaluating posterior decompressive techniques into unilateral laminotomy for bilateral decompression [4, 24, 25], bilateral laminotomy [2–4, 26] and split-spinous process laminotomy [27–30] to ensure clinical homogeneity.

Included studies

Included studies were published between 1993 and 2014 and included a total of 733 participants (see Table 1). All studies except one [3] performed analyses according to the intention-to-treat principle. The study by Postacchini et al. [3] compared three groups according to the treatment actually received, and thus compared 26 participants undergoing bilateral laminotomy, nine allocated to bilateral laminotomy but converted to conventional laminectomy and 32 participants allocated to and undergoing conventional laminectomy.

Two studies were excluded from the quantitative analysis as the result of clinical heterogeneity [3, 27]. Decisive arguments were the inclusion of concomitant intertransverse arthrodesis (in 12 out of 67 participants) and concomitant discectomy (in 7 out of 67 participants) by Postacchini et al. [3], and concomitant discectomy (in 44 out of 70 participants) by Cho et al. [27]. Concomitant discectomy was not among the predefined exclusion criteria of this review, but the exceptionally high rate of concomitant discectomy by Cho et al. compared with no

Table 1 Characteristics of included studies

Reference	Design	Comparison groups	Number of participants	Age (years)	Male/female	Length of follow-up	Complete follow-up	Primary outcome
Gurelik [24]	RCT	1) Unilateral laminotomy 2) Conventional laminectomy	1) 26 2) 26	1) 61 ± 10 2) 58 ± 9	1) 11/15 2) 10/16	9.1 months	Not specified	ODI
Yagi[25]	RCT	1) Unilateral (endoscopic) laminotomy 2) Conventional laminectomy	1) 20 2) 21	1) 73 (63-79) 2) 71 (66-73)	1) 8/12 2) 6/15	1) 18.8 months 2) 18.6 months	Not specified	JOA
Thome [4]	RCT	1) Bilateral laminotomy 2) Unilateral laminotomy 3) Conventional laminectomy	1) 37 2) 39 3) 34	1) 70 ± 7 2) 67 ± 9 3) 69 ± 10	1) 20/20 2) 15/25 3) 18/22	15.5 months	1) 37/39 2) 39/40 3) 34/38	RDQ, recovery, leg pain (improvement)
Celik [2]	RCT	1) Bilateral laminotomy 2) Conventional laminectomy	1) 37 2) 34	1) 59 ± 14 2) 61 ± 13	1) 17/20 2) 16/18	1) 5.4 years 2) 5.3 years	1) 37 of 40 lost to follow-up 2) 34 of 40 lost to follow-up	ODI, VAS leg pain
Fu [26]	RCT	1) Bilateral laminotomy 2) Conventional laminectomy	1) 76 2) 76	1) 57 (47–70) 2) 57 (45–73)	1) 37/39 2) 33/43	40.6 months	Not specified	ODI, recovery, VAS leg pain
Postacchini [3]	RCT	1) Bilateral laminotomy 2) Allocated to bilateral laminotomy but treated with conventional laminectomy 3) Conventional laminectomy	1) 26 2) 9 3) 32	57 (43–79)	34/36	3.7 years	67/70	Recovery, VAS leg pain (improvement)
Cho [27]	RCT	1) Split-spinous process laminotomy 2) Conventional laminectomy	1) 40 2) 30	1) 61 ± 11 2) 59 ± 15	1) 16/24 2) 15/15	1) 15.1 months 2) 14.8 months	Not specified	JOA
Liu [28]	RCT	1) Split-spinous process with unilateral osteotomy and laminotomy 2) Conventional laminectomy	1) 27 2) 29	1) 59 ± 5 2) 61 ± 3	1) 15/12 2) 18/11	2 years	Not specified	JOA, VAS leg pain
Rajasekaran [29]	RCT	1) Split-spinous process laminotomy 2) Conventional laminectomy	1) 28 2) 23	1) 57 ± 11 2) 55 ± 8	1) 16/12 2) 14/9	14.2 months	51/52	JOA, VAS leg pain
Watanabe [30]	RCT	1) Split-spinous process laminotomy 2) Conventional laminectomy	1) 18 2) 16	1) 69 ± 10 2) 71 ± 8	1) 10/8 2) 8/8	1 year	32/34	JOA

Reference	Secondary outcome	Definition symptomatic lumbar stenosis	Mean duration of symptoms	Radiological definition of lumbar stenosis	Mean number of levels decompressed	Concomitant discectomy	Exclusion criteria
Gurelik [24]	Complications, instability, walking distance	Neurogenic claudication with or without radiculopathy	Not specified	Not specified	1.7 levels	No	Vertebral instability, significant disc herniation and previous surgery for lumbar spine disorder

Table 1 continued

Reference	Secondary outcome	Definition symptomatic lumbar stenosis	Mean duration of symptoms	Radiological definition of lumbar stenosis	Mean number of levels decompressed	Concomitant discectomy	Exclusion criteria
Yagi[25]	Length of hospital stay, complications, instability, muscle atrophy, muscle cell injury, VAS back pain, operation duration, blood loss, analgesics	Neurogenic claudication with or without radiculopathy	At least 3 months and refractory to conservative treatment	Not specified	Only single level	No	> grade 1 spondylolisthesis, segmental instability, >1 level stenosis, herniated disc
Thome [4]	Complications, instability, walking distance, VAS back pain (improvement), operation duration, blood loss	Neurogenic claudication with or without radiculopathy	At least 3 months and refractory to conservative treatment	Not specified	1.7 levels	No	Herniated disc or instability (5 mm sagittal plane translation), history of lumbar stenosis surgery or lumbar fusion
Celik [2]	Length of hospital stay, complications, instability, walking distance, VAS back pain, operation duration, blood loss, analgesics	Neurogenic claudication with or without radiculopathy	Not specified	Anteroposterior diameter of central canal <10 mm	2.2 levels	No	Requiring discectomy, segmental instability
Fu [26]	Complications, instability, walking duration, VAS back pain	Neurogenic claudication with or without radiculopathy	Refractory to conservative treatment	Anteroposterior diameter central canal <10 mm, lateral recess diameter <3 mm	1.9 levels	No	Previous spinal surgery at the same level, isthmic spondylolisthesis, congenital spinal stenosis <8 mm caused by short pedicles, dynamic instability (sagittal translation >3 mm and angulation >10 degrees), cauda equina syndrome, active workers' compensation claim, dying of other disease or loss to follow-up
Postacchini [3]	VAS back pain (improvement), operation duration, blood loss	Requiring surgery, no specific symptoms of the condition defined	Not specified	Not specified	1.7 levels	8/67	Not specified
Cho [27]	Length of hospital stay, complications, instability, muscle cell injury, VAS back pain, operation duration, blood loss	Neurogenic claudication or lumbago	At least 6 months and refractory to conservative treatment	Anteroposterior diameter of central canal <11 mm, an interpediculate distance <16 mm or a lateral recess diameter <3 mm	1) 2.5 levels 2) 2.6 levels	1) 26/40 2) 18/30	>80 years of age with high anaesthetic risks or severe co-morbidity, patients requiring concomitant fusion
Liu [28]	VAS back pain, muscle atrophy, muscle cell injury, complications, instability, operation time, blood loss	Requiring surgery, no specific symptoms of the condition defined	Not specified	Not specified	1.3 levels	No	Spondylolisthesis or vertebral instability

Table 1 continued

Reference	Secondary outcome	Definition symptomatic lumbar stenosis	Mean duration of symptoms	Radiological definition of lumbar stenosis	Mean number of levels decompressed	Concomitant discectomy	Exclusion criteria
Rajasekaran [29]	VAS back pain, muscle cell injury, blood loss, operating time, duration of hospital stay, complications	Neurogenic claudication with or without radiculopathy	At least 6 months and refractory to conservative treatment	Not specified	1.6 levels	No	>3 levels, spondylolisthesis grade 2 or greater or vertebral instability (3 mm translation or 10 degree angular change), concomitant symptomatic cervical or thoracic stenosis, severe co-morbidities and prior lumbar spine surgery
Watanabe [30]	Muscle cell injury, back muscle atrophy, blood loss, operating time, analgesics, complications	Neurogenic claudication with or without radiculopathy	At least 6 months and refractory to conservative treatment	Not specified	1.4 levels	No	>3 levels; congenital, spondylolytic, traumatic and iatrogenic causes of lumbar stenosis; previous lumbar surgery; spinal disorders (such as ankylosing spondylitis, neoplasm or metabolic diseases); intermittent claudication resulting from peripheral arterial disease; severe osteoarthrosis or arthritis in the lower limbs; neurological disease causing impaired lower limb function; psychiatric disorders

RCT randomised controlled trial, *VAS* visual analogue scale, *RDQ* Roland Disability Questionnaire, *ODI* Oswestry disability index, *JOA* Japanese Orthopedic Association

discectomy in any of the other studies precludes a valid comparison of results.

Excluded studies

We excluded eight comparative studies from this review because they employed a retrospective study design [7, 31–37]. We excluded two studies that compared techniques of posterior decompression because of concomitant fusion procedures [38, 39]. Moreover, concomitant fusion procedures were unequally distributed among treatment groups, resulting in potential bias [39]. We excluded one randomised controlled trial because researchers reported follow-up of only three months [40]. This study compared unilateral laminotomy for bilateral decompression with conventional laminectomy. Perceived recovery favoured participants in the unilateral laminotomy group, but the difference was not clinically significant. Moreover, the duration of hospital stay was significantly shorter in the unilateral laminotomy group. We excluded eight studies because the control group did not meet the criteria of this review [6, 41–47]. We excluded three studies because the design precluded a reliable comparison of decompression techniques [48–50]. All studies report outcome measures of different decompression techniques that are the subject of this review, but the comparability of treatment groups cannot be ensured, and indications for the surgical treatment groups may vary. Moreover, two of these studies did not describe surgical techniques in sufficient detail [48, 49]. We excluded one study because study authors reported no outcome measures relevant to this review [51]. They compared only the extent of postoperative haematoma and the cross-sectional area of the spinal canal following unilateral laminotomy for bilateral decompression, bilateral laminotomy and conventional laminectomy.

Risk of bias in included studies

Four out of 10 studies had low risk of bias [2, 4, 29, 30], having met at least six of the risk of bias criteria. Poor performance on the risk of bias assessment was the result of poor methodology or poor reporting. The risk of bias summary of trials is shown in Table 2.

Effects of interventions

Disability

Investigators used different disability questionnaires among the studies included in this review [2, 4, 24–30]. Postacchini et al. did not report a validated disability score [3]. None of these studies, except the study by Fu et al.

Table 2 Risk of bias assessment: review authors' judgements about each risk of bias item for each included study

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants to the intervention (performance bias)	Blinding of care provider to the intervention (performance bias)	Blinding of outcome assessor to the intervention (detection bias)	Drop out rate described and acceptable (attrition bias)	All randomised participants analysed in the group to which they were allocated (attrition bias)	Selective reporting (reporting bias)	Groups similar at baseline regarding important clinical prognostic indicators	Co-interventions avoided or similar	Compliance acceptable in treatment groups	Timing of the outcome assessment similar in treatment groups
Gurelik [24]	Unsure	Unsure	Unsure	No	Unsure	Unsure	Yes	Yes	Yes	No	Yes	Yes
Yagi [25]	No	No	Unsure	No	Unsure	Unsure	Yes	Yes	Unsure	Unsure	Yes	Yes
Thome [4]	Yes	Yes	Unsure	No	Unsure	Unsure	Yes	Yes	Yes	Unsure	Yes	Yes
Celik [2]	Yes	Yes	Yes	No	Unsure	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fu [26]	No	No	Unsure	Unsure	Unsure	Unsure	Yes	Yes	Yes	Unsure	Yes	Yes
Postacchini [3]	No	No	Unsure	No	Yes	Yes	No	No	No	No	Yes	Unsure
Cho [27]	Unsure	Unsure	Unsure	No	Unsure	Unsure	Yes	Yes	No	Yes	Yes	Yes
Liu [28]	Unsure	Unsure	Unsure	No	Unsure	Unsure	Yes	No	Yes	Unsure	Yes	Unsure
Rajasekaran [29]	Yes	Unsure	Unsure	No	Yes	Yes	Yes	Yes	Yes	Unsure	Yes	Unsure
Watanabe [30]	Yes	Yes	Yes	No	Unsure	Yes	Yes	Yes	Yes	Yes	Yes	Unsure

[26], demonstrated a significant difference between the techniques of posterior decompression. The mean difference between the bilateral laminotomy group [0.37 ± 0.96 standard deviation (SD)] and the conventional laminectomy group (3.37 ± 8.55 SD) as reported by Fu et al. does not seem clinically relevant when a minimal clinically important difference in the ODI of 10 is considered [26]. We provided pooled estimates of RCTs by calculating standardised mean differences in disability questionnaire scores. Between those who received unilateral laminotomy and those undergoing laminectomy, low-quality evidence shows no significant difference regarding disability scores [three RCTs, 166 participants, MD −1.11, 95 % CI −11.91 to 9.69). Between those who received bilateral laminotomy and those undergoing laminectomy, very low-quality evidence reveals a significant difference regarding disability scores in favour of bilateral laminotomy (three RCTs, 294 participants, MD −2.73, 95 % CI −4.59 to −0.87). The quality of evidence had to be decreased because of the relatively high impact of one low-quality study on the combined quantitative analysis [26]. The difference did not reach the criteria of a minimal clinically important difference. Between those who received split-spinous process laminotomy and those undergoing laminectomy, low-quality evidence suggests no significant difference regarding disability scores (three RCTs, 139 participants, MD −1.68, 95 % CI −8.50 to 5.13), see Table 3.

Recovery

Thome et al. reported self-perceived overall recovery and found no significant difference between unilateral laminotomy and conventional laminectomy [4]. However, a significant difference in favour of the bilateral laminotomy group was assessed when compared with the conventional laminectomy group (36/37, 97.3 % vs 25/34, 73.5 %). Postacchini et al. used a scoring system based on the participant's perceived recovery and the examiner's evaluation, which included results of a neurological examination, the need for analgesics, the ability to work and carry out activities of daily living and walking ability. Investigators reported no significant differences between treatment groups: bilateral laminotomy 21/26 (81 %) with excellent/good recovery, allocated to the bilateral laminotomy group but converted to conventional laminectomy 7/9 (78 %) and conventional laminectomy 25/32 (78 %) [3]. Fu et al. assessed perceived recovery using a structural interview, which evaluated back and leg pain, walking ability and restriction from usual activities. In all, 68/76 (89 %) participants in the bilateral laminotomy group reported excellent/good results compared with 48/76 (63 %) in the conventional laminectomy group. The difference was statistically significant [26]. The recovery rate reported by Gurelik et al. is not included in this comparison because it is derived from the ODI [24]. Between those who received unilateral laminotomy and those undergoing laminectomy, low-quality evidence shows no significant difference (one high-quality RCT, 73 participants, OR 1.04, 95 % CI 0.37–2.98). Between those who received bilateral laminotomy and those undergoing laminectomy, low-quality evidence suggests a significant difference regarding self-perceived recovery in favour of bilateral laminotomy (two RCTs, 223 participants, OR 5.69, 95 % CI 2.55–12.71). The quality of evidence had to be decreased because of the relatively high impact of one low-quality study on the combined quantitative analysis [26], see Table 3.

Leg pain

Postacchini et al. and Thome et al. reported improvement in leg pain in 34/37 (92 %) participants and mean improvement of 71 out of 100 points among 35 participants undergoing bilateral laminotomy, respectively [3, 4]. Compared with 25/34 (74 %) participants reporting improvement and mean improvement of 84 out of 100 points among participants undergoing conventional laminectomy, Thome et al. concluded that a statistically significant difference favoured bilateral laminotomy, whilst Postacchini et al. found no statistically significant differences between treatment groups. Reporting of data in these studies does not allow for a quantitative comparison, nor a comparison with other studies. Celik et al. and Fu et al. compared leg pain VAS scores (0–10) of participants undergoing bilateral laminotomy and conventional laminectomy [2, 26]. Between those who received bilateral laminotomy and laminectomy, very low-quality evidence shows a significant difference regarding VAS leg pain in favour of bilateral laminotomy (two RCTs, 223 participants, MD −0.29, 95 % CI −0.48 to −0.11). The quality of evidence had to be decreased because of the relatively high impact of one low-quality study on the combined quantitative analysis and inconsistent results among studies [26]. The difference did not exceed the minimal clinically important difference of 1.5. Among participants who underwent unilateral laminotomy, Thome et al. reported an improvement in leg pain in 26/39 (68 %) compared with 25/34 (74 %) who underwent conventional laminectomy [4]. The difference was not significant. Liu et al. and Rajasekaran et al. compared leg pain VAS scores (0–10) of participants undergoing split-spinous process laminotomy and conventional laminectomy [28, 29]. Between those who received split-spinous process laminotomy and laminectomy, very low-quality evidence shows a significant difference regarding VAS leg pain in favour of split-spinous process laminotomy (two RCTs, 107 participants,

Table 3 Summary of findings

Unilateral laminotomy compared with conventional laminectomy

Outcomes	Comparisons		Relative effect (95 % CI)	Number of participants (studies)	Quality of the evidence (GRADE)	Comments
	Conventional laminectomy	Unilateral laminotomy				
Standardised disability index (0–100) Disability scores converted to 0–100 scale to allow for comparison of RDQ, ODI, JOA	Standardised disability index score 30.9 (range 23.0–35.8)	Standardised disability index score 29.8 (range 15.8–45.4)	Mean difference −1.11 (−11.91, 9.69) The difference is not statistically significant	166 (3) [4, 24, 25]	Low[a,b]	
Satisfactory recovery Satisfactory recovery was defined as 'good' or 'excellent' self-perceived recovery	25 of 34 (74 of 100) participants	29 of 39 (74 of 100) participants	OR 1.04 (0.37, 2.98) The difference is not statistically significant	73 (1) [4]	Low[c]	
VAS leg (0–10)	Mean VAS leg score not estimable	Mean VAS leg score not estimable	Mean difference not estimable	0 (0)	Low[c]	The outcome reporting of one study was not suitable for quantitative comparison [4]. No statistically significant difference regarding leg pain at rest or during walking was reported
VAS back (0–10)	Mean VAS back score not estimable	Mean VAS back score not estimable	Mean difference not estimable	0 (0)	Very low[a,b,d]	The outcome reporting of two studies was not suitable for quantitative comparison. Thome et al. reported no significant difference in back pain at rest or during walking, whilst Yagi et al. reported a clinically significant difference in favour of unilateral microendoscopic laminotomy [4, 25]
Incidence of postoperative instability	10 of 81 (12 of 100) participants	2 of 85 (2 of 100) participants	OR 0.28 (0.07, 1.15) The difference is not statistically significant	166 (3) [4, 24, 25]	Low[a,b]	
Incidence of perioperative complications	9 of 87 (10 of 100) participants	7 of 86 (8 of 100) participants	OR 0.73 (0.24, 2.20) The difference is not statistically significant	173 (3) [4, 24, 25]	Low[a,b]	

Table 3 continued

Bilateral laminotomy compared with conventional laminectomy						
	Conventional laminectomy	Bilateral laminotomy				
Standardised disability Index (0–100) Disability scores converted to 0–100 scale to allow for comparison of RDQ, ODI, JOA	Mean standardised disability index score 5.2 (range 3.4–35.8)	Mean standardised disability index score 2.5 (range 0.4–33.8)	Mean difference −2.73 (−4.59, −0.87) The difference is not clinically significant	294 (3) [2, 4, 26]	Very low[a,b,e]	
Satisfactory recovery Satisfactory recovery was defined as 'good' or 'excellent' self-perceived recovery	73 of 110 (66 of 100) participants	104 of 113 (92 of 100) participants	OR 5.69 (2.55, 12.71) The difference is statistically significant in favour of bilateral laminotomy	223 (2) [4, 26]	Low[a,e]	
VAS leg (0–10)	Mean VAS leg score 0.6 (range 0.36–2.3)	Mean VAS leg score 0.3 (range 0.01–2.5)	Mean difference −0.29 (−0.48, −0.11) The difference is not clinically significant	223 (2) [2, 26]	Very low[a,b,e]	The outcome reporting of two studies was not suitable for quantitative comparison. A statistically significant difference regarding leg pain at rest and during walking was reported in favour of bilateral laminotomy by Thome et al., whilst Postacchini et al. found no statistically significant difference [3, 4]
VAS back (0–10)	Mean VAS leg score 1.3 (range 0.63–4.4)	Mean VAS leg score 0.8 (range 0.05–4.2)	Mean difference −0.51 (−0.80, −0.23) The difference is not clinically significant	223 (2) [2, 26]	Low[a,e]	The outcome reporting of two studies was not suitable for quantitative comparison. Thome et al. reported no statistically significant difference regarding improvement in back pain at rest, but back pain during walking favoured participants treated with bilateral laminotomy [4]. Postacchini et al. reported a significant improvement in VAS back pain among participants treated with bilateral laminotomy compared with those who underwent conventional laminectomy [3]
Incidence of postoperative instability	12 of 144 (8 of 100) participants	0 of 150 (0 of 100) participants	OR 0.10 (0.02, 0.55) The difference is statistically significant in favour of bilateral laminotomy	294 (3) [2, 4, 26]	Low[a,f]	The outcome reporting of one study was not suitable for quantitative comparison. Postacchini et al. reported no postoperative instability in the bilateral laminotomy group compared with 3/41 participants treated with conventional laminectomy [3]

Table 3 continued

Split-spinous process laminotomy compared with conventional laminectomy

	Conventional laminectomy	Split-spinous process laminotomy				
Standardised disability index (0–100) Disability scores converted to–100 scale to allow for comparison of RDQ, ODI, JOA	Mean standardised disability index score 13.2 (range 12.4–17.2)	Mean standardised disability index score 11.6 (range 7.9–20.3)	Mean difference −1.68 (−8.50, 5.13) The difference is not statistically significant	139 (3) [28–30]	Low[a,b]	The outcome reporting of one study was not suitable for quantitative comparison. No statistically significant difference regarding functional disability was reported by Cho et al. [27]
Satisfactory recovery Satisfactory recovery was defined as 'good' or 'excellent' self-perceived recovery	Satisfactory recovery not estimable	Satisfactory recovery not estimable	OR not estimable	0 (0)	NA	
VAS leg (0–10)	Mean VAS leg score 1.7 (range 1.7–1.74)	Mean VAS leg score 1.4 (range 1.3–1.93)	Mean difference −0.29 (−0.41, −0.17) The difference is not clinically significant	223 (2) [28, 29]	Very low[a,b,g]	
VAS back (0–10)	Mean VAS leg score 2.8 (range 2.6–3.0)	Mean VAS leg score 1.7 (range 1.0–2.5)	Mean difference −1.07 (−2.15, −0.00) The difference is not clinically significant	107 (2) [28, 29]	Very low[a,b,g]	The outcome reporting of one study was not suitable for quantitative comparison. A statistically and clinically significant difference in favour of split-process laminotomy was reported by Cho et al. [28]
Incidence of postoperative instability	Postoperative instability not estimable	Postoperative instability not estimable	OR was not estimable		Very low[h]	The outcome reporting of one study was not suitable for quantitative comparison. No statistically significant difference regarding postoperative instability was reported by Liu et al. [27]
Incidence of perioperative complications	4 of 68 (6 of 100) participants	5 of 73 (7 of 100) participants	OR 1.21 (0.20, 7.16) The difference is not statistically significant	141 (3) [28–30]	Low[a,b]	The outcome reporting of one study was not suitable for quantitative comparison. No statistically significant difference regarding perioperative complications was reported by Cho et al. [27]

RCT randomised controlled trial, *CI* confidence interval, *OR* odds ratio, *VAS* visual analogue scale, *RDQ* Roland Disability Questionnaire, *ODI* Oswestry disability index, *JOA* Japanese Orthopedic Association

[a] The quality of evidence had to be decreased because less than 75 % of studies have low risk of bias

[b] The quality of evidence had to be decreased because the estimate of the effect is insufficiently precise

[c] Only one high-quality RCT was available for analysis [4]

[d] Included studies have inconsistent findings

[e] The quality of evidence had to be decreased because of the relatively high impact of one low-quality study [26]

[f] The quality of evidence had to be decreased because of high risk of bias due to a non-standardised assessment of spinal instability

[g] The quality of evidence had to be decreased because of the relatively high impact of one low-quality study [28]

[h] Only one low-quality RCT was available for analysis [27]

MD −0.29, 95 % CI −0.41 to −0.17). The quality of evidence had to be decreased because of the relatively high impact of one low-quality study on the combined quantitative analysis [28]. Again, the difference did not exceed the minimal clinically important difference of 1.5, see Table 3.

Length of hospital stay

Celik et al. reported no significant difference regarding length of hospital stay after bilateral laminotomy (mean 2.2 days) compared with conventional laminectomy (2.3 days) [2]. The quality of evidence is low (only one high-quality RCT, 71 participants, MD −0.10, 95 % CI −0.89 to 0.69). Yagi et al. reported a significantly shorter duration of hospital stay after unilateral endoscopic laminotomy (mean 4 days) compared with conventional laminectomy (mean 13 days) [25]. Results of studies comparing split-spinous process laminotomy with laminectomy are conflicting. Cho et al. reported a significantly shorter duration of hospital stay after split-spinous process laminotomy (mean 4 days) compared with conventional laminectomy (mean seven days) [27], but Rajasekaran et al. reported equal duration of hospital stay after split-spinous process laminotomy (mean 4.5 days) compared with conventional laminectomy (mean 4.4 days) [29]. The quality of evidence is low (only one high-quality RCT, 51 participants, MD −0.10, 95 % CI −0.46 to 0.66).

Complications

All studies reported procedure-related complications. None of the studies included in this review reported procedure-related mortality. The most commonly reported complication of the surgical procedure was a dural tear. Celik et al. and Thome et al. reported a significantly lower incidence of incidental dural tear in the bilateral laminotomy group compared with the laminectomy group (1/37 vs 7/34 and 2/40 vs 8/40, respectively) [2, 4]. Other studies did not report a significantly different incidence of dural tears among treatment groups [3, 26, 28, 29]. None of the studies included in this review reported significant differences between treatment groups regarding iatrogenic neurological impairment, wound infection or epidural haematoma. Between those who received bilateral laminotomy and those undergoing conventional laminectomy, low-quality evidence shows no significant differences regarding cumulative incidence of complications (three RCTs, 303 participants, OR 0.33, 95 % CI 0.07–1.59). Between those who received unilateral laminotomy and those undergoing conventional laminectomy, low-quality evidence indicates no significant differences regarding cumulative incidence of complications (three RCTs, 173 participants, OR 0.73, 95 % CI 0.24–2.20). Finally, between those who received split-spinous process laminotomy and those undergoing conventional laminectomy, low-quality evidence shows no significant differences regarding cumulative incidence of complications (three RCTs, 141 participants, OR 1.21, 95 % CI 0.20–7.16), see Table 3.

Surgically induced spinal instability

All studies, except the studies by Rajasekaran et al. and Watanabe et al., reported surgically induced spinal instability. Investigators used flexion–extension radiographs to assess spinal instability [2–4, 24–30]. Among studies comparing unilateral laminotomy with conventional laminectomy, Thome et al. reported postoperative radiological instability in 2/39 participants in the unilateral laminotomy group compared with 3/34 participants in the conventional laminectomy group [4]. All participants with instability underwent instrumented fusion. Gurelik et al. reported no postoperative instability in the unilateral laminotomy group (26 participants) compared with 5 out of 26 patients in the conventional laminectomy group [24]. It must be noted though that investigators performed a unilateral total facetectomy in seven participants in the laminectomy group and in none of those in the laminotomy group. Yagi et al. reported no postoperative spondylolisthesis in the unilateral laminotomy group compared with 2/21 participants in the conventional laminectomy group [25]. Between those who received unilateral laminotomy and those undergoing laminectomy, low-quality evidence showed no significant differences regarding the incidence of instability (three RCTs, 166 participants, OR 0.28, 95 % CI 0.07–1.15). Among studies comparing bilateral laminotomy with conventional laminectomy, Celik et al. reported no radiological instability in 37 participants in the bilateral laminotomy group compared with 3 out of 34 participants in the conventional laminectomy group [2]. Two of these participants underwent instrumented fusion, and the other participant declined subsequent surgery. Fu et al. reported no postoperative instability in 76 participants in the bilateral laminotomy group compared with 6 out of 76 participants in the conventional laminectomy group [26]. Four of these participants underwent instrumented fusion. Postacchini et al. reported no postoperative instability in the bilateral laminotomy group compared with 3/41 participants treated with conventional laminectomy [3]. Thome et al. reported no postoperative instability in 37 participants in the bilateral laminotomy group compared with 3 out of 34 participants in the conventional laminectomy group [4]. All participants with instability underwent instrumented fusion. Between those who received bilateral laminotomy and those undergoing laminectomy, low-quality evidence suggests a significantly higher incidence of instability in the conventional laminectomy group (three RCTs, 294 participants, OR 0.10, 95 % CI 0.02–0.55). The quality of evidence had to be decreased because of high risk of bias due to a non-standardised assessment of spinal instability. Cho et al. reported no postoperative instability in 40 participants in the split-spinous process laminotomy group [27]. Two out of 30 participants in the conventional laminectomy group developed postoperative spondylolisthesis, and one underwent subsequent instrumented fusion. The difference was not significant. Liu et al. reported no difference among 27 participants treated with split-spinous process laminotomy compared with 29 participants treated with conventional laminectomy [28]. No participants in either group developed instability. The quality of evidence is very low (only one low-quality RCT), see Table 3.

Muscle atrophy and muscle cell injury

Three studies reported paraspinal muscle denervation/atrophy [25, 28, 30]. After 1 year, Yagi et al. compared muscle atrophy ratios of multifidus and erector spinae muscles following unilateral microendoscopic laminotomy of 13 vs 35 % following conventional laminectomy [25]. The difference was statistically significant, and the quality of evidence was very low (only one low-quality RCT). Liu et al. and Watanabe et al. compared muscle atrophy ratios of multifidus and erector spinae muscles following split-spinous process laminotomy and conventional laminectomy after 3 months and 1 month, respectively [28, 30]. Between those who received split-spinous process laminotomy and laminectomy, low-quality evidence suggests a significant difference regarding postoperative back muscle atrophy ratios in favour of split-spinous laminotomy (two RCTs, 90 participants, MD −12.07, 95 % CI −20.01 to −4.13). The quality of evidence had to be decreased because of the relatively high impact of one low-quality study on the combined quantitative analysis [28].

Five studies reported muscle cell injury (creatine phosphokinase levels) [25, 27–30]. All studies but one (Rajasekaran et al.) reported statistically significant differences, with higher creatine phosphokinase levels (CPK-MM) in the conventional laminectomy groups. Following unilateral microendoscopic laminotomy, CPK-MM after 24 h was 270 IU/L, and following conventional laminectomy, CPK-MM was 620 IU/L (Yagi et al.) [25]. As only one low-quality RCT compared muscle cell injury after unilateral laminotomy versus conventional laminectomy, the quality of evidence is very low. Following a split-spinous process laminotomy, the CPK-MM was 161 IU/L, and it was 276 IU/L following conventional laminectomy (Cho et al.) [27]. Between those who received split-spinous process laminotomy and laminectomy, low-quality evidence shows no significant differences regarding postoperative creatine kinase levels (three RCTs, 141 participants, MD −194.87, 95 % CI −456.95 to 67.20). The quality of evidence had to be decreased because of severely variable standard deviations between studies, possibly as the result of different methods of measuring CPK-MM (Liu et al.: measurement on postoperative day three; Rajasekaran et al.: difference between preoperative measurement and measurement on postoperative day one; Watanabe et al.: measurement on postoperative day three) [28–30].

Walking distance

Only Gurelik et al. reported actual walking distance, as assessed by walking distance on a treadmill [24]. Walking distance was not significantly different among patients who underwent unilateral laminotomy (288.7 m) versus conventional laminectomy (203.7 m). Celik et al. and Thome et al. compared participants' self-reported walking distance [2, 4]. They reported no significant differences regarding walking distance between participants treated with bilateral laminotomy (3663 m), unilateral laminotomy (2958 m) and conventional laminectomy (2318 m) (Thome et al.). Celik et al. reported no significant differences regarding pain-free walking distance between participants treated with bilateral laminotomy (97 m) and those undergoing conventional laminectomy (94 m). Fu et al. reported walking tolerance [26]. After a mean of 40 months, 100 % of participants treated with bilateral laminotomy were able to walk longer than 30 min, 97 % were able to walk longer than 60 min and 89 % could walk an unlimited distance. Compared with participants treated with conventional laminectomy, of whom 100 % were able to walk longer than 30 min, 86 % were able to walk longer than 60 min and 51 % were able to walk an unlimited distance, only the percentage of participants who reported an unlimited walking distance increased significantly. In summary, low-quality evidence suggests that walking distance after bilateral laminotomy and conventional laminectomy did not differ (three RCTs, 294 participants), and very low-quality evidence shows that walking distance after unilateral laminotomy and conventional laminectomy does not differ (two RCTs, 125 participants). A quantitative comparison of data was not possible.

Back pain

Low back pain after surgery, assessed with a VAS, was reported by six studies [2, 25–29]. Among participants treated with bilateral laminotomy, Fu et al. reported a significantly lower VAS 0–10 (0.05), compared with conventional laminectomy (0.63) [26]. However, another study comparing bilateral laminotomy (VAS 4.2) versus conventional laminectomy (VAS 4.4) yielded no significant differences between treatment groups [2]. Among participants treated with unilateral microendoscopic laminotomy (VAS 0.8) and those treated with conventional laminectomy (VAS 3.4 cm), Yagi et al. reported a statistically significant difference in favour of unilateral microendoscopic laminotomy [25]. Among participants treated with bilateral laminotomy, unilateral laminotomy and conventional laminectomy, Thome et al. reported no statistically significant differences regarding improvement in back pain at rest, but described significantly improved back pain during walking among participants treated with bilateral laminotomy versus those treated with conventional laminectomy [4]. According to the as-treated analysis provided by Postacchini et al., the mean improvement on the VAS scale for back pain was significant among participants treated with bilateral laminotomy compared with those who crossed-over or were allocated to conventional laminectomy [3]. Two studies comparing split-spinous process laminotomy versus conventional laminectomy reported significantly decreased postoperative back pain VAS 0–10 [27, 28]. Cho et al. reported one-year postoperative VAS of 2.4 in the split-spinous process laminotomy group compared with 4.0 in the conventional laminectomy group [27]. Liu et al. reported one-year postoperative VAS back pain of 1.0 and 2.6, respectively [28]. In comparison, Rajasekaran et al. did not find a significant difference between split-spinous process laminotomy (2.5) and conventional laminectomy (3.0) regarding postoperative back pain after 1 year [29]. In summary, low-quality evidence showed that back pain is greater after conventional laminectomy than after bilateral laminotomy, but the mean difference does not reach the criteria of a minimal clinically important difference (two RCTs, 223 participants, MD −0.51, 95 % CI −0.80 to −0.23). The quality of evidence had to be decreased because of the relatively high impact of one low-quality study on the combined quantitative analysis [26]. A quantitative comparison of postoperative back pain after unilateral laminotomy (two RCTs, 114 participants) was not possible because of different reporting of outcome measures. Between those who receive split-spinous process laminotomy and those undergoing laminectomy, low-quality evidence shows a significant difference regarding back pain in favour of split-spinous process laminotomy, but the mean difference does not reach the criteria of a minimal clinically important difference (two RCTs, 97 participants, MD −1.07, 95 % CI −2.15 to −0.00), see Table 3.

Length of the surgical procedure

Eight studies reported length of the surgical procedure [2–4, 25, 27–30]. Thome et al. reported a significantly increased duration of bilateral laminotomy (90 min) compared with unilateral laminotomy (77 min) or conventional laminectomy (73 min) [4]. Postacchini et al. reported a significantly increased duration of bilateral laminotomy in cases of multiple-level decompression, but not when comparing single-level decompression [3]. By contrast, Celik et al. reported a shorter duration of bilateral laminotomy (83 min) compared with conventional laminectomy (107 min) [2]. Yagi et al. reported a longer duration of unilateral laminotomy (71 min) compared with conventional laminectomy (64 min), but the difference was not statistically significant [25]. Comparatively, Cho et al. reported a long duration of surgical procedures of 259 min among participants treated with a split-spinous process laminotomy and 193 min among those treated with conventional laminectomy, but they performed a concomitant discectomy in most participants and decompressed 2.6 levels on average per participant (see Table 1) [27]. Two studies comparing a split-spinous process laminotomy with conventional laminectomy reported a non-significantly shorter duration of conventional laminectomy [28, 29], and one study reported a non-significantly longer duration of conventional laminectomy [30]. Between those who receive bilateral laminotomy and those undergoing conventional laminectomy, low-quality evidence suggests no significant difference regarding length of the procedure (two RCTs, 142 participants, MD 0.3, 95 % CI −39.2 to 39.8). Between those who receive unilateral laminotomy and those undergoing conventional laminectomy, low-quality evidence shows no significant difference regarding length of the procedure (two RCTs, 114 participants, MD 6.3, 95 % CI −0.7 to 13.2). Between those who receive split-spinous process laminotomy and those treated with conventional laminectomy, low-quality evidence indicates no significant difference regarding length of the procedure (three RCTs, 141 participants, MD 4.6, 95 % CI −5.1 to 14.3).

Blood loss

Studies comparing perioperative blood loss among participants treated with bilateral laminotomy and those treated with conventional laminectomy did not report a statistically significant difference [2–4]. However, Thome et al. and Yagi et al. did find a statistically significant difference in favour of unilateral laminotomy when compared with conventional laminectomy (blood loss 177 vs 227 mL and 37 vs 71 mL, respectively). One study that compared a split-spinous process laminotomy versus conventional laminectomy reported a significant decrease in perioperative blood loss [28], whilst the other studies reported no significant difference [27, 29, 30]. Between those who receive bilateral laminotomy and those undergoing conventional laminectomy, moderate-quality evidence suggests no difference regarding perioperative blood loss (two RCTs, 142 participants, MD −20.2, 95 % CI −89.5 to 49.2). Between those who receive unilateral laminotomy and those treated with conventional laminectomy, low-quality evidence shows less perioperative blood loss with unilateral laminotomy (two RCTs, 114 participants, MD −34.1, 95 % CI −37.7 to −30.4). The quality of evidence had to be decreased because of the relatively high impact of one low-quality study on the combined quantitative analysis [25]. Between those who receive split-spinous process laminotomy and those undergoing conventional laminectomy, moderate-quality evidence shows no difference regarding perioperative blood loss (three RCTs, 141 participants, MD −3.8, 95 % CI −36.4 to 28.8).

Analgesics

Celik et al. reported no statistically significant difference regarding postoperative use of pethidine (mg) among participants treated with bilateral laminotomy compared with those treated with conventional laminectomy [2]. The quality of evidence was low (only one high-quality RCT, 71 participants, MD −53.0, 95 % CI −215.8 to 109.8). Yagi et al. reported significantly less use of diclofenac following unilateral (microendoscopic) laminotomy compared with conventional laminectomy, but study authors did not provide a quantitative comparison [25]. Watanabe et al. compared the use of non-steroidal anti-inflammatory drugs among participants treated with split-spinous process laminotomy versus conventional laminectomy during the first three days of follow-up [30]. The difference was not significant (mean 1.7 tablets in the split-spinous process laminotomy group and 2.3 tablets in the conventional laminectomy group).

Discussion

Evidence from this systematic review indicates generally equal results with techniques that preserve the posterior midline structures compared with conventional laminectomy. We considered functional disability, perceived recovery and leg pain as the most important aspects of lumbar stenosis to guide the decision for a particular technique. Unfortunately, investigators reported different outcome measures used throughout the studies as mean, mean improvement or percentage of participants showing improvement in a particular outcome. Direct comparison of functional disability was possible only when a standardised mean difference was calculated, but it did not suggest a clinically significant advantage of any technique of posterior decompression. Comparison of perceived recovery favoured bilateral laminotomy over conventional laminectomy with low quality of evidence, but investigators found no significant difference between unilateral laminotomy or split-spinous process laminotomy and conventional laminectomy. Researchers found no evidence that any technique of posterior decompression resulted in a clinically significant reduction in leg pain.

In case techniques of posterior decompression that preserve the posterior midline structures may be considered equally effective as conventional laminectomy regarding primary outcome measures, secondary outcome measures could provide decisive arguments for the choice of a particular technique. All studies included in this review demonstrated a decrease in postoperative instability following decompression with preservation of the posterior midline structures compared with conventional laminectomy. These findings support the hypothesis that postoperative lumbar instability is caused or accelerated by lumbar surgery and is not the result of a progressive degenerative condition. Postoperative instability is thought to be an important cause of low back pain [52], and is considered an indication for salvage surgery with concomitant instrumented fusion [53, 54]. Various biomechanical, clinical and radiological definitions of spinal stability are reported in the literature, but a consensus definition is lacking [55]. Therefore, the true incidence of instability after surgery for lumbar stenosis is unclear. The incidence of postoperative instability among studies included in this review varied from 19 to 0 % after conventional laminectomy [24, 28], compared to no cases of postoperative instability in any study after posterior decompression with techniques that preserve the posterior midline structures. Interpretation of these results deserves scrutiny, as absence of blinding of the outcome assessor and non-standardised intervals of detection harbour the potential for bias. Furthermore, studies included in this review used slightly different criteria of instability or did not specify the radiologic definitions of instability applied. Three studies reported the reoperation incidence with concomitant instrumented fusion due to vertebral instability [2, 4, 26]. The consequences of radiological instability for symptom severity and the reoperation rate due to radiological instability in other studies were poorly defined. Also, the length of the follow-up period and thus the potential to develop instability varied considerably among studies. Therefore, future research is necessary to further establish the relationship between techniques of decompression and the incidence of radiological and clinical instability.

Reduced back pain is hypothesised to be the result of limited disruption of back muscles and of the extent of resection of bony and soft tissue, but it may also be attributed to reduction in surgically induced instability. A significant reduction in postoperative creatine phosphokinase [25, 27, 28, 30] and atrophy ratios of multifidus and erector spinae muscle [25, 28, 30] were reported among participants treated with posterior midline structure-preserving techniques when compared with conventional laminectomy. Postoperative back pain was significantly less in these groups too, but the difference met the threshold criteria of a minimal clinically important difference in only one study [25]. It must be noted that the severity of back pain at baseline varied considerably among studies. A different selection of participants regarding preoperative back pain as well as the timing of assessment of postoperative back pain may influence these results. Therefore, it is currently unclear whether there is a true difference between unilateral laminotomy, bilateral laminotomy and split-spinous process laminotomy in terms of postoperative back pain, or whether comparisons are biased.

Four out of ten studies assessed walking distance [2, 4, 24, 26]. Only one study performed an objective assessment of walking distance using a treadmill, whilst others relied on self-reported walking distance. None reported a significant difference between treatment groups. Although reduced walking distance is an important component of the symptom complex of lumbar stenosis, the assessment of walking distance is relatively insensitive to change. Studies comparing surgery with conservative treatment for lumbar stenosis also found no differences between treatment groups regarding walking distance, although other outcome measures differed significantly between treatment groups [56, 57].

A possible disadvantage of techniques that preserve the posterior midline structures is increased length of the surgical procedure compared with laminectomy. However, the difference between these techniques of posterior decompression and conventional laminectomy did not reach statistical significance. Possibly, the addition of future studies to the final analysis will result in a significant difference, but it seems unlikely that the magnitude of this difference is relevant to clinical practice. Similarly, investigators found small differences in perioperative blood loss. Only three studies compared length of hospital stay [2, 25, 29]. The reported length of stay varied considerably between these studies for both intervention and control groups. Therefore, it seems unlikely that the significant difference reported by Yagi et al. can be attributed to the technique of decompression alone [25]. Further, the limited exposure created by techniques that preserve posterior midline structures and their complexity have been suggested to result in an increase in perioperative complications, especially regarding the incidence of dural injury [6, 31, 36]. However, none of the studies included in this review reported an increase in the incidence of complications as a result of these techniques. Possibly, this can be attributed to use of an operating microscope in all of these studies. Other complications, such as procedure-related mortality, neurological impairment, wound infection and epidural haematoma were not different among treatment groups.

The extent of lumbar stenosis and the presence of spondylolisthesis are of particular importance in the evaluation of surgical techniques. Postacchini et al. reported that laminotomy may not be suitable for all cases of lumbar stenosis [3]. In 9 out of 35 participants allocated to undergo bilateral laminotomy, conventional laminectomy was necessary to achieve adequate neural decompression. Study authors report that this was most often due to very severe central stenosis and degenerative spondylolisthesis, in which the thecal sac is compressed between the osteoligamentous posterior arch of the slipped vertebra and the posterosuperior border of the underlying vertebral body. No other study included in this review reported cases in which it was necessary to convert to conventional laminectomy. Possibly, through exclusion of cases of lumbar stenosis caused by severe narrowing of bony surroundings [26], spondylolisthesis [25, 28, 29] and vertebral instability [2, 4, 24–29], surgeons could achieve adequate decompression with laminotomy. Unfortunately, neither study provided a flowchart of the selection of participants regarding anatomical characteristics of lumbar stenosis or reported robust exclusion criteria. Therefore, the proportion of patients with lumbar stenosis that can be treated with these techniques is unclear, and the suitability of these techniques regarding anatomical characteristics remains poorly defined.

Study populations were considered sufficiently homogeneous to allow for quantitative and qualitative comparisons despite the reporting of different clinical definitions of symptomatic lumbar stenosis and poorly defined radiological characteristics of lumbar stenosis. These differences reflect the clinical variety of cases of lumbar stenosis in current clinical practice because of lack of consensus on criteria to define and classify lumbar stenosis [58]. Other differences between studies include use of a tubular retractor system in one study compared with an open procedure in all other studies [25], concomitant discectomy if necessary compared with no discectomy in all other studies [3, 27], and the inclusion of strictly single-level decompressions in one study compared with multiple-level decompressions in all other studies [25]. As a result of the limited number of included studies, stratification for these factors was not feasible. Review authors excluded two studies from the final analysis as the result of clinical heterogeneity [27, 29], because these studies included participants with concomitant discectomy and fusion procedures. Clinical heterogeneity regarding the number of spinal levels decompressed and use of a tubular retractor system were not considered exclusion criteria for the final analysis, as it seems unlikely that these factors are associated with treatment outcomes. It has been demonstrated that the number of stenotic spinal levels is not associated with treatment outcomes [59]. We did not find high-quality studies that compared microendoscopic laminotomy versus open laminotomy, but a similar comparison regarding microendoscopic discectomy and unilateral open transflaval discectomy did not result in different treatment outcomes [60].

Conclusion

Implications for practice

Evidence provided by this systematic review for the effects of unilateral laminotomy for bilateral decompression, bilateral laminotomy and split-spinous process laminotomy compared with conventional laminectomy on functional disability, perceived recovery and leg pain is of low or very low quality. Therefore, further research is necessary to establish whether these techniques offer a safe and effective alternative to conventional laminectomy. Proposed advantages of these techniques regarding the incidence of iatrogenic instability and postoperative back pain are plausible, but definitive conclusions are limited by poor methodology and poor reporting of outcome measures among included studies. Future research is necessary to establish the incidence of iatrogenic instability using standardised definitions of radiological and clinical instability at comparable follow-up intervals. Additionally, long-term results of these techniques are currently lacking.

Implications for research

More methodologically rigorous studies are needed to compare techniques of decompression for lumbar stenosis before high-quality evidence-based recommendations can be made. The methodological quality of studies can be vastly improved with the use of adequate randomisation methods and blinding of participants and outcome assessors. Comparability of studies can be improved by standardising the outcome measures and the follow-up time points. In addition, more long-term outcome data (i.e. 5 years) are needed. More specifically, future research is necessary to allow for the distinction of subgroups based on anatomical characteristics of stenosis (e.g. single- vs multiple-level stenosis, bony vs soft stenosis). Further, the clinical relevance of radiological instability regarding symptom severity and reoperation rate with instrumented fusion should be addressed. Finally, researchers should conduct studies that compare a technique involving only partial resection of the vertebral arch with removal of the posterior midline structures or laminoplasty versus conventional laminectomy.

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References

1. Gibson JN, Waddell G (2005) Surgery for degenerative lumbar spondylosis. The Cochrane database of systematic reviews (4):CD001352. doi:10.1002/14651858.CD001352.pub3
2. Celik SE, Celik S, Goksu K, Kara A, Ince I (2010) Microdecompressive laminotomy with a 5-year follow-up period for severe lumbar spinal stenosis. J Spinal Disord Tech 23(4):229–235. doi:10.1097/BSD.0b013e3181a3d889
3. Postacchini F, Cinotti G, Perugia D, Gumina S (1993) The surgical treatment of central lumbar stenosis. Multiple laminotomy compared with total laminectomy. The Journal of bone and joint surgery British 75(3):386–392
4. Thome C, Zevgaridis D, Leheta O, Bazner H, Pockler-Schoniger C, Wohrle J, Schmiedek P (2005) Outcome after less-invasive decompression of lumbar spinal stenosis: a randomized comparison of unilateral laminotomy, bilateral laminotomy, and laminectomy. J Neurosurg Spine 3(2):129–141. doi:10.3171/spi.2005.3.2.0129
5. Katz JN, Lipson SJ, Larson MG, McInnes JM, Fossel AH, Liang MH (1991) The outcome of decompressive laminectomy for degenerative lumbar stenosis. J Bone Joint Surg Am 73(6):809–816
6. Delank KS, Eysel P, Zollner J, Drees P, Nafe B, Rompe JD (2002) Undercutting decompression versus laminectomy. Clinical and radiological results of a prospective controlled trial. Der Orthopade 31 (11):1048–1056. doi:10.1007/s00132-002-0369-y (discussion 1057)
7. Rompe JD, Eysel P, Zollner J, Nafe B, Heine J (1999) Degenerative lumbar spinal stenosis. Long-term results after undercutting decompression compared with decompressive laminectomy alone or with instrumented fusion. Neurosurg Rev 22(2–3):102–106
8. Hopp E, Tsou PM (1988) Postdecompression lumbar instability. Clin Orthop Relat Res 227:143–151
9. Mayer TG, Vanharanta H, Gatchel RJ, Mooney V, Barnes D, Judge L, Smith S, Terry A (1989) Comparison of CT scan muscle measurements and isokinetic trunk strength in postoperative patients. Spine 14(1):33–36
10. Sihvonen T, Herno A, Paljarvi L, Airaksinen O, Partanen J, Tapaninaho A (1993) Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. Spine 18(5):575–581
11. Bresnahan L, Ogden AT, Natarajan RN, Fessler RG (2009) A biomechanical evaluation of graded posterior element removal for treatment of lumbar stenosis: comparison of a minimally invasive approach with two standard laminectomy techniques. Spine 34(1):17–23. doi:10.1097/BRS.0b013e318191438b

12. Johnsson KE, Willner S, Johnsson K (1986) Postoperative instability after decompression for lumbar spinal stenosis. Spine 11(2):107–110
13. Guiot BH, Khoo LT, Fessler RG (2002) A minimally invasive technique for decompression of the lumbar spine. Spine 27(4):432–438
14. Spetzger U, Bertalanffy H, Naujokat C, von Keyserlingk DG, Gilsbach JM (1997) Unilateral laminotomy for bilateral decompression of lumbar spinal stenosis. Part I: anatomical and surgical considerations. Acta Neurochir (Wien) 139(5):392–396
15. Adams MA, Hutton WC (1983) The mechanical function of the lumbar apophyseal joints. Spine 8(3):327–330
16. Adams MA, Hutton WC, Stott JR (1980) The resistance to flexion of the lumbar intervertebral joint. Spine 5(3):245–253
17. Hindle RJ, Pearcy MJ, Cross A (1990) Mechanical function of the human lumbar interspinous and supraspinous ligaments. J Biomed Eng 12(4):340–344
18. Higgins JPT AD, Sterne JAC (2011) Chapter 8: assessing risk of bias in included studies. In: Higgins JPT GS (ed) Cochrane handbook for systematic reviews of interventions version 5.1.0 (updated March 2011). The Cochrane Collaboration, 2011. http://www.cochrane-handbook.org
19. The Nordic Cochrane Centre TCC (2011) Review Manager (RevMan) vol Version 5.1. Copenhagen
20. Ostelo RW, Deyo RA, Stratford P, Waddell G, Croft P, Von Korff M, Bouter LM, de Vet HC (2008) Interpreting change scores for pain and functional status in low back pain: towards international consensus regarding minimal important change. Spine 33(1):90–94. doi:10.1097/BRS.0b013e31815e3a10
21. Atkins D, Best D, Briss PA, Eccles M, Falck-Ytter Y, Flottorp S, Guyatt GH, Harbour RT, Haugh MC, Henry D, Hill S, Jaeschke R, Leng G, Liberati A, Magrini N, Mason J, Middleton P, Mrukowicz J, O'Connell D, Oxman AD, Phillips B, Schunemann HJ, Edejer T, Varonen H, Vist GE, Williams JW, Jr. Zaza S, Group GW (2004) Grading quality of evidence and strength of recommendations. Bmj 328 (7454):1490. doi:10.1136/bmj.328.7454.1490
22. Furlan AD, Pennick V, Bombardier C, van Tulder M, Editorial Board CBRG (2009) 2009 updated method guidelines for systematic reviews in the Cochrane Back Review Group. Spine 34(18):1929–1941. doi:10.1097/BRS.0b013e3181b1c99f
23. Nerland US, Jakola AS, Solheim O, Weber C, Rao V, Lonne G, Solberg TK, Salvesen O, Carlsen SM, Nygaard OP, Gulati S (2014) Comparative effectiveness of microdecompression and laminectomy for central lumbar spinal stenosis: study protocol for an observational study. BMJ open 4(3):e004651. doi:10.1136/bmjopen-2013-004651
24. Gurelik MBC, Kars Z, Karadag O, Ozum U, Bayrakli F (2012) Unilateral laminotomy for decompression of lumbar stenosis is effective and safe: a prospective randomized comparative study. J Neurol Sci 29(4):744–753
25. Yagi M, Okada E, Ninomiya K, Kihara M (2009) Postoperative outcome after modified unilateral-approach microendoscopic midline decompression for degenerative spinal stenosis. J Neurosurg Spine 10(4):293–299. doi:10.3171/2009.1.SPINE08288
26. Fu YS, Zeng BF, Xu JG (2008) Long-term outcomes of two different decompressive techniques for lumbar spinal stenosis. Spine 33(5):514–518. doi:10.1097/BRS.0b013e3181657dde
27. Cho DY, Lin HL, Lee WY, Lee HC (2007) Split-spinous process laminotomy and discectomy for degenerative lumbar spinal stenosis: a preliminary report. J Neurosurg Spine 6(3):229–239. doi:10.3171/spi.2007.6.3.229
28. Liu X, Yuan S, Tian Y (2013) Modified unilateral laminotomy for bilateral decompression for lumbar spinal stenosis: technical note. Spine 38(12):E732–E737. doi:10.1097/BRS.0b013e31828fc84c
29. Rajasekaran S, Thomas A, Kanna RM, Prasad Shetty A (2013) Lumbar spinous process splitting decompression provides equivalent outcomes to conventional midline decompression in degenerative lumbar canal stenosis: a prospective, randomized controlled study of 51 patients. Spine 38(20):1737–1743. doi:10.1097/BRS.0b013e3182a056c1
30. Watanabe K, Matsumoto M, Ikegami T, Nishiwaki Y, Tsuji T, Ishii K, Ogawa Y, Takaishi H, Nakamura M, Toyama Y, Chiba K (2011) Reduced postoperative wound pain after lumbar spinous process-splitting laminectomy for lumbar canal stenosis: a randomized controlled study. J Neurosurg Spine 14(1):51–58. doi:10.3171/2010.9.SPINE09933
31. Khoo LT, Fessler RG (2002) Microendoscopic decompressive laminotomy for the treatment of lumbar stenosis. Neurosurgery 51(5 Suppl):S146–S154
32. Morgalla MH, Noak N, Merkle M, Tatagiba MS (2011) Lumbar spinal stenosis in elderly patients: is a unilateral microsurgical approach sufficient for decompression? J Neurosurg Spine 14(3):305–312. doi:10.3171/2010.10.SPINE09708
33. Osman TMC, Kelleher M, McEvoy L, Bolger C (2009) Intersegmental decompression versus laminectomy in the surgical treatment of lumbar spinal stenosis. Br J Neurosurg 23(5):489–490
34. Rahman M, Summers LE, Richter B, Mimran RI, Jacob RP (2008) Comparison of techniques for decompressive lumbar laminectomy: the minimally invasive versus the "classic" open approach. Minimally invasive neurosurgery : MIN 51 (2):100–105. doi:10.1055/s-2007-1022542
35. Shih P, Wong AP, Smith TR, Lee AI, Fessler RG (2011) Complications of open compared to minimally invasive lumbar spine decompression. J Clin Neurosci 18(10):1360–1364. doi:10.1016/j.jocn.2011.02.022
36. Thomas NW, Rea GL, Pikul BK, Mervis LJ, Irsik R, McGregor JM (1997) Quantitative outcome and radiographic comparisons between laminectomy and laminotomy in the treatment of acquired lumbar stenosis. Neurosurgery 41 (3):567–574 (discussion 574–565)
37. Watanabe K, Hosoya T, Shiraishi T, Matsumoto M, Chiba K, Toyama Y (2005) Lumbar spinous process-splitting laminectomy for lumbar canal stenosis. Technical note. J Neurosurg Spine 3(5):405–408. doi:10.3171/spi.2005.3.5.0405
38. Krut'ko AV (2012) Results of decompressive-stabilizing procedures via unilateral approach in lumbar spinal stenosis. Zhurnal voprosy neirokhirurgii imeni N N Burdenko 76 (2):33–40 (discussion 40–31)
39. Yu CS, Tay BK (1992) Wide versus selective decompression in the operative treatment of lumbar spinal stenosis. Singapore Med J 33(4):378–379
40. Usman M, Ali M, Khanzada K, Ishaq M, Naeem ul H, Aman R, Ali M (2013) Unilateral approach for bilateral decompression of lumbar spinal stenosis: a minimal invasive surgery. J Coll Physicians Surg Pak 23(12):852–856. doi:12.2013/JCPSP.852856
41. Aleem IS, Rampersaud YR (2014) Elderly patients have similar outcomes compared to younger patients after minimally invasive surgery for spinal stenosis. Clin Orthop Relat Res 472(6):1824–1830. doi:10.1007/s11999-013-3411-y
42. Arai Y, Hirai T, Yoshii T, Sakai K, Kato T, Enomoto M, Matsumoto R, Yamada T, Kawabata S, Shinomiya K, Okawa A (2014) A prospective comparative study of 2 minimally invasive decompression procedures for lumbar spinal canal stenosis: unilateral laminotomy for bilateral decompression (ULBD) versus muscle-preserving interlaminar decompression (MILD). Spine 39(4):332–340. doi:10.1097/BRS.0000000000000136
43. Cavusoglu H, Kaya RA, Turkmenoglu ON, Tuncer C, Colak I, Aydin Y (2007) Midterm outcome after unilateral approach for

bilateral decompression of lumbar spinal stenosis: 5-year prospective study. Eur Spine J 16(12):2133–2142. doi:10.1007/s00586-007-0471-2
44. Dalgic A, Uckun O, Ergungor MF, Okay O, Daglioglu E, Hatipoglu G, Pasaoglu L, Caglar YS (2010) Comparison of unilateral hemilaminotomy and bilateral hemilaminotomy according to dural sac area in lumbar spinal stenosis. Minimally invasive neurosurgery :MIN 53(2):60–64. doi:10.1055/s-0029-1246147
45. Kim K, Isu T, Sugawara A, Matsumoto R, Isobe M (2008) Comparison of the effect of 3 different approaches to the lumbar spinal canal on postoperative paraspinal muscle damage. Surg Neurol 69(2):109–113. doi:10.1016/j.surneu.2007.04.021 (discussion 113)
46. Kim SWJC, Kim CG, Lee SM, Shin H (2007) Minimally invasive lumbar spinal decompression: a comparative study between bilateral laminotomy and unilateral laminotomy for bilateral decompression. J Korean Neurosurg Soc 42(3):195–199
47. Ruetten S, Komp M, Merk H, Godolias G (2009) Surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach versus conventional microsurgical technique: a prospective, randomized, controlled study. J Neurosurg Spine 10(5):476–485. doi:10.3171/2008.7.17634
48. Jones AD, Wafai AM, Easterbrook AL (2014) Improvement in low back pain following spinal decompression: observational study of 119 patients. European Spine J 23(1):135–141. doi:10.1007/s00586-013-2964-5
49. Munting E, Roder C, Sobottke R, Dietrich D, Aghayev E, Spine Tango C (2015) Patient outcomes after laminotomy, hemilaminectomy, laminectomy and laminectomy with instrumented fusion for spinal canal stenosis: a propensity score-based study from the Spine Tango registry. European Spine J 24(2):358–368. doi:10.1007/s00586-014-3349-0
50. Zhang C, Zhou HX, Feng SQ, Ning GZ, Wu Q, Li FY, Zheng YF, Wang P (2013) The efficacy analysis of selective decompression of lumbar root canal of elderly lumbar spinal stenosis. Zhonghua wai ke za zhi (Chin J Surg) 51(9):816–820
51. Leonardi MA, Zanetti M, Min K (2013) Extent of decompression and incidence of postoperative epidural hematoma among different techniques of spinal decompression in degenerative lumbar spinal stenosis. J Spinal Disord Tech 26(8):407–414. doi:10.1097/BSD.0b013e31824a03eb
52. Iida Y, Kataoka O, Sho T, Sumi M, Hirose T, Bessho Y, Kobayashi D (1990) Postoperative lumbar spinal instability occurring or progressing secondary to laminectomy. Spine 15(11):1186–1189
53. Hanley EN Jr (1995) The indications for lumbar spinal fusion with and without instrumentation. Spine 20(24 Suppl):143S–153S
54. Sonntag VK, Marciano FF (1995) Is fusion indicated for lumbar spinal disorders? Spine 20(24 Suppl):138S–142S
55. Leone A, Guglielmi G, Cassar-Pullicino VN, Bonomo L (2007) Lumbar intervertebral instability: a review. Radiology 245(1): 62–77. doi:10.1148/radiol.2451051359
56. Amundsen T, Weber H, Nordal HJ, Magnaes B, Abdelnoor M, Lilleas F (2000) Lumbar spinal stenosis: conservative or surgical management?: a prospective 10-year study. Spine 25 (11):1424-1435 (discussion 1435–1426)
57. Malmivaara A, Slatis P, Heliovaara M, Sainio P, Kinnunen H, Kankare J, Dalin-Hirvonen N, Seitsalo S, Herno A, Kortekangas P, Niinimaki T, Ronty H, Tallroth K, Turunen V, Knekt P, Harkanen T, Hurri H, Finnish Lumbar Spinal Research G (2007) Surgical or nonoperative treatment for lumbar spinal stenosis? A randomized controlled trial. Spine 32(1):1–8. doi:10.1097/01.brs.0000251014.81875.6d
58. de Schepper EI, Overdevest GM, Suri P, Peul WC, Oei EH, Koes BW, Bierma-Zeinstra SM, Luijsterburg PA (2013) Diagnosis of lumbar spinal stenosis: an updated systematic review of the accuracy of diagnostic tests. Spine 38(8):E469–E481. doi:10.1097/BRS.0b013e31828935ac
59. Park DK, An HS, Lurie JD, Zhao W, Tosteson A, Tosteson TD, Herkowitz H, Errico T, Weinstein JN (2010) Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine 35(4):439–446. doi:10.1097/BRS.0b013e3181bdafb9
60. Arts MP, Brand R, van den Akker ME, Koes BW, Bartels RH, Peul WC, Leiden-The Hague Spine Intervention Prognostic Study G (2009) Tubular diskectomy vs conventional microdiskectomy for sciatica: a randomized controlled trial. Jama 302(2):149–158. doi:10.1001/jama.2009.972