NATIONAL INSTITUTE FOR HEALTH AND CARE EXCELLENCE

INTERVENTIONAL PROCEDURES PROGRAMME

Interventional procedure overview of lateral interbody fusion in the lumbar spine for low back pain

As a person gets older, the discs that support the vertebrae (back bones) can deteriorate. Sometimes this causes such severe pain and disability that surgery is needed.

Lateral interbody spinal fusion involves removing all, or part, of the damaged disc and inserting a supporting structure. It aims to join the 2 back bones together to prevent the painful joint moving. The procedure is done through a cut in the person's side.

Introduction

The National Institute for Health and Care Excellence (NICE) has prepared this interventional procedure (IP) overview to help members of the interventional procedures advisory committee (IPAC) make recommendations about the safety and efficacy of an interventional procedure. It is based on a rapid review of the medical literature and specialist opinion. It should not be regarded as a definitive assessment of the procedure.

Date prepared

This IP overview was prepared in June 2016.

Procedure name

- Lateral (including extreme, extra and direct lateral) interbody fusion in the lumbar spine for low back pain

Specialist societies

- British Association of Spinal Surgeons.

Description

Indications and current treatment

Chronic low back pain may result from degenerative changes in the intervertebral discs or spinal facet joints. Conservative treatments include analgesics, non-steroidal anti-inflammatory medication and manual therapy.

For cases of severe, life-limiting chronic low back pain that does not respond to conservative treatments, surgery may be appropriate. This may include bony fusion of vertebrae (to immobilise segments of the vertebral column thought to be responsible for back pain, using either a posterior or anterior approach) or inserting a prosthetic intervertebral disc (which preserves lumbar mobility with the aim of reducing the risk of degenerative change in adjacent intervertebral disc spaces). Other surgical alternatives include non-rigid stabilisation techniques.

What the procedure involves

The aim of lateral interbody fusion in the lumbar spine is to achieve a spinal fusion procedure by a lateral approach, to avoid the major muscle groups in the back (posterior approach) or the organs and blood vessels in the abdomen (anterior approach).

The procedure is done with the patient under general anaesthesia. A probe is inserted laterally through the psoas muscle, under fluoroscopic guidance, to lie alongside the affected disc. A posterior incision is also sometimes made, to allow access for manipulation of the probe. Nerve monitoring is recommended by many specialists and is described in several of the studies. Dilators are inserted around the probe and a retractor is positioned to give the surgeon direct access to the spine. A discectomy is carried out and a cage implant inserted to hold the vertebrae in position. A bone graft (usually from the hip) is inserted between the 2 vertebrae, sometimes with additional support from screws, plates or rods. The procedure may be done at more than 1 level during the same operation. A recent variation of this procedure is oblique lateral interbody fusion, which involves retroperitoneal access anterior to the psoas. It may take a few months before patients are able to return to their normal activities after the procedure.

There are a number of different devices used for this procedure.

Literature review

Rapid review of literature

The medical literature was searched to identify studies and reviews relevant to lateral interbody fusion in the lumbar spine for low back pain. The following

databases were searched, covering the period from their start to 21 March 2016: MEDLINE, PREMEDLINE, EMBASE, Cochrane Library and other databases. Trial registries and the internet were also searched. No language restriction was applied to the searches (see appendix C for details of search strategy). Relevant published studies identified during consultation or resolution that are published after this date may also be considered for inclusion.

The following selection criteria (table 1) were applied to the abstracts identified by the literature search. Where selection criteria could not be determined from the abstracts the full paper was retrieved.

Table 1 Inclusion criteria for identification of relevant studies

Characteristic	Criteria
Publication type	Clinical studies were included. Emphasis was placed on identifying good quality studies. Abstracts were excluded where no clinical outcomes were reported, or where the paper was a review, editorial, or a laboratory or animal study. Conference abstracts were also excluded because of the difficulty of appraising study methodology, unless they reported specific adverse events that were not available in the published literature.
Patient	Patients with low back pain, degenerative disc disease, spinal stenosis or disc herniation.
Intervention/test	Lateral (including extreme, extra and direct lateral) interbody fusion in the lumbar spine.
Outcome	Articles were retrieved if the abstract contained information relevant to the safety and/or efficacy.
Language	Non-English-language articles were excluded unless they were thought to add substantively to the English-language evidence base.

List of studies included in the IP overview

This IP overview is based on approximately 9,000 patients treated by lateral interbody fusion from 3 systematic reviews (with some patient overlap), 2 non-randomised comparative studies (1 of which is also included in the systematic reviews) 1 randomised controlled trial (RCT) and non-randomised comparative study, 3 case series (2 of which are also included in the first systematic review) and 6 case reports (5 of which are also included in the first systematic review)[1–15].

Other studies that were considered to be relevant to the procedure but were not included in the main extraction table (table 2) have been listed in appendix A.

Table 2 Summary of key efficacy and safety findings on lateral interbody fusion in the lumbar spine for low back pain

Study 1 Lehmen JA (2015)

Details

Study type	**Systematic review**
Country	US
Recruitment period	Search date: 1995 to February 2015
Study population and number	**n=237 articles** (22 reports on anatomy, 17 biomechanics/testing, 11 technical descriptions, 40 case reports, 30 reports on complications, 43 reports on clinical and radiographical outcomes, 23 on deformity, 10 on trauma or thoracic applications, and 41 review articles) Patients with degenerative (non-deformity) spinal disease, scoliosis or both.
Age and sex	Not reported
Patient selection criteria	Any full-length article that described the minimally disruptive lateral transpsoas approach to the lumbar spine for interbody fusion was included in the review.
Technique	Minimally disruptive lateral transpsoas approach to the lumbar spine for interbody fusion, including extreme lateral interbody fusion (XLIF), lateral lumbar interbody fusion (LLIF), direct lateral interbody fusion (DLIF) and non-retracted transpsoas approaches (shallow docking).
Follow-up	**Mean 9.8 months (range 1.5–40)** (n=7,763 patients, 80 study arms)
Conflict of interest/source of funding	None

Analysis

Study design issues: Outcome variables were pooled where there was reasonable homogeneity in patient population and technique.

Study population issues: The review included all reports of lateral lumbar interbody fusion, regardless of indication. A qualitative analysis was done for 4 primary review questions about anatomical justification, complication and outcome profiles, differences in technique and use of neuromonitoring, and economic viability, across the 3 domains of quality, quantity and consistency of support for the answer. Ratings of high, moderate, low or very low were then assigned to the conclusion from each question, based on the GRADE guidelines.

Other issues: The authors noted there were significant differences in indication for use, patient sample characteristics, levels treated, supplemental fixation used, technique, use of neuromonitoring, and terminology and classification of complications. This made it difficult to make conclusions about the safety of the procedure. The authors concluded that there was moderate strength evidence in support of reproducible and reasonable complications, side effects and outcome profiles following the procedure, which may be technique dependent. Some studies are also included in the systematic reviews by Härtl R et al. (2016) and Joseph J et al. (2015); there are overlaps of approximately 2,000 and 3,600 patients respectively.

Key efficacy and safety findings

Efficacy | Safety

Clinical and radiographical outcomes

Weighted averages

	Mean follow-up, months (range)	Fusion	VAS improvement	ODI improvement	Outcome satisfaction	Patient would have procedure again
All studies	9.8 (1.5–40) n=7,763 (80)	93.6% n=907 (22)	60.0% n=2,097 (41)	48.4% n=1,234 (29)	89.3% n=491 (9)	85% n=334 (6)
Degenerative spinal disease	11.1 (1.5–36) n=1,887 (24)	96.7% n=292 (9)	67.1% n=693 (16)	55.1% n=313 (10)	89% n=129 (2)	91% n=129 (2)
Scoliosis	17.4 (1.5–40) n=473 (12)	91.9% n=106	57.9% n=178 (8)	48.2% n=135 (5)	88% n=103 (2)	85% n=103 (2)
Mixed scoliosis, with mixed degenerative and scoliosis indications	9.3 (1.5–40) n=5,781 (54)	92.2% n=615 (13)	56.4% n=1,404 (25)	46.0% n=921 (19)	89.3% n=362 (7)	81.1% n=205 (4)
Mixed degenerative, with mixed degenerative and scoliosis indications	9.2 (1.5–36) n=7,737 (67)	93.9% n=801 (18)	60.1% n=1,919 (33)	48.4% n=1,099 (24)	89.6% n=388 (7)	85% n=231 (4)
Traditional lateral (XLIF) only	10.2 (1.5–36) n=4,869 (58)	93.2% n=856 (20)	60.0% n=1,968 (36)	47.5% n=1,170 (27)	89.2% n=491 (9)	85.0% n=334 (6)
Non-traditional/mixed XLIF and non-XLIF lateral only	9.1 (1.5–40) n=2,894 (22)	100% n=51 (2)	58.8% n=129 (5)	64.6% n=64 (2)	-	-

n=number of patients (study arms) with reported data and able to be calculated in the weighted average

Side effects/complications

Weighted averages

	Thigh side effects	Hip flexion weakness	Motor neural deficits	All motor deficits (neural and hip flexion weakness)	Reoperations	Total complications
All studies	26.3% n=2,772	20.5% n=1,360 (22)	2.6% n=1,568 (14)	16.7% n=3,471 (35)	5.6% n=2,080 (24)	12.0% n=2,678 (37)
Degenerative spinal disease	9.5% n=414 (11)	14.7% n=190 (7)	1.0% n=651 (3)	4.2% n=820 (9)	3.6% n=1,211	8.0% n=1,596 (16)
Scoliosis	33.1% n=117 (6)	34% n=128 (2)	-	-	10.6% n=114 (4)	27.5% n=280 (9)
Mixed scoliosis, with mixed degenerative and scoliosis indications	28.8% n=2,425 (30)	21.1% n=2,369 (23)	3.9% n=864 (10)	20.3% n=2,598 (25)	8.4% n=869 (13)	17.8% n=1,082 (21)
Mixed degenerative, with mixed degenerative and scoliosis indications	26.0% n=2,602 (33)	18.3% n=1,179 (19)	2.7% n=1,515 (13)	15.8% n=3,311 (33)	5.3% n=1,966 (20)	10.2% n=2,398 (28)
Traditional lateral (XLIF) only	16.4% n=1,343 (25)	20.9% n=970 (18)	1.6% n=1,148 (9)	12.1% n=1,869 (22)	5.4% n=1,882 (21)	10.6% n=2,464 (31)
Non-traditional/mixed XLIF and non-XLIF lateral only	35.6% n=1,429 (15)	20.7% n=1,229 (8)	5.1% n=390 (5)	22.1% n=1,602 (13)	7.0% n=198 (3)	27.3% n=214 (6)

Abbreviations used: ODI, Oswestry Disability Index; VAS, visual analogue scale; XLIF, extreme lateral interbody fusion

Study 2 Härtl R (2016)

Details

Study type	**Systematic review**
Country	Studies were based in US, Italy, Australia and Brazil.
Recruitment period	Search date: February 2013
Study population and number	**n=34 studies (24 extreme lateral interbody fusion [ELIF], 9 anterior lumbar interbody fusion [ALIF], 1 ELIF and ALIF); 3,721 patients (2,342 ELIF versus 1,379 ALIF)** Patients with chronic degenerative disc disease or chronic manifestation of disc herniation.
Age and sex	ELIF: mean 43–83 years; ALIF: mean 39–46 years.
Patient selection criteria	Patients with chronic (lasting more than 12 weeks) degenerative disc disease or chronic manifestation of disc herniation. Studies including patients with tumours of fractures were excluded.
Technique	Extreme lateral interbody fusion (ELIF) was compared with anterior lumbar interbody fusion (ALIF). Of the 24 studies on ELIF, 21 used neuromonitoring during the procedure. The ELIF/ALIF study reported using neuromonitoring in the ELIF arm. Details of the technique for ELIF varied across studies and some used adjunctive posterior decompression and instrumentation procedures.
Follow-up	**ELIF: 45 days to 50 months; ALIF: 24 to 60 months**
Conflict of interest/source of funding	The meta-analysis was done with the support of the AO Foundation via the AOSpine TK Grant. Two authors have no financial relationship with the sponsoring organisation; 1 author is an employee of the AO Foundation but his salary is not dependent on publication of the article. All authors have full control of all primary data. The authors noted that many of the studies were supported by industries directly involved in the manufacturing of the implants used for the procedure.

Analysis

Study design issues: All ELIF studies included in the review were case series; 8 of the 9 ALIF studies were RCTs. There was 1 retrospective cohort study that compared ELIF with ALIF. The primary aim of the review was to compare the complications between ELIF and ALIF. A subgroup analysis of the adverse event rates within the ELIF studies, with and without neuromonitoring, was also done. A separate analysis was done excluding Food and Drug Administration (FDA) premarket approvals on the basis that they report adverse events more rigorously than published manuscripts. In addition, most of the FDA ALIF studies were prospective unlike the retrospective case series for ELIF.

Study population issues: The primary diagnosis for the ELIF studies was degenerative disc disease at single or multiple levels, with a majority of levels from L1 to L5. The primary diagnosis for all included ALIF studies was degenerative disc disease at a single level (8 studies) or at 2 or more levels (1 study) from L3 to S1. Some studies included a proportion of patients with scoliosis.

Other issues: The authors noted that a quantitative synthesis of data and sensitivity analysis were not possible because of the limited number of RCTs for ELIF, variability of outcome measures and the heterogeneity of methods used across the studies. Some studies are also included in the systematic review by Lehmen and Gerber EJ (2015); there is an overlap of approximately 2,000 patients treated by ELIF.

Key safety findings

Safety

Number of patients analysed: **2,342 ELIF versus 1,379 ALIF**

Reported adverse event rates (all studies)

- ELIF=16.6% (389/2,342)
- ALIF (all studies)=117.8% (1,506/1,379)
- ALIF (excluding FDA reports)=26.5% (144/544)

Comparison of adverse event rates between ELIF and ALIF with and without FDA reports

Type of adverse event	**ELIF n=2,342**	**ALIF without FDA reports n=544**			**ALIF with FDA reports n=1,379**		
	% (n)	% (n)	Risk ratio (95% CI)	p value	% (n)	Risk ratio (95% CI)	p value
Wound-related (psoas haematoma, infection)	0.64 (15)	1.29 (7)	0.50 (0.20 to 1.2)	0.1438	1.89 (26)	0.34 (0.18 to 0.64)	0.00067
Neurological (transient motor weakness, hypoaesthesia, transient or persistent thigh symptoms, injury to lumbosacral plexus, injury to femoral nerve)	8.9 (209)	5.0 (27)	1.8 (1.2 to 2.7)	0.0015	9.4 (130)	0.95 (0.77 to 1.17)	0.605
Cardiac (postoperative atrial fibrillation, myocardial infarction)	0.68 (16)	0.18 (1)	3.7 (0.49 to 28.0)	0.1697	1.8 (25)	0.38 (0.20 to 0.70)	0.002
Haematological (postoperative anaemia, hypotensive event treated with fluid bolus)	0.38 (9)	1.10 (6)	0.35 (0.12 to 0.98)	0.0598	0.87 (12)	0.44 (0.19 to 1.05)	0.0661
Deep vein thrombosis	0.04 (1)	0.74 (4)	0.06 (0.0065 to 0.52)	0.0056	0.36 (5)	0.12 (0.014 to 1.01)	0.0315
Respiratory (asthma, pneumothorax, pneumonia, pulmonary embolism)	0.68 (16)	0	37.2 (0.07 to 18620)	0.0413	0.94 (13)	0.73 (0.35 to 1.50)	0.391
Gastrointestinal (ileus, gastric volvulus, bowel injury)	1.07 (25)	0.55 (3)	1.94 (0.59 to 6.4)	0.2771	8.41 (116)	0.13 (0.08 to 0.20)	<0.0001
Renal (urinary tract infection, urinary retention)	0.51 (12)	0	27.9 (0.05 to 14050)	0.09	0.73 (10)	0.71 (0.31 to 1.63)	0.4214
Pseudarthrosis	0.13 (3)	2.57 (14)	0.05 (0.01 to 0.17)	<0.0001	1.02 (14)	0.13 (0.04 to 0.44)	0.00019
Adjacent level disease	0.30 (7)	2.21 (12)	0.14 (0.05 to 0.34)	<0.0001	0.94 (13)	0.32 (0.13 to 0.79)	0.01301
Intraoperative dural tears	0.13 (4)	0.55 (3)	0.23 (0.05 to 1.15)	0.09872	0.36 (5)	0.47 (0.13 to 1.75)	0.2779
Vertebral body (fracture, remote compression fracture)	0.77 (18)	0	41.8 (0.08 to 20890)	0.02744	0.22 (3)	3.53 (1.04 to 11.97)	0.02622
Hardware failure (cage subsidence or breakage, intraoperative pedicle fracture, implant bone interface failure)	1.32 (31)	3.13 (17)	0.42 (0.24 to 0.76)	0.00649	3.41 (47)	0.39 (0.25 to 0.61)	<0.0001
Secondary surgical procedure (revisions, supplemental fixations, reoperations)	1.71 (40)	4.60 (25)	0.37 (0.23 to 0.61)	0.0002	8.77 (121)	0.20 (0.14 to 0.28)	<0.0001

In the ELIF group, 43.1% [90/209] of the neurological adverse events resolved within 3 months of the procedure; 15.8% [33/209] lasted longer than 3 months and up to 2 years or throughout the last follow-up; there was no information on the remaining 41.1% [86/209] of complications. In the ALIF group, 48.1% [13/27] of the neurological adverse events resolved within 42 days of the procedure; 14.8% [4/27] were present more than 210 days postoperatively and 25.9% [7/27] were still present at 60 months follow-up.

There were 4 reported cases of vascular injury in the ALIF group and no reported vascular/blood vessel injuries in the ELIF group.

Overall rate of adverse events in ELIF studies: 16.3% (364/2227) in studies that reported using neuromonitoring and 21.7% (25/115) in studies that did not (p=0.1397). Rate of neurological complications in ELIF studies: 9.3% (207/2227) in studies that reported using neuromonitoring and 1.7% (2/115) in studies that did not (p=0.0015).

Abbreviations used: ALIF, anterior lumbar interbody fusion; ELIF, extreme lateral interbody fusion

Study 3 Joseph JR (2015)

Details

Study type	**Systematic review**
Country	Review does not report where individual studies were based
Recruitment period	Search date: May 2015
Study population and number	**n=96 studies (42 lateral lumbar interbody fusion [LLIF], 54 minimally invasive transforaminal lumbar interbody fusion [MI-TLIF]); 9,714 patients (4,260 versus 5,454)** Patients treated by LLIF or MI-TLIF (no indications specified)
Age and sex	Not reported
Patient selection criteria	Studies with a minimum of 10 patients that specifically mentioned complications were included. Publications from the same institutions or senior authors were checked for patient overlap. In these situations, the study with the largest number of patients or largest reported number of complications was included and the remaining studies were excluded. Studies that combined other fusion procedures in the analysis such as posterior lateral interbody fusion or anterior lumbar interbody fusion were excluded. Non-English-language studies were excluded.
Technique	Studies were only included if the procedure used tubular retractors rather than a 'mini-open' approach. On average, 1.69 levels were fused per patient in the LLIF group and 1.11 levels were fused per patient in the MI-TLIF group (p<0.001).
Follow-up	**Not reported**
Conflict of interest/source of funding	One author is a consultant for Medtronic, Biomet, and Globus and receives a royalty from Globus. Another author is a consultant f or Globus and Biomet and receives a royalty from Globus.

Analysis

Study design issues: The search was done through the PubMed database and reference lists were manually checked. The primary outcome of the review was total complication rate. Pain was not considered a complication and was not included in the analysis. Durotomies were considered intraoperative complications. Permanent neurological deficits were defined as motor deficit present at last follow-up. Studies that did not specifically mention the number of levels operated on were presumed to be single-level procedures. The authors noted there was a risk for publication bias. They also noted that the quality of data available was relatively poor, with a predominance of non-comparative retrospective studies. There were no RCTs or prospective comparative studies. The studies differed in their definition and reporting of complications and surgical techniques varied. If studies did not mention certain complications, it was assumed for the primary outcome analysis that those complications were not present rather than not reported.

Study population issues: The review does not report the indications for treatment.

Other issues: The LLIF procedures had a shorter overall follow-up period because LLIF is a newer technique than MI-TLIF. Some studies are also included in the systematic review by Lehmen and Gerber EJ (2015); there is an overlap of approximately 3,600 patients treated by LLIF.

Key safety findings

Safety

Number of patients analysed: **9,714 (4,260 versus 5,454)**

Comparison of total and specific complications between LLIF and MI-TLIF

	LLIF			MI-TLIF			
Complication	**No. of patients**	**No. of events**	**Rate/patient %**	**No. of patients**	**No. of events**	**Rate/patient %**	**p value**
Total	4,260	1,339	31.4	5,454	1,045	19.2	<0.0001
Sensory deficit	2,160	585	27.1	1,885	380	20.2	<0.0001
Temporary neurological deficit	2,957	278	9.4	1,349	30	2.2	<0.0001
Permanent neurological deficit	2,525	62	2.5	1,382	14	1.0	0.002
Intraoperative complication	2,181	42	1.9	3,587	128	3.6	0.0003
Medical complication	1,762	74	4.2	3,197	160	5.0	0.201
Wound complication	1,254	10	0.8	4,243	69	1.6	0.034
Hardware failure				2,887	63	2.2	
Subsidence	1,900	206	10.8				
Reoperation	2,193	82	3.7	4,693	201	4.3	0.29

Abbreviations used: LLIF, lateral lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion

Study 4 Smith WD (2012)

Details

Study type	**Non-randomised comparative study**
Country	US (2 centres)
Recruitment period	2004–08
Study population and number	**n=202 (115 extreme lateral interbody fusion [XLIF] versus 87 open anterior lumbar interbody fusion [ALIF])** Patients with low back pain
Age and sex	XLIF: 49% female; mean age 58.4 years ALIF: 53% female; mean age 46.1 years
Patient selection criteria	Not reported.
Technique	Extreme lateral interbody fusion was done using XLIF (NuVasive, US) with percutaneous bilateral pedicle screw fixation. Patients indicated for adjunctive L5-S1 fusion had concomitant percutaneous trans-sacral approach for discectomy and fusion (AxiALIF, TranS1, US). Intraoperative neurophysiological electromyography was used on all patients. Open anterior lumbar interbody fusion was done using Ocelot carbon fibre cages (DePuy Spine, US) or lumbar tapered fusion device (LT-Cage, Medtronic, US) and posterior bilateral pedicular fixation was done using a spinal fixation system. Grafting material in both groups included autograft with synthetic biological extenders or a local bone source with bone morphogenetic protein-2. There were 61 XLIF and 48 ALIF 1-level procedures (most commonly L4 to L5 and L5 to S1) and 54 XLIF and 39 ALIF 2-level procedures (most commonly L4 to S1).
Follow-up	**24 months (for a proportion of patients)**
Conflict of interest/source of funding	Not reported

Analysis

Follow-up issues: Long-term outcomes were measured in a subset of 52 XLIF patients and 43 ALIF patients. Data at 24 month follow-up was only available for 63.5% (33/52) of patients in the XLIF group and 65.1% (28/43) of patients in the ALIF group.

Study design issues: Data were collected from consecutive patients, identified partially through a prospective registry and partially through retrospective chart review. The primary aim of the study was to compare the costs of the 2 procedures; these data have not been extracted for the purposes of this overview. The secondary aim was to assess complication rates and functional outcomes.

Study population issues: Patients in the XLIF group were statistically significantly older than patients in the ALIF group (mean 58 versus 46 years, $p<0.001$). More patients in the XLIF group had prior spine surgery (38%) compared with those in the ALIF group (17%, $p=0.002$). The mean body mass index and rate of comorbidities were similar in both groups. Most patients in both groups had multiple diagnoses, including degenerative disc disease, stenosis, and post-laminectomy syndrome; 4 patients had degenerative scoliosis (all were in the XLIF group).

Other issues: This study is included in the systematic reviews by Härtl R et al. (2016) and Lehmen and Gerber EJ (2015).

Key efficacy and safety findings

Efficacy

Number of patients analysed: 202

Treatment characteristics

1-level procedures

	XLIF	ALIF	p value
Mean operative time (minutes)	93.4	150.6	<0.001
Mean estimated blood loss (ml)	79.1	241.7	<0.001
Mean length of hospital stay (hours)	36.3	71.9	<0.001

2-level procedures

	XLIF	ALIF	p value
Mean operative time (minutes)	121.8	186.4	<0.001
Mean estimated blood loss (ml)	95.6	353.8	<0.001
Mean length of hospital stay (hours)	42.6	95.9	<0.001

Mean low back pain score (0–10 scale, 0=no pain, 10=worst possible pain)

Follow-up	XLIF	ALIF	p value
Baseline	7.5 (n=52)	7.5 (n=43)	Not significant
6 months	2.7 (n=42)*	2.6 (n=31)*	Not significant
12 months	2.4 (n=33)*	2.6 (n=28)*	Not significant

*p<0.001 at all postoperative time points compared with baseline

Mean leg pain score (0–10 scale, 0=no pain, 10=worst possible pain)

Follow-up	XLIF	ALIF	p value
Baseline	5.8 (n=52)	5.4 (n=43)	Not significant
12 months	1.6 (n=33)*	2.0 (n=28)*	Not significant

*p<0.001 at all postoperative time points compared with baseline

Mean disability (Oswestry Disability Index)

Follow-up	XLIF	ALIF	p value
Baseline	58.6% (n=52)	58.9% (n=43)	Not significant
12 months	23.2% (n=33)	24.2% (n=28)	Not significant

*p<0.001 at all postoperative time points compared with baseline

Safety

Perioperative complications

Total:
- XLIF=8.2% (9/115)
- ALIF=16.7% (16/87), p=0.041

Minor complications:
- XLIF=5.2% (6/115)
- ALIF=10.3% (9/87), p=0.269

Posterior instrumentation infection:
- XLIF=0.9% (1/115)
- ALIF=5.7% (5/87), p=0.109

Deep vein thrombosis:
- XLIF=0% (0/115)
- ALIF=1.1% (1/87), p=0.888

Myocardial infarction:
- XLIF=0.9% (1/115)
- ALIF=0% (0/87), p=1.00

Pneumonia:
- XLIF=0.9% (1/115)
- ALIF=0% (0/87), p=1.00

Abbreviations used: ALIF, anterior lumbar interbody fusion; XLIF, extreme lateral interbody fusion

Study 5 Isaacs RE (2016) and Sembrano JN (2016)

Details

Study type	**RCT and non-randomised comparative study**
Country	US
Recruitment period	2009–12
Study population and number	**n=55** (29 minimally invasive lateral interbody fusion [XLIF] versus 26 minimally invasive transforaminal interbody fusion [TLIF]); randomised arm 15 XLIF versus 14 TLIF, non-randomised 14 XLIF versus 12 TLIF) Patients with degenerative spondylolisthesis with spinal stenosis
Age and sex	XLIF: mean 63 years; TLIF: mean 64 years XLIF: 55% female; TLIF: 58% female
Patient selection criteria	Age ≥18 years; symptomatic grade I or II degenerative spondylolisthesis at 1 or 2 contiguous lumbar levels between L1 and L5, and surgical candidate for interbody lumbar fusion surgery; symptoms include radiculopathy or neurogenic claudication with or without back pain; unresponsive to ≥6 months of conservative treatment or progressive neurological symptoms despite conservative treatment. Exclusion criteria included: lumbar pathologies needing treatment at more than 2 levels, previous lumbar fusion surgery, lytic spondylolisthesis or a defect of the pars interarticularis, radiographic confirmation of grade IV facet joint disease or degeneration, non-contained or extruded herniated nucleus pulposus, spinal metastases or active spinal tumour malignancy, active local or systemic infection, rheumatoid arthritis or other autoimmune disease, progressive neuromuscular disease.
Technique	XLIF: XLIF device (NuVasive Inc, US) was used with dynamically evoked discrete-threshold electromyography. After ipsilateral and contralateral annulotomy, discectomy and endplate preparation, a polyether-ether-ketone intervertebral spacer was inserted. A direct decompression was not done to allow for analysis of the effect of indirect decompression. Percutaneous bilateral pedicle screws were placed in all patients. TLIF: MAS TLIF device (NuVasive Inc, US) was used for the pedicle-based approach using a split blade retractor. A contralateral decompression was only done if it could be done through the ipsilateral incision. Contralateral percutaneous pedicle screws were used to complete the bilateral construct; contralateral facet fusion was optional. In 6 patients, a tubular rather than pedicle-based retractor was used. Allograft cellular bone matrix was used for 75% (21/29) XLIF procedures and 77% (20/26) TLIF procedures. Other graft material included autograft, bone marrow aspirate, demineralised bone matrix and corticocancellous chips.
Follow-up	**24 months**
Conflict of interest/source of funding	Funds were received from NuVasive Inc, US, to support the study.

Analysis

Follow-up issues: At 24 months, 76% (42/55) of patients were available for clinical and 71% (39/55) of patients were available for radiographical follow-up.

Study design issues: Prospective, multicentre study. Each patient was invited to participate in a randomised study, where the procedure was determined by a blinded allocation card. If the patient declined to participate, an observational enrolment option was given, where the procedure was chosen by the patient. Patient-reported outcomes were collected at baseline and each postoperative visit and included measures of disability (Oswestry disability index [ODI]), back and leg pain (visual analogue scale), and quality of life (SF-36 physical and mental component scores). MRI studies were done at baseline and after 3 months and a CT study was done after 12 months. Radiographical measurements were made by an independent imaging core lab, except for bridging bone, which was done by an independent spinal surgeon. A study sample size of 55 patients in each group was needed to detect a difference from 36.1 to 31.1 on the ODI. Low enrolment rates meant the study was not powered for each statistical interaction.

Study population issues: Baseline characteristics were similar between the 2 groups; there were statistically significantly more patients with diabetes mellitus in the XLIF group than in the TLIF group (28% versus 4%, p=0.027) and baseline low back pain was significantly higher in the XLIF group (7.3 versus 5.7, p=0.027).

Key efficacy and safety findings

Efficacy

Number of patients analysed: **55 (29 versus 26)**

Total procedural time and hospital stay were similar between the groups. Estimated blood loss was significantly lower in the XLIF than the TLIF group (79% versus 27% of patients respectively with <100 ml of blood loss, p<0.001).

Effect on pre-existing neural deficits

Pre-existing motor weakness resolved in 12/12 patients treated by XLIF and 7/9 patients treated by TLIF (p=0.171); pre-existing abnormal sensation resolved in 7/7 patients treated by XLIF and 5/5 patients treated by TLIF (p=0.417).

Clinical measures

	XLIF		TLIF		p value*
	Baseline	24 months	Baseline	24 months	
Low back pain (0-10 VAS, mean)	7.3	1.9	5.7	2.1	0.045
Leg pain (0-10 VAS, mean)	7.0	1.5	6.8	1.8	0.889
Oswestry Disability Index (mean)	43%	20%	44%	19%	0.455
SF-36 physical (mean)	37.7	61.4	39.5	64.9	Not reported
SF-36 mental (mean)	51	67.2	52.2	69.2	Not reported

* between groups at 24 months; within groups, all outcomes were statistically significantly improved (p<0.05)

Patient satisfaction

At 24 month follow-up, 91% of XLIF patients and 80% of TLIF patients were satisfied with their outcome (p=0.393) and 100% and 90% of patients respectively would be willing to have the same procedure had their outcome been known in advance (p=0.210).

Radiographic findings

Average disc height, mm (sd)

Time point	XLIF	TLIF	p value
Baseline	7.6 (1.9)	6.7 (2.3)	0.108
6 months	9.5 (2.2)*	7.9 (1.8)*	0.004
12 months	9.0 (2.1)*	7.7 (1.9)*	0.017
24 months	9.1 (2.3)*	7.4 (1.4)	0.003

***** p<0.05 compared with baseline

Canal dimensions

Time point	XLIF	TLIF	p value
Baseline	8.8 (sd 3.7) mm diam	9.4 (sd 2.8) mm diam	0.060
	135.1 (sd 62.8) mm^2 area	166.8 (sd 62.5) mm^2 area	0.482
3 months	10.0 (sd 3.4) mm diam	11.8 (sd 1.9) mm diam	<0.001
	153.9 (sd 63.0) mm^2 area	219.6 (sd 67.0) mm^2 area	0.012

Fusion results (by level)

	Time point	XLIF (36 levels)	TLIF (29 levels)	p value
Interbody bridging	12 months	100% (30/30)	88% (22/25)	0.088
	24 months	100% (28/28)	95% (19/20)	0.417
	Last evaluation	100% (32/32)	96% (25/26)	0.448
Fused (solid bridging and <3° range of motion)	12 months	100% (25/25)	74% (17/23)	0.008
	24 months	100% (27/27)	95% (18/19)	0.413
	Last evaluation	100% (30/30)	88% (21/24)	0.082

Safety

Adverse events

Postoperative hip flexion weakness

- XLIF=31% (9/29) (all resolved within 6 months)
- TLIF=0% (0/26), p<0.001

Postoperative distal motor weakness (neural)

- XLIF=3.5% (1/29) (resolved within 6 months)
- TLIF=0% (0/26), p=1.000

Postoperative sensory deficit (neural)

- XLIF=10.3% (3/29) (1 resolved within 6 months, all resolved within 12 months)
- TLIF=7.7% (2/26) (both resolved by 6 months), p=1.000

Ileus

- XLIF=7.0% (2/29)
- TLIF=0% (0/26)

Other adverse events included 3 instances of dural tear, 1 intraoperative pedicle fracture, and 1 pseudoarthrosis (revised at 15 months postoperatively) in the TLIF group.

Graft migration at 12 month follow-up

- XLIF=0% (0/30)
- TLIF=4% (1/26), p=0.207

Graft migration at 24 month follow-up

- XLIF=0% (0/29)
- TLIF=5% (1/21), p=0.167

Graft subsidence at 12 month follow-up

- XLIF=3% (1/30)
- TLIF=4% (1/26), p=0.456

Graft subsidence at 24 month follow-up

- XLIF=3% (1/29)
- TLIF=10% (2/21), p=0.268

Abbreviations used: sd, standard deviation; TLIF, transforaminal lumbar interbody fusion; XLIF, extreme lateral interbody fusion

Study 6 Hrabalek L (2014)

Details

Study type	**Non-randomised comparative study**
Country	Czech Republic
Recruitment period	1996–2011
Study population and number	n=**208** (88 lateral interbody fusion [XLIF] versus 120 anterior lumbar interbody fusion [ALIF]) Patients with low back pain
Age and sex	XLIF: mean 51 years (range 17–74); ALIF: mean 44 years (range 17–76) XLIF: 57% (50/88) female; ALIF: 44% (53/120) female
Patient selection criteria	Patients with low back pain; diagnoses included degenerative disc disease, failed back surgery syndrome, spondylolisthesis, retrolisthesis, and post-traumatic disc injury. In most patients, symptoms were refractory to conservative management for a minimum of 6 months. Contraindications were severe osteoporosis, tumour, infection, fresh fracture of the spine, spondylolisthesis of grades III or IV and significant stenosis.
Technique	XLIF: triggered electromyography was used for intraoperative neuromonitoring. Discectomy and endplate preparation was followed by implant of PEEK spacer. Artificial bone filled by the patient's blood and bone marrow was impacted in the spacer. 92 levels were operated on: L5–6 (n=3), L4–5 (n=57), L3–4 (n=12), L2–3 (n=11), L1–2 (n=6), T12–L1 (n=3) ALIF: Titanium or PEEK spacers were used with cancellous bone from the iliac crest and from the removed parts of the vertebral bodies, and artificial bone. At least 1 patient in this group had a total disc replacement. 128 levels were operated on: L4–5 (n=79), L3–4 (n=19), L2–3 (n=13), L1–2 (n=14), T12–L1 (n=3) Concomitant anterior plating or posterior spinal fusion and instrumentation was done as necessary.
Follow-up	**minimum 6 months**
Conflict of interest/source of funding	Not reported

Analysis

Follow-up issues: Patients were only included if they had at least 6 months follow-up.

Study design issues: All complications were prospectively documented. Any patient with signs or symptoms of lumbar sympathectomy was tested using thermography at least 2 months after surgery. The aim of the study was to compare complication rates between the 2 approaches.

Key efficacy and safety findings

Efficacy	Safety
Number of patients analysed: **208 (88 versus 120)** 95.2% (198/208) of patients were satisfied with the procedure and reported improvement. Ten patients were not improved or were worsened (radiological and clinical results were similar in both groups).	***Major complications*** • XLIF=1.1% (1/88) (partial and transient injury to the L5 nerve root during implant insertion at level L4–5. Intraoperative neuromonitoring was not yet being used in this first case.) • ALIF=0% (0/120) ***Minor complications*** **XLIF=24% (21/88)** • Transient pain of left groin or anterior thigh=12.5% (11/88) • Numbness of left anterolateral thigh or groin=10.2% (9/88) • Lumbar post-sympathectomy syndrome=4.5% (4/88) (including 3 cases at level L4/5 and 1 case at level L5/6) **ALIF=27% (32/120)** • Small peritoneal opening without visceral injury=2.5% (3/120) • Pleural opening at level T12–L1=0.8% (1/120) • Injury to the iliolumbal vein without excessive bleeding and with subsequent ligation=0.8% (1/120) • Lumbar post-sympathectomy syndrome=15.8% (19/120) (including 15 cases at level L4/5, 2 cases at level L3/4 and 2 cases at level L2/3) • Transient pain of left groin=3.3% (4/120) • Numbness of left anterolateral thigh or groin=5% (6/120) • Seroma of the wound from the donor side=0.8% (1/120) **Adjacent segment disease** • XLIF=0% (0/88) • ALIF=2.5% (3/120) (after 4 or 5 years)
Abbreviations used: ALIF, anterior lumbar interbody fusion; XLIF, lateral interbody fusion	

Study 7 Khajavi K (2015)

Details

Study type	**Case series**
Country	US
Recruitment period	2008–12
Study population and number	**n=160** Patients with degenerative spondylolisthesis (n=68), degenerative disc disease (n=20), adjacent segment disease (n=26), or post-laminectomy syndrome (n=46)
Age and sex	Mean 61 years; 66% female
Patient selection criteria	Exclusion criteria: patients with scoliosis, tumour, vertebral body fracture, discitis, or pseudarthrosis. Patients treated outside of L1–5 levels were also excluded. Treatment for L5–6 was decided on a case-by-case basis.
Technique	Mini-open lateral transpsoas approach (XLIF, NuVasive Inc, US). 197 levels were treated (114 L4–5, 49 L3–4). Direct posterior decompressions were done in 41% (65/160) of patients. Supplemental percutaneous posterior fixation was used in 88% (140/160) of patients.
Follow-up	**Mean 18.5 months**
Conflict of interest/source of funding	The main author is a consultant for and has received research funds from NuVasive Inc, though none related to the current study.

Analysis

Study design issues: Data were collected at a single centre as part of a prospective registry. The aim of the study was to compare interim clinical improvements in patients treated by XLIF for various degenerative lumbar conditions. Clinical outcomes included the Oswestry Disability Index (ODI), numeric rating scale (NRS) for low back pain and leg pain and short form-36 (SF-36) physical and mental component. Postoperative approach-related thigh/groin sensory changes or hip flexion weakness, were considered to be complications in the presence of clear neurological deficit or if hospital admission or surgical intervention was needed. Otherwise, cases of transient nerve-related pain or mechanical hip flexion weakness were classified as side effects.

Study population issues: Statistically significantly more patients with degenerative spondylolisthesis had an additional posterior procedure (decompression, fixation, or both) compared with patients in the degenerative disc disease group (100% versus 60%, $p<0.001$). The mean age was highest for patients in the adjacent segment disease group (66 years) and lowest in the degenerative disc disease group (48 years, $p<0.001$). Baseline ODI score was lower for degenerative disc disease patients ($p=0.052$). There were no other baseline differences between the groups.

Other issues: this study is included in the systematic review by Joseph JR et al. (2015).

Key efficacy and safety findings

Efficacy

Number of patients analysed: **160**

Mean operative time=171 minutes
Mean blood loss=73 ml
postoperative length of stay=1.3 days

Self-reported mean clinical scores and improvements for all patients

	Oswestry Disability Score	Low back pain	Leg pain	SF-36 physical component score
Baseline	44.1	6.9	7.1	30.9
Last follow-up	23.5	2.8	3.1	43.2

Self-reported clinical scores and improvements by diagnosis, mean±sd

	Adjacent segment disease	post-laminectomy syndrome	degenerative disc disease	degenerative spondylolisthesis	p value
ODI					
Baseline	49.1±2.7	45.9±2.3	38.1±3.3	42.7±1.7	0.052
Last follow-up	31.7±3.7	24.8±3.1	22.3±4.5	19.9±2.4	0.066
Improvement (%)	36.2±8.3	46.4±6.9	46.5±10.0	50.8±5.2	0.532
Low back pain					
Baseline	7.3±0.5	6.8±3.8	6.4±0.6	7.0±0.3	0.705
Last follow-up	4.1±0.5	2.7±0.3	2.8±0.5	2.4±0.3	0.021
Improvement (%)	42.0±7.2	56.0±5.3	59.1±8.5	62.8±4.3	0.110
Leg pain					
Baseline	7.1±0.5	7.3±0.4	6.4±0.6	7.1±0.3	0.619
Last follow-up	3.8±0.6	3.0±0.5	2.7±0.7	3.1±0.4	0.659
Improvement (%)	43.3±8.9	55.1±6.9	58.4±10.2	54.5±5.3	0.651
SF-36 physical component score					
Baseline	29.6±1.6	30.1±1.3	33.4±1.8	31.2±1.0	0.422
Last follow-up	39.4±2.1	41.7±1.8	44.5±2.4	45.2±1.0	0.083
Improvement (%)	40.5±10.2	44.9±8.7	44.7±11.9	51.9±6.4	

Percentage of patients reaching minimum clinically important difference (MCID) and substantial clinical benefit (SCB)

	Adjacent segment disease	post-laminectomy syndrome	degenerative disc disease	degenerative spondylolisthesis	p value	Total n=160
ODI						
MCID	60.0	69.4	64.7	76.2	0.461	70.2
SCB	60.0	69.4	62.5	77.8	0.327	70.7
Low back pain						
MCID	75.0	81.4	83.3	92.5	0.140	85.5
SCB	70.8	74.4	83.3	92.5	0.029	82.9
Leg pain						
MCID	70.0	80.0	72.3	82.1	0.727	80.0
SCB	68.0	73.2	77.8	70.1	0.894	71.5
SF-36 physical component score						
MCID	65.2	71.9	64.7	88.1	0.486	77.1
SCB	73.9	75.0	76.5	94.9	0.022	84.0

Safety

Major complications=0.6% (1/160)

- Myocardial infarction=0.6% (1/160)

Minor complications=11.9% (19/160)

- Dural tear=2.5% (4/160)
- Transient dorsiflexion weakness=1.9% (3/160)
- Urinary retention=1.9% (3/160)
- Anaemia needing transfusion=1.9% (3/160)
- Vertebral body fracture=1.3% (2/160)
- Superficial wound dehiscence=1.9% (3/160)
- Urinary incontinence=0.6% (1/160)

Side effects=22.6% (36/160)

- Approach-related thigh/groin pain=13.8% (22/160)
- Hip flexion=8.8% (14/160)

All resolved within 6 months without additional intervention or sequelae.

There were no statistically significant differences between complication rate or approach-related side effects between the diagnosis groups.

Abbreviations used: MCID, minimum clinically important difference; ODI, Oswestry Disability Index; SCB, substantial clinical benefit

Study 8 Lykissas MG (2014)

Details

Study type	**Case series**
Country	US
Recruitment period	2006–12
Study population and number	**n=144** (Group 1: 72 lateral interbody fusion with recombinant human bone morphogenetic protein-2 [rhBMP-2] versus Group 2: 72 lateral interbody fusion with cancellous allograft or iliac crest autograft). Patients with degenerative spinal conditions.
Age and sex	Group 1: mean age 65 years; 53% (38/72) female Group 2: mean age 67 years; 53% (38/72) female
Patient selection criteria	Inclusion criteria: patients treated by lateral lumbar interbody fusion with the supplementary use of recombinant human bone morphogenetic protein-2 (rhBMP-2), cancellous autograft, or iliac crest bone autograft for stimulation of bone growth; patients with degenerative spinal conditions; follow-up longer than 6 months. Patients with prior thoracolumbar spine surgery were excluded.
Technique	Lateral retroperitoneal transpsoas approach and lumbar interbody fusion at 1 or more levels using either the extreme lateral interbody fusion system (XLIF, NuVasive Inc, US) or the COUGAR system (DePuy Spine Inc, US). Intraoperative electromyography and active-run electromyography were used in every patient. Patients were divided into 2 groups according to rhBMP-2 use. In group 1, rhBMP-2 was applied in a total of 147 levels: 33.3% L3–4, 30.6% L4–5, 26.5% L2–3, 8.8% L1–2, 0.7% T12–L1. Supplemental internal fixation with posterior pedicle screws or other interbody fusion procedures were used in 53% (38/72) of patients. In group 2, cancellous allograft or iliac crest autograft was used in a total of 147 levels: 33.3% L3–4, 29.9% L4–5, 27.2% L2–3, 8.8% L1–2, 0.7% T12–L1. A stand-alone lateral interbody fusion was done in 47% (34/72) of patients.
Follow-up	**Mean 15.5 months (range 6–53)**
Conflict of interest/source of funding	The study was funded internally though the spine surgery service at the study centre. Author disclosures not related to the study include royalties, grant, consulting and stock ownership for a number of companies including DePuy Spine, LifeSpine, Ortho Development Corp., RTI Biologics Inc, Spineview, NuVasive Inc, and Ethicon.

Analysis

Follow-up issues: Patients were only included if they had at least 6 months follow-up.

Study design issues: Patient records were retrospectively reviewed. Patients were divided into 2 groups: group 1 (rhBMP-2 use, n=72) and group 2 (autograft/allograft use; n=72) and were matched by age, gender, weight, body mass index, side of approach, total number of treated segments, use of supplemental posterior fusion, and length of follow-up. The presence of anterior thigh or groin pain was recorded at each postoperative visit.

Study population issues: The proportion of preoperative sensory and motor deficits was similar between the 2 groups.

Other issues: This study is included in the systematic reviews by Lehmen and Gerber EJ (2015) and Joseph JR (2015).

Key efficacy and safety findings

Efficacy	Safety
Number of patients analysed: **144**	**Sensory deficit immediately after procedure** • Group 1=45.8% (33/72) • Group 2=48.6% (35/72) Odds ratio 0.895, 90% CI 0.516 to 1.550, p=0.739, NNH=36 **Persistent sensory deficit in the lower extremities at last follow-up** • Group 1=40.3% (29/72) • Group 2=27.8% (20/72) Odds ratio 1.754, 90% CI 0.976 to 3.151, p=0.115, NNH=8 **Motor deficit in the lower extremities immediately after procedure** • Group 1=51.4% (37/72) • Group 2=38.9% (28/72) Odds ratio 1.661, 90% CI 0.953 to 2.895, p=0.133, NNH=8 **Persistent motor deficit in the lower extremities at last follow-up** • Group 1=48.6% (35/72) • Group 2=23.6% (17/72) Odds ratio 3.060, 90% CI 1.681 to 5.571, p=0.002, NNH=4 **Anterior thigh or groin pain immediately after procedure** • Group 1=51.4% (37/72) • Group 2=34.7% (25/72) Odds ratio 1.987, 90% CI 1.133 to 3.488, p=0.045, NNH=6 **Persistent anterior thigh or groin pain at last follow-up** • Group 1=11.1% (8/72) • Group 2=0% (0/72) Odds ratio 16.470, 90% CI 1.477 to 183.700, p=0.006, NNH=9
Abbreviations used: NNH, number needed to harm	

Study 9 Kueper J (2015)

Details

Study type	**Case series**
Country	US
Recruitment period	2006–13
Study population and number	**n=900** Patients who underwent a lateral lumbar interbody fusion (indications not described). The 5 patients with vascular injury had degenerative scoliosis, spondylolisthesis, spondylosis, thoracic scoliosis, degenerative disc disease, spinal stenosis, and junctional level degeneration above a prior posterior lumbar interbody fusion.
Age and sex	Mean 62 years (range 27–91); 59% (528/900) female
Patient selection criteria	Not reported
Technique	Single-incision mini-open approach for lateral lumbar interbody fusion. Mean 1.9 levels treated per patient (range 1–5); 1 level T9–10, 16 level T12–L1, 163 level L1–2, 436 level L2–3, 584 level L3–4, 553 level L4–5, 1 level L5–S1.
Follow-up	**Not reported**
Conflict of interest/source of funding	None

Other issues: This study is included in the systematic review by Lehmen and Gerber EJ (2015).

Analysis

Key efficacy and safety findings

Safety
Number of patients analysed: **900** **Major vascular complications=0.1% (1/900)** Laceration of the abdominal aorta – emergently repaired through an exploratory laparotomy. **Minor vascular complications=0.4% (4/900)** All minor vascular injuries were segmental vessel lacerations, which were readily ligated under direct visualisation without further extension of the incision with no clinical sequelae. None of the patients had long-term sequelae from their intraoperative vascular injuries.

Study 10 Galan TV (2012)

Details

Study type	**Case report**
Country	US
Recruitment period	Not reported
Study population and number	**n=1** Patient with incisional hernia after extreme lateral interbody fusion
Age and sex	75 year old woman
Patient selection criteria	Not applicable
Technique	L4–5 discectomy with an extreme lateral interbody fusion via a retroperitoneal transpsoas approach, supplemented with posterior instrumented fusion.
Follow-up	**4 weeks**
Conflict of interest/source of funding	Three authors have nothing to disclose. The other 3 author disclosures include consulting, speaking or teaching arrangements, travel, grants, fellowship support, royalties, for companies including Synthes, Depuy, AO Spine, Osteotech, Lanx, Trans1, and Medtronic.

Other issues: This study is included in the systematic review by Lehmen and Gerber EJ (2015).

Key efficacy and safety findings

Incisional hernia

The patient had a history of low back and left lower-extremity pain with radiographic evidence of foraminal stenosis and degenerative spondylolisthesis (grade I). She was treated by L4–5 discectomy with an extreme lateral interbody fusion via a retroperitoneal transpsoas approach, supplemented with posterior instrumented fusion.

The patient reported significant relief of her back and lower-extremity pain during the follow-up visits. Approximately 4 weeks after surgery, the patient noticed a tender prominence over the lateral surgical incision on her flank. A CT scan showed a hernia with the sigmoid colon pushing through the transversalis fascia and attenuation of the oblique muscle layers.

The hernia was successfully repaired by laparoscopy.

Study 11 Murray MR (2012)

Details

Study type	**Case report**
Country	US
Recruitment period	Not reported
Study population and number	**n=1** Patient with an abscess at the site of a haematoma after direct lateral interbody fusion
Age and sex	63-year-old woman
Patient selection criteria	Not applicable
Technique	L2–5 direct lateral interbody fusion followed 2 days later by an L2–4 posterior decompression and a T10–S1 fusion with posterior segmental instrumentation.
Follow-up	**8 months**
Conflict of interest/source of funding	The first author has nothing to disclose. The other 2 author disclosures include stock ownership, speaking or teaching arrangements, travel, and board of directors for companies including Zimmer, DePuy, Stryker, Orthopaedic Leadership Institute, and Medtronic.

Other issues: This study is included in the systematic review by Lehmen and Gerber EJ (2015).

Key efficacy and safety findings

Abscess at the site of a haematoma

The patient developed a large retroperitoneal haematoma after an L2–5 direct lateral interbody fusion, which was managed conservatively. During the patient's stay in hospital, an asymptomatic urinary tract infection was detected; the urine culture was positive for *Pseudomonas*. This was treated with oral antibiotics. At 8-month follow-up, the patient reported persistent low-grade fevers and a gradually enlarging, uncomfortable palpable mass in her right flank. An MRI showed a fluid collection with no continuity with the spinal canal. The collection was aspirated and cultured, and *Pseudomonas* was isolated. The patient was treated with oral antibiotics and recovered without further sequelae.

Study 12 Santillan A (2010)

Details

Study type	**Case report**
Country	US
Recruitment period	Not reported
Study population and number	**n=1** Patient with lumbar artery pseudoaneurysm after extreme lateral interbody fusion
Age and sex	55-year-old man
Patient selection criteria	Not applicable
Technique	Extreme lateral interbody fusion at the L2–3 level.
Follow-up	**4 days**
Conflict of interest/source of funding	None

Other issues: This study is included in the systematic review by Lehmen and Gerber EJ (2015).

Key efficacy and safety findings

Lumbar artery pseudoaneurysm

The patient was diagnosed with a large left retroperitoneal haematoma on CT, 48 hours after an extreme lateral interbody fusion at the L2–3 level. The patient was resuscitated with fluids and blood products for haemorrhagic shock and was referred for catheter spinal angiogram. The angiogram showed irregular contour of the proximal left L2 lumbar artery adjacent to the superior left lateral fixation screw, consistent with localised arterial wall disruption and traumatic pseudoaneurysm. Two helical platinum coils were deployed to obstruct flow past the pseudoaneurysm and liquid embolisation was used to occlude the pseudoaneurysm. The patient was discharged home 2 days later.

Study 13 Assina R (2014)

Details

Study type	**Case report**
Country	US
Recruitment period	Not reported
Study population and number	**n=1** Patient with major vascular injury after extreme lateral interbody fusion
Age and sex	50-year-old woman
Patient selection criteria	Not applicable
Technique	Extreme lateral interbody fusion at the L4–5 level.
Follow-up	**None**
Conflict of interest/source of funding	None

Other issues: This study is included in the systematic review by Lehmen and Gerber EJ (2015).

Key efficacy and safety findings

Major vascular injury leading to fatality

The patient's medical history was significant for hypertension, coronary artery disease, peripheral vascular disease, hypercholesterolaemia, and depression. During an extreme lateral interbody fusion to treat an L4-5 degenerated disc, the patient had a massive, exsanguinating, retroperitoneal haemorrhage. The surgeon noticed that the anterior detachable blade of a retractor had advanced ventral to the L4-5 disc space. The patient was transferred for emergency surgery with the retractor left in place.

The retractor tip had transected the right common iliac vein and was within the lumen of the left common iliac vein. Massive blood loss occurred and it was noted that there were many areas of perforation along the distal inferior vena cava. There was a significant portion of the right common iliac vein missing as well as a large defect in the proximal left common iliac vein. The right internal and external iliac veins were also injured. The inferior vena cava and the left common iliac defects were repaired but the right iliac venous drainage could not be salvaged because of the extensive damage caused by the detachable retractor blade.

The patient had bilateral lower-extremity full compartment fasciotomy and was transferred to the intensive care unit with an open abdomen and a negative-pressure wound vacuum in place. Over the course of the next 4 weeks, the patient returned to the operating theatre 5 times. She was eventually discharged to a rehabilitation facility but returned to hospital after 7 days with a retroperitoneal abscess and bacteraemia. A few days later, she died from multiple organ failure secondary to septic shock.

Study 14 Morr S (2013)

Details

Study type	**Case report**
Country	US
Recruitment period	Not reported
Study population and number	**n=1** Patient with complex regional pain syndrome after lateral lumbar interbody fusion for symptomatic degenerative spondylolisthesis.
Age and sex	42-year-old man
Patient selection criteria	Not applicable
Technique	Stand-alone lateral interbody fusion at the L4–5 level, with placement of PEEK interbody graft filled with morcellised allograft.
Follow-up	**None**
Conflict of interest/source of funding	One author is a consultant to Lanx and Synthes.

Other issues: This study is included in the systematic review by Lehmen and Gerber EJ (2015).

Key efficacy and safety findings

Complex regional pain syndrome
Postoperatively, the patient experienced significant improvement in his symptoms. A CT scan confirmed proper placement of the cage, and successful restoration of interbody height and alignment. On postoperative day 4, the patient had new-onset mild burning and warmth in the left foot. There was discolouration of the leg and foot, mild swelling, warmth and increased sensitivity to touch. The symptoms were treated conservatively with close observation, limb elevation at night, and limited pain medication. They resolved within 8 weeks.

Study 15 Balsano M (2015)

Details

Study type	**Case report**
Country	Italy
Recruitment period	Not reported
Study population and number	**n=1** Patient with bowel perforation after extreme lateral lumbar interbody fusion for symptomatic degenerative disc disease.
Age and sex	70-year-old man
Patient selection criteria	Not applicable
Technique	2-level XLIF (NuVasive Inc, US) at L3–L4 and L4–L5 without supplemental internal fixation.
Follow-up	**None**
Conflict of interest/source of funding	None

Key efficacy and safety findings

Bowel perforation

After completing the L4–L5 level, the retractor was removed and the L3–L4 disc was approached. Following completion of the L3–L4 level, the retractor was removed and no peritoneal violations were evident upon inspection. On postoperative day 1, the patient was neurologically intact and haematologically stable but had a fever of 38.4°C. Antibacterial and antipyretic therapy was started. The patient continued to progress, with worsening nausea, severe abdominal pain and a bloated belly. A laparotomy revealed perforation of the splenic curvature of the colon. A temporary colostomy was done because of peritonitis, and kept for 3 months. After this, the colostomy was closed and the patient fully recovered, with normal functioning of the bowel.

Efficacy

Fusion

In a systematic review of 237 articles on lateral lumbar interbody fusion, the weighted average for the rate of fusion in all patients was 94% (n=907 patients, 22 study arms)[1].

Pain

In the systematic review of 237 articles, the weighted average for improvement in pain, measured on a visual analogue scale, was 60% (n=2,097 patients, 41 study arms)[1]. In a non-randomised comparative study of 202 patients treated by extreme lateral interbody fusion (XLIF) or open anterior lumbar interbody fusion (ALIF), low back pain scores, measured on a scale 0–10, improved from 7.5 at baseline in both groups (n=95) to 2.4 and 2.6 respectively at 12-month follow-up (n=61; p<0.001 compared with baseline; p=not significant for between group comparison)[4]. Mean leg pain, measured on a scale 0–10, improved from 5.8 in the XLIF group and 5.4 in the ALIF group at baseline (n=95) to 1.6 and 2.0 respectively at 12-month follow-up (n=61), in the same study (p<0.001 compared with baseline; p=not significant for between group comparison)[4]. In an RCT and non-randomised comparative study of 55 patients treated by XLIF or transforaminal interbody fusion (TLIF), mean low back pain scores improved from 7.3 and 5.7 at baseline to 1.9 and 2.1 respectively at 24 month follow-up (p=0.045 between groups at 24 months and p<0.05 within groups)[5]. Mean leg pain scores improved from 7.0 and 6.8 at baseline to 1.5 and 1.8 respectively at 24 month follow-up (p=0.889 between groups at 24 months and p<0.05 within groups), in the same study[5]. In a case series of 160 patients, the mean scores for low back pain and leg pain improved from 6.9 and 7.1 at baseline to 2.8 and 3.1 respectively at the last follow-up (mean follow-up 18.5 months; p values not reported)[7].

Disability

In the systematic review of 237 articles, the weighted average for improvement in disability, measured on the Oswestry Disability Index (ODI), was 48% (n=1,234 patients, 29 study arms)[1]. In the non-randomised comparative study of 202 patients treated by XLIF or ALIF, the ODI improved from 59% at baseline in both groups (n=95) to 23% and 24% respectively at 12 month follow-up (n=61; p<0.001 compared with baseline; p=not significant for between group comparison)[4]. In the RCT and non-randomised comparative study of 55 patients treated by XLIF or TLIF, the ODI improved from 43% and 44% at baseline to 20% and 19% respectively at 24 month follow-up (p<0.05 compared with baseline; p=0.455 for between group comparison)[5]. In the case series of 160 patients, the ODI improved from 44% at baseline to 23.5% at the last follow-up (mean follow-up 18.5 months; p value not reported)[7].

Patient satisfaction

In the systematic review of 237 articles, the weighted average for patient satisfaction was 89% (n=491 patients, 9 study arms); 85% of patients indicated that they would have the procedure again if their outcome had been known in advance[1]. In the RCT and non-randomised comparative study of 55 patients treated by XLIF or TLIF, 91% and 80% of patients respectively were satisfied with their outcome at 24 month follow-up (p=0.393) and 100% and 90% of patients respectively would be willing to have the same procedure had their outcome been known in advance (p=0.210)[5]. In a non-randomised comparative study of 208 patients treated by XLIF or ALIF, 95% (198/208) of patients were satisfied with the procedure and reported improvement; 10 patients were not improved or were worsened (radiological and clinical results were similar in both groups)[6].

Quality of life

In the RCT and non-randomised comparative study of 55 patients treated by XLIF or TLIF, mean quality of life scores for the SF-36 physical component improved from 37.7 and 39.5 respectively at baseline to 61.4 and 64.9 at 24 month follow-up (p<0.05 compared with baseline); mean quality of life scores for the SF-36 mental component improved from 51 and 52.2 respectively at baseline to 67.2 and 69.2 at 24 month follow-up (p<0.05 compared with baseline)[5]. In the case series of 160 patients, the SF-36 physical component score improved from 30.9 at baseline to 43.2 at the last follow-up (mean follow-up 18.5 months; p value not reported)[7].

Safety

Neurological adverse events

In a systematic review of 237 articles, the weighted averages for thigh side effects, hip flexion weakness and motor neural deficits were 26% (n=2,772), 21% (n=1,360 patients, 22 study arms) and 17% (n=1,568, 14 study arms) respectively[1]. In a systematic review of 34 studies, neurological adverse events (transient motor weakness, hypoaesthesia, transient or persistent thigh symptoms, injury to lumbosacral plexus, injury to femoral nerve) were reported in 9% (209/2,342) of patients treated by extreme lateral interbody fusion (ELIF) compared with 5% (27/544) of patients treated by anterior lumbar interbody fusion (ALIF) when FDA reports were excluded (p=0.0015) and 9% (130/1,379) of patients treated by ALIF when FDA reports were included (p=0.605)[2]. In the ELIF group, 43% (90/209) of the neurological adverse events resolved within 3 months of the procedure, 16% (33/209) lasted longer than 3 months and up to 2 years or throughout the last follow-up; there was no information on the remaining 41% (86/209) of complications. Sensory deficit was reported in 27% (585/2160) of patients treated by lateral lumbar interbody fusion (LLIF) compared with 20% (380/1885) of patients treated by minimally invasive transforaminal lumbar interbody fusion (MI-LIF, p<0.0001) in a systematic review of 96 studies

(9,714 patients)[3]. Temporary neurological deficit was reported in 9% (278/2,957) of patients treated by LLIF and 2% (30/1,349) of patients treated by MI-LIF (p<0.0001) and permanent neurological deficit was reported in 3% (62/2,525) and 1% (14/1,382) of patients respectively (p=0.002), in the same study.

Postoperative hip flexion weakness was reported in 31% (9/29) of patients treated by XLIF and in no patients treated by TLIF in an RCT and non-randomised comparative study of 55 patients (p<0.001); all resolved within 6 months[5]. Postoperative distal motor weakness was reported in 3.5% (1/29) and 0% (0/26) of patients respectively (p=1.00) and sensory deficit was reported in 10% (3/29) and 8% (2/26) of patients respectively (p=1.00), in the same study; all resolved within 12 months. A partial and transient injury to the L5 nerve root during implant insertion at level L4–5 was reported in 1 patient treated by XLIF in a non-randomised comparative study of 208 patients; intraoperative neuromonitoring was not yet being used in this first case[6]. Transient dorsiflexion weakness was reported in 2% (3/160) of patients in a case series of 160 patients[7]. Persistent sensory deficit in the lower extremities at the last follow-up (mean 16 months) was reported in 40% (29/72) of patients treated by lateral interbody fusion using recombinant human bone morphogenetic protein-2 (rhBMP-2) and 28% (20/72) of patients treated by lateral interbody fusion using cancellous allograft or iliac crest autograft (p=0.115) in a case series of 144 patients[8]. Persistent motor deficit was reported in 49% (35/72) of patients treated by lateral interbody fusion using rhBMP-2 and 24% (17/72) of patients treated by lateral interbody fusion using cancellous allograft or iliac crest autograft (p=0.002), in the same study[8]. Transient numbness in the thigh or groin was reported in 10% (9/88) of patients treated by XLIF in a non-randomised comparative study of 208 patients[6].

Thigh or groin pain

Transient pain of the groin or thigh was reported in 13% (11/88) of patients treated by XLIF in the non-randomised comparative study of 208 patients[6]. Approach-related thigh or groin pain was reported in 14% (22/160) of patients in the case series of 160 patients[7]. Persistent thigh or groin pain was reported in 11% (8/72) of patients treated by lateral interbody fusion using rhBMP-2 and 0% (0/72) of patients treated by lateral interbody fusion using cancellous allograft or iliac crest autograft (p=0.006)[8].

Reoperations

In the systematic review of 237 articles, the weighted average for reoperations was 6% (n=2,080 patients, 24 study arms)[1]. A secondary surgical procedure (revisions, supplemental fixations, reoperations) was reported in 2% (40/2,342) of patients treated by ELIF compared with 5% (25/544) of patients treated by ALIF when FDA reports were excluded (p=0.0002) and 9% (121/1,379) of patients treated by ALIF when FDA reports were included (p<0.0001) in the systematic review of 34 studies[2].

Vascular injury

Laceration of the abdominal aorta was reported in 1 patient in a case series of 900 patients; this was emergently repaired through an exploratory laparotomy[9]. Segmental vessel lacerations were reported in <1% (4/900) of patients in the same study; all were ligated under direct visualisation without further extension of the incision with no clinical sequelae. Major vascular injury was reported in a case report; a detachable retractor blade caused extensive damage to the iliac veins, the patient experienced massive blood loss and died a few weeks later from multiple organ failure secondary to septic shock[13]. Lumbar artery pseudoaneurysm, which was successfully treated by embolisation, was reported in 1 patient in a case report[12].

Wound-related complications

Wound-related complications (psoas haematoma, infection) were reported in <1% (15/2,342) of patients treated by ELIF, <1% (7/544) of patients treated by ALIF when FDA reports were excluded (p=0.1438) and 2% (26/1,379) of patients treated by ALIF when FDA reports were included (p=0.00067) in the systematic review of 34 studies[2]. Superficial wound dehiscence was reported in 2% (3/160) of patients in a case series of 160 patients[7]. Incisional hernia was reported in 1 patient in a case report; the hernia was successfully repaired by laparoscopy[10]. Abscess at the site of a haematoma was reported in 1 patient in a case report; the patient was treated with oral antibiotics and recovered without further sequelae[11].

Gastrointestinal complications

Gastrointestinal complications (ileus, gastric volvulus, bowel injury) were reported in 1% (25/2,342) of patients treated by ELIF, <1% (3/544) of patients treated by ALIF when FDA reports were excluded (p=0.2771) and 8% (116/1,379) of patients treated by ALIF when FDA reports were included (p<0.0001) in the systematic review of 34 studies[2]. Ileus was reported in 7% (2/29) of patients treated by XLIF and no patients treated by transforaminal interbody fusion (TLIF) in the RCT and non-randomised comparative study of 55 patients[5]. Bowel perforation after extreme lateral lumbar interbody fusion was described in a case report: the patient had a temporary colostomy for 3 months before making a full recovery[15].

Renal complications

Renal complications (urinary tract infection or urinary retention) were reported in 1% (12/2,342) of patients treated by ELIF, no patients treated by ALIF when FDA reports were excluded (p=0.09) and 1% (10/1,379) of patients treated by ALIF when FDA reports were included (p=0.4214) in the systematic review of 34 studies[2]. Urinary retention was reported in 2% (3/160) of patients and urinary incontinence was reported in 1 patient in a case series of 160 patients[7].

Vertebral body fracture

Vertebral body fracture or remote compression fracture was reported in 1% (18/2,342) of patients treated by ELIF, no patients treated by ALIF when FDA reports were excluded (p=0.0274) and <1% (3/1,379) of patients treated by ALIF when FDA reports were included (p=0.0262) in the systematic review of 34 studies[2]. Vertebral body fracture was reported in 1% (2/160) of patients in the case series of 160 patients[7].

Device-related complications

Hardware failure (cage subsidence or breakage, intraoperative pedicle fracture, implant bone interface failure) was reported in 1% (31/2,342) of patients treated by ELIF, 3% (17/544) of patients treated by ALIF when FDA reports were excluded (p=0.0065) and 3% (47/1,379) of patients treated by ALIF when FDA reports were included (p<0.0001) in the systematic review of 34 studies[2]. Graft migration and graft subsidence at 24-month follow-up were reported in 0% (0/29) and 3% (1/29) of patients treated by XLIF and 5% (1/21) and 10% (2/21) of patients treated by TLIF respectively in the RCT and non-randomised comparative study of 55 patients[5].

Dural tear

Intraoperative dural tear was reported in <1% (4/2,342) of patients treated by ELIF, 1% (3/544) of patients treated by ALIF when FDA reports were excluded (p=0.0987) and <1% (5/1,379) of patients treated by ALIF when FDA reports were included (p=0.2779) in the systematic review of 34 studies[2]. Dural tear was reported in 3% (4/160) of patients in the case series of 160 patients[7].

Other

Complex regional pain syndrome was reported in 1 patient in a case report[14]. The symptoms were treated conservatively and resolved within 8 weeks. Lumbar post-sympathectomy syndrome was reported in 5% (4/88) of patients treated by XLIF in the non-randomised comparative study of 208 patients (including 3 cases at level L4/5 and 1 case at level L5/6)[6].

Validity and generalisability of the studies

- There is heterogeneity with regard to patient populations included in the studies.
- Studies varied with regard to the use of supplemental fixation, techniques for lateral interbody fusion, neuromonitoring use and the terminology and classification of complications.

- In the systematic review that was specifically focused on the safety of lateral interbody fusion compared with anterior lumbar interbody fusion, some of the complications may have been associated with adjunctive procedures[2].
- Most of the evidence is from the US.
- There is a lack of long-term data.

Existing assessments of this procedure

The Canadian Agency for Drugs and Technologies in Health published a rapid response report on 'Direct Lateral Interbody Fusion in Patients Requiring Surgery for Spinal Instability', in 2015[16]. The report stated the key findings as:

'Identified studies of limited quality suggested that direct lateral interbody fusion (DLIF) is a clinically effective procedure for patients requiring surgery for conditions that may result in spinal instability. Limited-quality, conflicting evidence was identified for the clinical effectiveness of DLIF as compared to other lumbar fusion surgical techniques. Identified data on comparative complication rates was also conflicting. The most frequently reported complications of DLIF were transient anterior thigh pain, anterior thigh numbness, and/or hip flexor weakness. Two uncontrolled before-after studies were identified that found no statistically significant differences in outcomes of pain or disability for one-level vs two-level DLIF, however DLIF on 2 or more levels was associated with an increased length of hospital stay in another uncontrolled study. No cost-effectiveness studies were identified, however a cost-analysis found DLIF may offer cost savings as compared to an open anterior lumbar interbody fusion procedure due to decreased operating room time, length of hospital stay, and pharmaceutical management of pain. No relevant guidelines were identified.'

Related NICE guidance

Below is a list of NICE guidance related to this procedure. Appendix B gives details of the recommendations made in each piece of guidance listed.

Interventional procedures

- Lateral (including extreme, extra and direct lateral) interbody fusion in the lumbar spine. NICE interventional procedure guidance 321 (2009) (current guidance). Available from http://www.nice.org.uk/guidance/IPG321
- Percutaneous electrothermal treatment of the intervertebral disc annulus for low back pain and sciatica. NICE interventional procedure guidance 544 (2016). Available from http://www.nice.org.uk/guidance/IPG544

- Percutaneous coblation of the intervertebral disc for low back pain and sciatica. NICE interventional procedure guidance 543 (2016). Available from http://www.nice.org.uk/guidance/IPG543
- Insertion of an annular disc implant at lumbar discectomy. NICE interventional procedure guidance 506 (2014). Available from http://www.nice.org.uk/guidance/IPG506
- Peripheral nerve-field stimulation for chronic low back pain. NICE interventional procedure guidance 451 (2013). Available from http://www.nice.org.uk/guidance/IPG451
- Transaxial interbody lumbosacral fusion. NICE interventional procedure guidance 387 (2011). Available from http://www.nice.org.uk/guidance/IPG387
- Non rigid stabilisation techniques for the treatment of low back pain. NICE interventional procedure guidance 366 (2010). Available from http://www.nice.org.uk/guidance/IPG366
- Interspinous distraction procedures for lumbar spinal stenosis causing neurogenic claudication. NICE interventional procedure guidance 365 (2010). Available from http://www.nice.org.uk/guidance/IPG365
- Percutaneous intradiscal laser ablation in the lumbar spine. NICE interventional procedure guidance 357 (2010). Available from http://www.nice.org.uk/guidance/IPG357
- Prosthetic intervertebral disc replacement in the lumbar spine. NICE interventional procedure guidance 306 (2009). Available from http://www.nice.org.uk/guidance/IPG306
- Percutaneous endoscopic laser lumbar discectomy. NICE interventional procedure guidance 300 (2009). Available from http://www.nice.org.uk/guidance/IPG300
- Automated percutaneous mechanical lumbar discectomy. NICE interventional procedure guidance 141 (2005). Available from http://www.nice.org.uk/guidance/IPG141

NICE guidelines

- Low back pain in adults: early management. NICE clinical guideline 88 (2009). Available from http://www.nice.org.uk/guidance/CG88. This guidance is currently under review and is expected to be updated in September 2016.

Specialist advisers' opinions

Specialist advice was sought from consultants who have been nominated or ratified by their Specialist Society or Royal College. The advice received is their individual opinion and is not intended to represent the view of the society. The advice provided by Specialist Advisers, in the form of the completed questionnaires, is normally published in full on the NICE website during public consultation, except in circumstances but not limited to, where comments are considered voluminous, or publication would be unlawful or inappropriate. Two Specialist Adviser Questionnaires for lateral interbody fusion in the lumbar spine for low back pain were submitted and can be found on the NICE website.

Patient commentators' opinions

NICE's Public Involvement Programme sent xxx questionnaires to xxx NHS trusts for distribution to patients who had the procedure (or their carers). NICE received xxx completed questionnaires.

Section to be inserted if there is no patient commentary

NICE's Public Involvement Programme was unable to gather patient commentary for this procedure.

Section to be inserted if patient commentators raised no new issues

The patient commentators' views on the procedure were consistent with the published evidence and the opinions of the specialist advisers.

Section to be inserted if patient commentators raised new issues

The patient commentators raised the following issues about the safety/efficacy of the procedure, which did not feature in the published evidence or the opinions of

specialist advisers, and which the committee considered to be particularly relevant:

- [insert additional efficacy and safety issues raised by patient commentators and highlighted by IPAC, add extra rows as necessary].
- [Last item in list].

Company engagement

A structured information request was sent to 7 companies who manufacture a potentially relevant device for use in this procedure. NICE received 6 completed submissions. These were considered by the IP team and any relevant points have been taken into consideration when preparing this overview.

Issues for consideration by IPAC

- Studies that only include patients with scoliosis have been excluded where possible, although some were included in the systematic reviews.
- Ongoing trials:
  - A Prospective, 5-Year Global Study on MAST™ Minimally Invasive Fusion Procedures for the Treatment of the Degenerative Lumbar Spine (MASTERS-D2) (NCT02617563); 38 sites located in Europe, Middle East, Canada, Latin America and Asia Pacific; prospective cohort study; estimated enrolment 560; estimated study completion date November 2022.
  - A Multicenter, Prospective, Observational Study to Assess Outcomes for Patients Treated for Lumbar Spinal Conditions Using an OLIF25™ and/or OLIF51™Approach (NCT02657421); USA and Puerto Rico; prospective cohort study; estimated enrolment 500; estimated study completion date November 2020.
  - A Comparison of Complication Rates Between Lateral Approaches to the Lumbar Spine: K2M RAVINE® Far Lateral System Versus NuVasive XLIF® (NCT02068729); prospective cohort study; estimated primary completion date June 2017; estimated enrolment 222 (enrolling by invitation).

- XLIF versus OLIF for Lumbar Spinal Stenosis - a Randomized Clinical Trial (JPRN-UMIN000018348); Japan; target sample size 100; start date 1 August 2015; estimated completion date not reported.

References

1. Lehmen JA, Gerber EJ. (2015) MIS lateral spine surgery: a systematic literature review of complications, outcomes, and economics. European Spine Journal 24: S287–313
2. Härtl R, Joeris A, McGuire RA. (2016) Comparison of the safety outcomes between two surgical approaches for anterior lumbar fusion surgery: anterior lumbar interbody fusion (ALIF) and extreme lateral interbody fusion (ELIF). European Spine Journal 25: 1484–521
3. Joseph JR, Smith BW, La Marca F et al. (2015) Comparison of complication rates of minimally invasive transforaminal lumbar interbody fusion and lateral lumbar interbody fusion: a systematic review of the literature. Neurosurgical Focus 39: E4
4. Smith WD, Christian G, Serrano S et al. (2012) A comparison of perioperative charges and outcome between open and mini-open approaches for anterior lumbar discectomy and fusion. Journal of Clinical Neuroscience 19: 673–80
5. Sembrano JN, Tohmeh A, Isaacs R et al. (2016) Two-year comparative outcomes of MIS lateral and MIS transforaminal interbody fusion in the treatment of degenerative spondylolisthesis. Part I: Clinical findings. Spine 41: S123–32

   Isaacs R E, Sembrano JN, Tohmeh AG et al. (2016) Two-year comparative outcomes of MIS lateral and MIS transforaminal interbody fusion in the treatment of degenerative spondylolisthesis. Part II: Radiographic findings. Spine 41: S133–44
6. Hrabalek L, Adamus M, Gryga A et al. (2014) A comparison of complication rate between anterior and lateral approaches to the lumbar spine. Biomedical Papers of the Medical Faculty of Palacky University in Olomouc, Czech Republic 158: 127–32
7. Khajavi K, Shen A, Lagina M et al. (2015) Comparison of clinical outcomes following minimally invasive lateral interbody fusion stratified by preoperative diagnosis. European Spine Journal 24: S322–30
8. Lykissas MG, Aichmair A, Sama AA et al. (2014) Nerve injury and recovery after lateral lumbar interbody fusion with and without bone morphogenetic protein-2 augmentation: a cohort-controlled study. The Spine Journal 14: 217–24
9. Kueper J, Fantini GA, Walker BR et al. (2015) Incidence of vascular complications during lateral lumbar interbody fusion: an examination of the mini-open access technique. European Spine Journal 24: 800–9

10. Galan TV, Mohan V, Klineberg EO et al. (2012) Case report: incisional hernia as a complication of extreme lateral interbody fusion. The Spine Journal 12: e1–6

11. Murray MR, Weistroffer JK, Schafer MF. (2012) Case report of an abscess developing at the site of a hematoma following a direct lateral interbody fusion. The Spine Journal 12: e1–4

12. Santillan A, Patsalides A, Gobin YP. (2010) Endovascular embolization of iatrogenic lumbar artery pseudoaneurysm following extreme lateral interbody fusion (XLIF). Vascular and Endovascular Surgery 44: 601–3

13. Assina R, Majmundar NJ, Herschman Y et al. (2014) First report of major vascular injury due to lateral transpsoas approach leading to fatality. Journal of Neurosurgery: Spine 21: 794–8

14. Morr S, Kanter AS. (2013) Complex regional pain syndrome following lateral lumbar interbody fusion. Journal of Neurosurgery: Spine 19: 502–6

15. Balsano M, Carlucci S, Ose M et al. (2015) A case report of a rare complication of bowel perforation in extreme lateral interbody fusion. European Spine Journal 24 Suppl 3: 405–8

16. Direct Lateral Interbody Fusion in Patients Requiring Surgery for Spinal Instability: A Review of the Comparative Clinical and Cost-Effectiveness, and Guidelines [Internet]. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2015 Jun 25. Available from: http://www.ncbi.nlm.nih.gov/books/NBK304466/

Appendix A: Additional papers on lateral interbody fusion in the lumbar spine for low back pain

The following table outlines the studies that are considered potentially relevant to the IP overview but were not included in the main data extraction table (table 2). It is by no means an exhaustive list of potentially relevant studies.

Case series with fewer than 30 patients have been excluded.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Abbasi H, Abbasi A (2015) Oblique Lateral Lumbar Interbody Fusion (OLLIF): Technical Notes and Early Results of a Single Surgeon Comparative Study. Cureus 7: e351	Non-randomised comparative study n=124 (69 versus 55)	For a single-level oblique lateral lumbar interbody fusion (OLLIF), the mean surgery time is 69 min and blood loss is 29 ml. Surgery time was approximately twice as fast as open transforaminal lumbar interbody fusion (TLIF) (mean: 135 min) and blood loss is reduced by over 80% compared with TLIF (mean: 355 ml).	Non-randomised comparison with limited outcomes.
Acosta FL, Liu J, Slimack N et al. (2011) Changes in coronal and sagittal plane alignment following minimally invasive direct lateral interbody fusion for the treatment of degenerative lumbar disease in adults: a radiographic study. Journal of Neurosurgery Spine 15: 92-96	Case series n=36	Direct lateral interbody fusion significantly improves segmental, regional, and global coronal plane alignment in patients with degenerative lumbar disease. Although DLIF increases the segmental sagittal Cobb angle at the level of instrumentation, it does not improve regional lumbar lordosis or global sagittal alignment.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Adogwa O, Farber SH, Fatemi P et al. (2016) Do obese patients have worse outcomes after direct lateral interbody fusion compared to non-obese patients? Journal of Clinical Neuroscience 25: 54-57	Case series n=63 FU=24 months	Postoperative complications rates were similar between obese and non-obese patients. There was no statistically significant difference in the incidence of durotomy (p=0.91), anterior thigh numbness (p=0.60), cerebrospinal fluid leak (p=0.91), postoperative infection (p=0.37), or bleeding requiring transfusion (p=0.16). No patient experienced a nerve injury or psoas hematoma. Both cohorts had similar 2 year improvement in VAS for back pain, leg pain, and ODI.	Studies with more patients or longer follow-up are included.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Ahmadian A, Bach K, Bolinger B et al. (2015) Stand-alone minimally invasive lateral lumbar interbody fusion: multicenter clinical outcomes. Journal of Clinical Neuroscience 22: 740-746	Case series n=59 FU=12 months	Fusion rate was 93% of patients (95% of levels) at 12 months. Two patients required reoperation. The mean preoperative VAS and ODI were 69.1 and 51.8, respectively. VAS improved to 37.8 ($p<0.0005$). ODI improved to 31.8 ($p<0.0005$). 70% of patients had grade 0 subsidence while 30% had grade I and grade II subsidence. Stand-alone MIS-LIF is a viable option in a carefully selected patient population for both single and multilevel disease and shows significant improvement in health related quality of life.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Ahmadian A, Verma S, Mundis GM et al. (2013) Minimally invasive lateral retroperitoneal transpsoas interbody fusion for L4-5 spondylolisthesis: clinical outcomes. Journal of Neurosurgery Spine 19: 314–20	Case series n=31 FU=18 months	With its established surgical corridors through the retroperitoneum and psoas muscle, the MIS-LIF combined with posterior percutaneous pedicle screw fixation/reduction is a safe, reproducible, and effective technique for patients with symptomatic degenerative spondylolisthesis at the L4-5 vertebral segment.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Ahmadian A, Deukmedjian AR, Abel N et al. (2013) Analysis of lumbar plexopathies and nerve injury after lateral retroperitoneal transpsoas approach: diagnostic standardization. Journal of Neurosurgery Spine 18: 289–97	Review n=18 studies (2310 patients)	The incidence of documented nerve and/or root injury and abdominal paresis ranged from 0% to 3.4% and 4.2% respectively. Motor weakness ranged from 0.7% to 33.6%. Sensory complications ranged from 0% to 75%. There is underreporting of postoperative lumbar plexus nerve injury and a lack of standardisation of clinical findings of neural complications.	The aim of the study is to standardise the clinical findings of lumbar plexopathies and nerve injuries.
Aichmair A, Lykissas MG, Girardi FP et al. (2013) An institutional six-year trend analysis of the neurological outcome after lateral lumbar interbody fusion: a 6-year trend analysis of a single institution. Spine 38: E1483–90	Case series n=293 FU=15 months	There was a decreasing proportional trend over time for postoperative sensory deficits, motor deficits, and anterior thigh pain, which can be considered a representation of an institutional learning curve.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Alimi M, Hofstetter CP, Cong GT et al. (2014) Radiological and clinical outcomes following extreme lateral interbody fusion. Journal of Neurosurgery Spine 20: 623-635	Case series n=90 FU=18 months	Clinical evaluation at an average follow-up of 17.6 months revealed an improvement in the ODI and the VAS scores for back, buttock, and leg pain by 21% and 3.7, 3.6, and 3.7 points, respectively ($p<0.0001$). According to the Macnab criteria, 85% of patients had an excellent, good, or fair functional outcome. New postoperative thigh numbness and weakness was detected in 4% and 2% of the patients, respectively, which resolved within the first 3 months after surgery in all but 1 case.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Barbagallo GM, Albanese V, Raich AL et al. (2014) Lumbar Lateral Interbody Fusion (LLIF): Comparative Effectiveness and Safety versus PLIF/TLIF and Predictive Factors Affecting LLIF Outcome. Evidence based Spinecare Journal 5: 28-37	Systematic review n=6 studies	There is insufficient evidence of the comparative effectiveness of lumbar lateral interbody fusion (LLIF) versus posterior lumbar interbody fusion (PLIF) or transforaminal lumbar interbody fusion (TLIF) surgery. There is low-quality evidence suggesting that LLIF surgery results in fewer complications or reoperations than PLIF/TLIF surgery. And there is insufficient evidence that any preoperative factors exist that predict patient outcome after LLIF surgery.	A more recent systematic review is included (Lehmen and Gerber EJ, 2015), which includes this study.
Bendersky M, Sola C, Muntadas J et al. (2015) Monitoring lumbar plexus integrity in extreme lateral transpsoas approaches to the lumbar spine: a new protocol with anatomical bases. European Spine Journal 24: 1051-1057	Case series n=107	No patient (0%) had new motor postoperative deficits. Nineteen (17.8%) patients had minor and transient sensory symptoms, lasting less than a month. One patient (0.9%) had longer duration of sensory complaints (3 months).	Studies with more patients or longer follow-up are included.
Berjano P, Balsano M, Buric J et al. (2012) Direct lateral access lumbar and thoracolumbar fusion: preliminary results. European Spine Journal 21 Suppl-42	Case series n=97 FU=12 months	No permanent neurological impairment, vascular or visceral injuries were observed. Transient neurological symptoms presented in 7% of cases, all resolved within 1 month from surgery. Transient thigh discomfort was observed in 9%. Clinical success was recorded in 92% of cases.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Berjano P, Langella F, Damilano M et al. (2015) Fusion rate following extreme lateral lumbar interbody fusion. European Spine Journal 24 Suppl-71	Case series n=53 FU=34.5 months	87% (68/78) of the operated levels were considered as completely fused, 8 (10%) were considered as stable, probably fused, and 2 (3%) of the operated levels were diagnosed as pseudarthrosis. When stratified by type of graft material complete fusion was obtained in 75% of patients in which autograft was used to fill the cages, compared to 89% of patients in which calcium triphosphate was used, and 83% of patients in which Attrax was used.	Studies with more patients or longer follow-up are included.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Buric J, Bombardieri D (2016) Direct lesion and repair of a common iliac vein during XLIF approach. European Spine Journal 25 Suppl 1: 89–93	Case report n=1	**Vascular injury** Direct intraoperative lesion and repair of a major vascular injury of common iliac vein during an extreme lateral interbody fusion L4-L5 procedure.	Vascular injury is already mentioned as a complication in table 2.
Buric J, Del Gaizo C, Bombardieri D et al. (2012) Extreme lateral interbody fusion (XLIF) of the initial consecutive case series. Learning curve at 1 year follow-up. European Spine Journal 21: 801	Case series n=34 FU=1 year	Clinical and radiological results showed satisfactory outcomes both in clinical terms and fusion rates. The learning curve was short. Absence of major visceral and vascular lesions and lower surgical time makes it a useful alternative to anterior interbody fusion. The major limit is the L5-S1 level.	Studies with more patients or longer follow-up are included.
Cahill KS, Martinez JL, Wang MY et al. (2012) Motor nerve injuries following the minimally invasive lateral transpsoas approach. Journal of Neurosurgery Spine 17: 227-231	Case series n=118	The overall incidence of femoral nerve injury after the lateral transpsoas approach was 1.7%; however, the level-specific incidence was 4.8% for procedures performed at the L4-5 disc space. Approximately 4% of patients had postoperative abdominal flank bulge. Surgeons will be able to minimize these motor nerve injuries through judicious use of the procedure at the L4-5 level and careful attention to the T-11 and T-12 motor nerves during exposure and closure of the abdominal wall.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Cheng I, Briseno MR, Arrigo RT et al. (2015) Outcomes of Two Different Techniques Using the Lateral Approach for Lumbar Interbody Arthrodesis. Global Spine Journal 5: 308-314	Case series n=120	Overall, 18% of patients sustained a postoperative neurologic adverse event following lateral interbody fusions. The traditional transpsoas approach had a statistically lower rate of neurologic-specific adverse events for single-level fusions compared with a direct visualisation approach.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Daffner SD, Wang JC (2010) Migrated XLIF cage: case report and discussion of surgical technique. Orthopedics 33: 518	Case report n=1	**Migrated cage** Imaging studies demonstrated the cage to have extruded laterally 1 month after the procedure. The cage was revised using a mini-open lateral approach. A new cage was placed with the addition of a lateral plate. The patient's leg pain resolved shortly after the revision, and at 1-year follow-up, she appeared to have a solid fusion with no further complications.	Cage migration is already mentioned as a complication in table 2. Study is included in Lehmen JA and Gerber EJ (2015).
Epstein NE (2016) More nerve root injuries occur with minimally invasive lumbar surgery, especially extreme lateral interbody fusion: A review. Surgical neurology international 7 (Suppl:3) 3-95	Review	This review indicates that minimally invasive (TLIF/PLIF/ALIF/XLIF) lumbar surgery resulted in a higher incidence of root injuries, radiculitis, or plexopathy versus open lumbar surgical techniques.	The study reviews a mixture of procedures, using selected studies and reviews.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Formica M, Berjano P, Cavagnaro L et al. (2014) Extreme lateral approach to the spine in degenerative and post traumatic lumbar diseases: selection process, results and complications. European Spine Journal 23 Suppl-92	Case series n=39 FU=16 months	XLIF proved to be a safe, effective, minimally invasive technique that allows valid arthrodesis to be carried out. Patients achieved positive clinical outcomes and satisfactory fusion rates, with sustained restoration of lordosis, spinal alignment and disc height.	Studies with more patients or longer follow-up are included.
Formica C, Buzzi G, Cavaleri L et al. (2013) Extreme lateral interbody fusion (xlif) in degenerative lumbar pathologies. Selection process and preliminary results. European Spine Journal 22: 908-909	Case series n=36 FU=6–15 months	XLIF is a safe and effective minimally invasive technique (in the sense of tissue sparing surgery) that allows a valid arthrodesis to be achieved, guaranteed by the positioning of a large anterior support with no invasion of the spinal canal during the approach.	Studies with more patients or longer follow-up are included.
Grimm BD, Leas DP, Poletti SC et al. (2016) Postoperative Complications Within the First Year After Extreme Lateral Interbody Fusion: Experience of the First 108 Patients. Clinical Spine Surgery 29: E151-6	Case series n=108 FU=1 year	Complication rate=23% (25/108) Transient ipsilateral thigh numbness, pain and/or hip flexor weakness is a frequent postoperative finding most commonly when the L4-5 level is instrumented. Dense femoral nerve palsy is a debilitating complication that may occur despite intraoperative neurophysiologic monitoring. It should be noted that this retrospective study may underreport the true incidence of complications among these patients.	Studies with more patients or longer follow-up are included.
Hrabalek L, Sternbersky J, Adamus M (2015) Risk of sympathectomy after anterior and lateral lumbar interbody fusion procedures. Biomedical Papers of the Medical Faculty of Palacky University in Olomouc, Czech Republic 159: 318-326	Case series n=28	**Sympathectomy** Lumbar sympathectomy (SE) was diagnosed in 0.5% after ALIF at L5/S1, in 15% after ALIF at Th12-L5 and in 4% after XLIF at T12-L5. SE severely reduced the quality of life in 2 cases. The ability to distinguish differences in leg temperature by palpation after SE was found in 32%. All physical examinations together were insufficient for reliably disclosing SE.	Post-sympathectomy syndrome is included as a complication in table 2.
Karikari I, Adogwa O, Owens TR et al. (2013) Failure of indirect decompression with the extreme lateral interbody (XLIF) approach: A study of radiographic factors. Clinical Neurosurgery 60: 173	Case series n=40 FU=6 months	In a multivariate logistic regression model, increasing right and left subarticular diameters greater than 2.25 mm and 2.35 mm, respectively, and an axial central canal diameter greater than 123.1 mm were independently predictive of successful indirect decompression (>30% change in sagittal canal diameter).	Studies with more patients or longer follow-up are included.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Karikari IO, Grossi PM, Nimjee SM et al. (2011) Minimally invasive lumbar interbody fusion in patients older than 70 years of age: analysis of peri- and postoperative complications. Neurosurgery 68: 897-902	Case series n=41 FU=15 months	Minimally invasive interbody fusions can be performed in the elderly (ages 70 years and older) with an overall low rate of major complications. Graft subsidence in this population when not supplemented with posterior instrumentation is a concern. Age should not be a deterrent to performing complex minimally invasive interbody fusions in the elderly.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Khajavi K, Shen A, Hutchison A (2015) Substantial clinical benefit of minimally invasive lateral interbody fusion for degenerative spondylolisthesis. European Spine Journal 24: Suppl-21	Case series n=60 FU=20 months	MIS lateral interbody fusion in the treatment of DS resulted in significant improvements in clinical and radiographic outcomes, with a low complication rate and a high proportion of patients achieving substantial clinical benefit.	Studies with more patients or longer follow-up are included.
Kim SJ, Lee YS, Kim YB et al. (2014) Clinical and radiological outcomes of a new cage for direct lateral lumbar interbody fusion. Korean Journal of Spine 11: 145-151	Case series n=163	The new type of cage seems to result in more disc angle and less subsidence. But indirect foraminal decompression seems to be less effective than standard cage. Intraoperative endplate destruction occurs more frequently due to a steeper lordotic angle of the new cage.	Study focuses on the use of a new cage.
Knight RQ, Schwaegler P, Hanscom D et al. (2009) Direct lateral lumbar interbody fusion for degenerative conditions: early complication profile. Journal of Spinal Disorders & Techniques 22: 34-37	Non randomised comparative study n=98 (58 lateral fusion) FU=1 year	Major adverse events approximated 8.6% with approach-related complaints of nerve irritation nearing 3.4%. Mild complications occurred in 13.7% of patients. Meralgia paresthetica was a primary approach-related complaint. Most complaints significantly reduced by first postoperative visit. One patient (1.7%) had symptoms lasting over a year that did not adversely affect function. Overall morbidity reduction noted by estimated blood loss is considerably less compared with the historical cohort.	Studies with more patients or longer follow-up are included. (Included in table 2 of the 2009 overview.) Study is included in Lehmen JA and Gerber EJ (2015).
Le TV, Smith DA, Greenberg MS et al. (2012) Complications of lateral plating in the minimally invasive lateral transpsoas approach. Journal of Neurosurgery Spine 16: 302-307	Case series n=101	Six complications were identified, resulting in an incidence of 6%. Three hardware failures, 2 coronal plane vertebral body (VB) fractures, and 1 lateral VB fracture were identified. All complications occurred in multilevel cases. All cases presented with recurrent back pain except one, which was identified incidentally.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Le TV, Burkett CJ, Deukmedjian AR et al. (2013) Postoperative lumbar plexus injury after lumbar retroperitoneal transpsoas minimally invasive lateral interbody fusion. Spine 38: E13-E20	Case series n=71	There was a 19% (14/71) rate of immediate postoperative ipsilateral thigh numbness during the study period. The annual rates of numbness progressively decreased annually. There was a 26% (6/23), 25% (5/20), and 11% (3/28) rate for 2008, 2009, and 2010, respectively. All patients with numbness had a fusion construct that involved L4-L5. More than half the patients, 55% (39/71), had immediate postoperative ipsilateral iliopsoas or quadriceps weakness. Of these, the vast majority had resolution by 3 months (92%), and all had complete resolution by 2 years.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Le TV, Vivas AC, Dakwar E (2012) The effect of the retroperitoneal transpsoas minimally invasive lateral interbody fusion on segmental and regional lumbar lordosis. The scientific world journal 516706	Case series n=35 FU=13 months	The MIS-LIF improves segmental lordosis and disc height in the lumbar spine but not regional lumbar lordosis. Anterior longitudinal ligament sectioning and/or the addition of a more lordotic implant may be necessary in cases where significant increases in regional lumbar lordosis are desired.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Lee YS, Park SW, Kim YB (2014) Direct lateral lumbar interbody fusion: clinical and radiological outcomes. Journal of Korean Neurosurgical Society 55: 248-254	Case series n=90 FU=6 months	Fusion rates at 6 and 12 months were 61% and 88% respectively. Complications occurred in 17 patients (19%). However, most of the complications were resolved within 2 months.	Studies with more patients or longer follow-up are included.
Lee YP, Regev GJ, Chan J et al. (2013) Evaluation of hip flexion strength following lateral lumbar interbody fusion. Spine Journal: Official Journal of the North American Spine Society 13: 1259-1262	Case series n=33 FU=6 months	Hip flexion was weakened immediately after the lateral interbody fusion procedure, which may be attributed to psoas muscle injury during the procedure. However, this damage was temporary, with almost complete return to baseline values by 2 weeks.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).

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Lee CS, Chung SS, Pae YR et al. (2014) Mini-open approach for direct lateral lumbar interbody fusion. Asian Spine Journal 8: 491-497	Case series n=74	Trials of mini-open lateral approach would be helpful before the trial of extreme lateral interbody fusion or direct lateral interbody fusion. However, special attention is required for complications such as transient lumbosacral plexus palsy.	Studies with more patients or longer follow-up are included.
Lykissas MG, Aichmair A, Hughes AP et al. (2014) Nerve injury after lateral lumbar interbody fusion: a review of 919 treated levels with identification of risk factors. Spine Journal 5:749–758	Case series n=451 FU=15 months	When patients with neural deficits present before surgery were excluded, persistent surgery-related sensory and motor deficits were identified in 9.3% and 3.2% of the patients, respectively. Among 87 patients with minimum follow-up of 18 months, persistent surgery-related sensory and motor deficits were recorded in 9.6% and 2.3% of the patients, respectively. Among patients with stand-alone LLIF, the level treated was identified as a risk factor for postoperative lumbosacral plexus injury. The use of recombinant human bone morphogenetic protein 2 was associated with persistent motor deficits.	Study is included in Lehmen JA and Gerber EJ (2015).
Malham GM, Ellis NJ, Parker RM et al. (2012) Clinical outcome and fusion rates after the first 30 extreme lateral interbody fusions. The scientific world journal 246989-2012.	Case series n=30 FU=11.5 months	The XLIF approach provides superior treatment, clinical outcomes and fusion rates compared to conventional surgical approaches with lowered complication rates. Mentor supervision for early cases and strict adherence to the surgical technique including neuromonitoring is essential.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Malham GM, Parker RM, Goss B et al. (2015) Clinical results and limitations of indirect decompression in spinal stenosis with laterally implanted interbody cages: results from a prospective cohort study. European Spine Journal 24 Suppl-45	Case series n=122	Unplanned second stage decompression was required in 11 patients. Of these patients, 7/11 early in this series had pathology that was underappreciated including spondylolisthesis from high grade facet arthropathy with instability (3), bony lateral recess stenosis (3) and both spondylolisthesis/stenosis (1). Three patients had iatrogenic leg pain through cage misplacement.	Study focuses on evaluating clinical scenarios where indirect decompression was and was not sufficient in symptom resolution.
Malham GM, Parker RM, Goss B et al. (2014) Indirect foraminal decompression is independent of metabolically active facet arthropathy in extreme lateral interbody fusion. Spine 39: E1303-E1310	Case series n=52 FU=2 days	Significant indirect neural decompression is possible in XLIF, regardless of the presence of metabolically active facet arthropathy.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Marchi L, Abdala N, Oliveira L et al. (2012) Stand-alone lateral interbody fusion for the treatment of low-grade degenerative spondylolisthesis. The scientific world journal 456346	Case series n=52 FU=24 months	Cage subsidence occurred in 9/52 cases (17%) and 7/52 cases (13%) spine levels needed revision surgery. At the 24-month evaluation, solid fusion was observed in 86.5% of the levels treated. The minimally invasive lateral approach has been shown to be a safe and reproducible technique to treat low-grade degenerative spondylolisthesis.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Marchi L, Abdala N, Oliveira L et al. (2013) Radiographic and clinical evaluation of cage subsidence after stand-alone lateral interbody fusion. Journal of Neurosurgery Spine 19: 110-118	Case series n=107 FU=12 months	Wider cages avoid subsidence and better restore segmental lordosis in stand-alone lateral interbody fusion. Cage subsidence is identified early in follow-up and can be accessed using the proposed classification scale.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Nemani VM, Aichmair A, Taher F et al. (2014) Rate of revision surgery after stand-alone lateral lumbar interbody fusion for lumbar spinal stenosis. Spine 5: E326–31	Case series n=117	10% of patients who had stand-alone lateral lumbar interbody fusion ultimately needed revision surgery, most commonly for persistent radiculopathy and symptomatic implant subsidence. Average time to revision was 10.8 months.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Ohtori S, Orita S, Yamauchi K et al. (2015) Mini-Open Anterior Retroperitoneal Lumbar Interbody Fusion: Oblique Lateral Interbody Fusion for Lumbar Spinal Degeneration Disease. Yonsei Medical Journal 56: 1051-1059	Case series n=35 FU=6 months	Pain scores significantly improved after surgery, compared to those before surgery ($p<0.05$). There was no patient who underwent revision surgery. There was no spinal nerve, major vessel, peritoneal, or urinary injury. Few patients showed symptoms from psoas invasion.	Studies with more patients or longer follow-up are included.
Ozgur BM, Agarwal V, Nail E et al. (2010) Two-year clinical and radiographic success of minimally invasive lateral transpsoas approach for the treatment of degenerative lumbar conditions. SAS journal 4: 41-46	Case series n=62 FU=2 years	Pain scores (VAS) decreased significantly from preoperative to 2 years follow-up by 37% ($p<0.0001$). Functional scores (ODI) decreased significantly by 39% from preoperative to 2 years follow-up ($p<0.0001$). Clinical success by ODI-change definition was achieved in 71% of patients. Radiographic success was achieved in 91% of patients, with 1 patient with pseudarthrosis requiring posterior revision.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Papanastassiou ID, Eleraky M, Vrionis FD (2011) Contralateral femoral nerve compression: An unrecognized complication after extreme lateral interbody fusion (XLIF). Journal of Clinical Neuroscience 18: 149-151	Case reports n=2	**Contralateral femoral nerve compression** In the first patient the injury was caused by a displaced endplate fragment compressing the contralateral nerve root; in the second patient, the injury resulted from a far-lateral herniation after the XLIF procedure. Both patients experienced resolution of their symptoms after being reoperated. Overall, this complication was encountered in 2/32 levels treated during the study period.	Femoral nerve injury is already mentioned as a complication in table 2. Study is included in Lehmen JA and Gerber EJ (2015).
Peiro-Garcia A, Dominguez-Esteban I, Alia-Benitez J (2015) Retroperitoneal hematoma after using the extreme lateral interbody fusion (XLIF) approach: Presentation of a case and a review of the literature. Rev Esp.Cir Ortop Traumatol S1888-4415 (15) 00019-3	Case report n=1	**Retroperitoneal haematoma** Retroperitoneal haematoma is a major complication, with few cases reported. This is the first case reported in a Stand-alone XLIF and also the first case reported with haemorrhagic shock. Non-specific symptoms such tachycardia, hypotension, and anaemia are the most prevalent in this complication.	Retroperitoneal haematoma is already mentioned as a complication in table 2.
Phan K, Rao PJ, Scherman DB et al. (2015) Lateral lumbar interbody fusion for sagittal balance correction and spinal deformity. Journal of Clinical Neuroscience 22: 1714–21	Systematic review n=21 articles (n=948) Median follow-up=14 months	Pooled weighted average mean visual analogue scores decreased from 6.8 at baseline to 2.9 ($p<0.0001$). Pooled weighted average mean ODI scores decreased from 44.5 at baseline to 20.5 ($p<0.0001$).	Most of the patients included in the review had scoliosis.
Pimenta L, Marchi L, Oliveira L et al. (2013) A prospective, randomized, controlled trial comparing radiographic and clinical outcomes between stand-alone lateral interbody lumbar fusion with either silicate calcium phosphate or rh-BMP2. Journal of Neurological Surgery 74: 343-350	RCT (silicate calcium phosphate [SiCaP] versus rhBMP2) n=30	Complications were transient hip flexion weakness (13%), insufficient indirect decompression (7%), subsidence (17%), excessive bone formation (4%), and adjacent segment disease (14%). Complication rates between the groups were similar, though with slightly more instances of subsidence in the SiCaP group and higher rates of excessive bone formation and adjacent segment disease in the rh-BMP2 group. Rates of fusion at different time points were different between the groups, with the SiCaP patients progressing more slowly toward solid fusion. However, at 36 months, 100% of patients undergoing XLIF achieved solid fusion.	Small RCT comparing lateral interbody fusion with either silicate calcium phosphate or rh-BMP2. Study is included in Lehmen JA and Gerber EJ (2015).

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Pumberger M, Hughes AP, Huang RR et al. (2012) Neurologic deficit following lateral lumbar interbody fusion. European Spine Journal 21: 1192–9	Case series n=235 Fu=12 months	At 12 month follow-up: • Sensory deficit=1.6% • psoas mechanical deficit=1.6% • Lumbar plexus related deficits=2.9%	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Rodgers WB, Gerber EJ, Rodgers JA (2012) Clinical and radiographic outcomes of extreme lateral approach to interbody fusion with beta-tricalcium phosphate and hydroxyapatite composite for lumbar degenerative conditions. International Journal of Spine Surgery 6: 24-28	Case series n=50 FU=12 months	Radiographic fusion was observed in 41 of 44 assessed levels (93%). Blood loss was less than 100 ml in 96% of patients. Of the patients, 93% spent 1 night or less in the hospital. By the 6-week follow-up, all clinical outcomes were significantly improved ($p<0.05$). Improvements were maintained or increased throughout the course of follow-up.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Rodgers WB, Cox CS, Gerber EJ (2010) Early complications of extreme lateral interbody fusion in the obese. Journal of Spinal Disorders & Techniques 23: 393-397	Case series n=313 FU=3 months	There were no transfusions and no infections. Complications were minimal and about the same in each group. Unlike traditional open lumbar fusion procedures, minimally invasive surgery (XLIF) has no greater risk of complication in the obese patient.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Rodgers WB, Gerber EJ, Patterson JR (2010) Fusion after minimally disruptive anterior lumbar interbody fusion: Analysis of extreme lateral interbody fusion by computed tomography. SAS journal 4: 63-66	Case series n=66 FU=12 months	97% (85/88) of levels were judged fused by CT. 97% (64/66) of patients were judged fused by CT. Patient satisfaction at 12 months after surgery was high, with 89% reportedly "satisfied or very satisfied" with their results. No revisions were necessary for pseudarthrosis.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Rodgers WB, Lehmen JA, Gerber EJ et al. (2012) Grade 2 spondylolisthesis at L4-5 treated by XLIF: safety and midterm results in the "worst case scenario". The Scientific World Journal 356712-2012.	Case series n=63 FU=12 months	Average pain (visual analogue scale) decreased from a score of 8.7 at baseline to 2.2 at 12 months postoperatively. Average anterior slippage was reduced by 73% and was well maintained. Average disk height (4.6mm pre-op and 9.0mm post-op) nearly doubled after surgery. Slight settling (average 1.3mm) occurred over the 12-month follow-up period. There were no neural injuries and no nonunions noted.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Rodgers WB, Gerber EJ, Patterson J (2011) Intraoperative and early postoperative complications in extreme lateral interbody fusion: an analysis of 600 cases. Spine 36: 26-32	Case series n=600 FU=6 weeks	The overall incidence of perioperative complications was 6.2%: 9 (1.5%) in-hospital surgery-related events, 17 (2.8%) in-hospital medical events, 6 (1.0%) out-of-hospital surgery-related events, and 5 (0.8%) out-of-hospital medical events. There were no wound infections, no vascular injuries, no intraoperative visceral injuries, and 4 (0.7%) transient postoperative neurologic deficits. Eleven events (1.8%) resulted in additional procedures/reoperation.	Study is included in the systematic review by Lehmen and Gerber EJ (2015), which is in table 2.
Rodgers WB, Gerber EJ, Rodgers JA (2010) Lumbar fusion in octogenarians: the promise of minimally invasive surgery. Spine 35: S355-60	Non-randomised comparative study n=60 FU=3 months	Complication rate, blood loss/transfusion rate, and hospital stay were significantly lower in the extreme lateral interbody fusion (XLIF) group ($p<0.0001$). XLIF patients left the hospital an average of 4 days earlier than the open posterior lumbar interbody fusion (PLIF) patients, most discharged home (92.5% XLIF vs. 0% PLIF) rather than to skilled nursing facilities. Six deaths occurred in the PLIF follow-up, 3 within 3 months postoperatively; there was 1 death at 6 months postoperatively XLIF.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Sakai T, Tezuka F, Wada K et al. (2016) Risk Management for Avoidance of Major Vascular Injury due to Lateral Transpsoas Approach. Spine 41: 450-453	Case series n=323	To avoid critical complications in extreme lateral lumbar interbody fusion, careful preoperative radiological evaluation of the major vessels and intraoperative care are important.	The study focuses on identifying risk factors for vascular injury, using retrospective analysis of CT scans.
Sharma AK, Kepler CK, Girardi FP et al. (2011) Lateral lumbar interbody fusion: clinical and radiographic outcomes at 1 year: a preliminary report. Journal of Spinal Disorders & Techniques 24: 242-250	Case series n=43 FU=1 year	The lateral lumbar interbody fusion approach is effective in correcting the coronal plane deformity and in gaining lordosis at individual instrumented levels. The complications are mostly approach-related and transitory.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Silverstein J, Mermelstein L, DeWal H et al. (2014) Saphenous nerve somatosensory evoked potentials: a novel technique to monitor the femoral nerve during transpsoas lumbar lateral interbody fusion. Spine 39: 1254-1260	Case series n=41	Somatosensory evoked potential (SSEP) changes were noted in 5 of the 41 surgical procedures, with 3 of the patients waking up with a femoral nerve deficit. None of the patients with stable SSEP's developed sensory or motor deficits postoperatively. No patient in this series demonstrated intraoperative electromyography changes indicative of an intraoperative nerve injury.	Studies with more patients or longer follow-up are included.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Silvestre C, Mac-Thiong JM, Hilmi R et al. (2012) Complications and Morbidities of Mini-open Anterior Retroperitoneal Lumbar Interbody Fusion: Oblique Lumbar Interbody Fusion in 179 Patients. Asian Spine Journal 6: 89–97	Case series n=179 FU= 0.94 year	There were 19 patients with a single complication and one with 2 complications, including 2 patients with postoperative radiculopathy after L3-5 OLIF. There was no abdominal weakness or herniation. Minimally invasive OLIF can be performed easily and safely in the lumbar spine from L2 to L5, and at L1-2 for selected cases. It is associated with minimal blood loss and short operations, and with decreased risk of abdominal wall weakness or herniation.	Studies with more patients or longer follow-up are included.
Skovrlj B, Belton P, Zarzour H et al. (2015) Perioperative outcomes in minimally invasive lumbar spine surgery: A systematic review. World Journal of Orthopedics 6: 996-1005	Systematic review n=20 direct lateral studies	For lateral approaches, there is insufficient evidence to find non-inferior perioperative outcomes at this time.	No meta-analysis.
Smith WD, Wohns R, Christian G et al. (2016) Outpatient Minimally Invasive Lumbar Interbody Fusion: Predictive Factors and Clinical Results. Spine 41 Suppl 8:S106-22	Case series n=1033 for predictive study, n=72 for clinical study	Being younger, having elevated preoperative haemoglobin levels, fewer levels being treated, for less advanced disease may predict early postoperative discharge.	Study focuses on predictors of early postoperative discharge.
Taher F, Hughes AP, Lebl DR et al. (2013) Contralateral motor deficits after lateral lumbar interbody fusion. Spine 22: 1959–63	Case series n=244 FU=1 year	3% (7/244) of patients had a postoperative contralateral motor deficit, the most severe of which was a 1/5 weakness of the quadriceps muscle. An average of 3 levels (range: 2-4) was fused in 7 patients who developed a contralateral motor deficit, and in 3 of the 7 patients, an anterior lumbar interbody fusion (ALIF) was performed in addition to the LLIF. At 1 year follow-up, 3 patients presented with complete resolution of their muscle weakness, 1 patient still had mild weakness, 1 patient had decreased range of motion in the affected joint, and 1 patient had a 2/5 foot drop. One patient was lost to follow-up.	Study is included in Lehmen JA and Gerber EJ (2015).
Talia AJ, Wong ML, Lau HC et al. (2015) Comparison of the different surgical approaches for lumbar interbody fusion. Journal of Clinical Neuroscience 22: 243–51	Review	There is no evidence that one surgical approach is clinically superior to another. Additional retrospective, prospective and randomised controlled trials are needed before one particular interbody fusion technique or one particular graft material can be deemed superior to the alternatives.	No meta-analysis.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Tender GC (2014) Caudal vertebral body fractures following lateral interbody fusion in nonosteoporotic patients. Ochsner Journal 14: 123-130	Case reports n=2	**Caudal vertebral body fractures** Caudal vertebral body fracture is a major potential complication after the minimally invasive lateral approach for lumbar fusions. Risk factors may include placement of a lateral plate, the size of the smaller anteroposterior cage, endplate violation, and oblique placement of the interbody cage.	Vertebral body fractures are already described as an adverse event in table 2. Study is included in Lehmen JA and Gerber EJ (2015).
Tohmeh AG, Watson B, Tohmeh M et al. (2012) Allograft cellular bone matrix in extreme lateral interbody fusion: preliminary radiographic and clinical outcomes. The scientific world journal 2012 263637-2012	Case series n=40 FU=12 months	ODI improved 41%, low back pain improved 55%, leg pain improved 43%, and QOL (SF-36) improved 56%. At 12 months, 92% reported being "very" or "somewhat" satisfied with their outcome and 86% being either "very" or "somewhat likely" to choose to undergo the procedure again. Complete fusion was observed in 90% (55/61) of XLIF levels.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Tohmeh AG, Rodgers WB, Peterson MD (2011) Dynamically evoked, discrete-threshold electromyography in the extreme lateral interbody fusion approach. Journal of Neurosurgery Spine 14: 31-37	Case series n=102	The ability to identify and report a discrete, real-time EMG threshold during the transpsoas approach helps to avoid nerve injury and is required for the safe performance of the XLIF procedure. Additionally, nerve location is variable, thus reinforcing the need for real-time directional and proximity information.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Tohmeh AG, Khorsand D, Watson B et al. (2014) Radiographical and clinical evaluation of extreme lateral interbody fusion. Spine 39: E1582–91	Case series n=140 FU=12–36 months	At 12 month follow-up, disability improved by 44%, low back pain by 49%, leg pain by 48% and quality of life by 50% ($p<0.001$). Settling >4 mm occurred in 5% of cages immediately postoperatively and in 24% at 12 months postoperatively. Taller cage height, narrower cage width, and shorter cage length were significantly associated with increased risk of cage settling more than 4 mm.	Study focuses on rates of cage settling. Study is included in Lehmen JA and Gerber EJ (2015).
Uribe JS, Isaacs RE, Youssef JA et al. (2015) Can triggered electromyography monitoring throughout retraction predict postoperative symptomatic neuropraxia after XLIF? Results from a prospective multicenter trial. European Spine Journal 24 Suppl-85	Case series n=323	Prolonged retraction time and coincident increases in triggered electromyography (t-EMG) thresholds are predictors of declining nerve integrity. Increasing t-EMG thresholds, while predictive of injury, were also observed in a large number of patients without iatrogenic injury, with a greater predictive value in cases with extended duration.	Study focuses on triggered electromyography monitoring.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Uribe JS, Myhre SL, Youssef JA. (2016) Preservation or restoration of segmental and regional spinal lordosis using minimally invasive interbody fusion techniques in degenerative lumbar conditions. Spine 41: S50-58	Review 23 studies (16 lateral interbody fusion)	Minimally invasive approaches are able to impact regional and local segmental alignment. Preoperative patient factors can impact the extent of correction gained. The interbody procedure type is one of several variables that influence radiographical outcome.	The study focuses on lordosis and includes different procedures.
Wiltfong RE, Bono CM, Malveaux WMSC et al. (2012) Lumbar interbody fusion: review of history, complications, and outcome comparisons among methods. Current Orthopaedic Practice 23: 193–202	Review	Compared to open techniques, the minimally invasive techniques yield less blood loss, decreased hospital stay, decreased postoperative back pain, and longer operative times. Each method of lumbar interbody fusion results in high rates of fusion and good clinical outcomes, despite complications and learning curves. More level 1 studies are needed to make generalisations regarding the outcomes of 1 method compared with another.	A more recent systematic review is included (Lehmen JA and Gerber EJ, 2015).
Youssef JA, McAfee PC, Patty CA et al. (2010) Minimally invasive surgery: lateral approach interbody fusion: results and review. Spine 35(26 Suppl):S302-11	Case series n=84 FU=16 months	Current data corroborates and contributes to the existing body of literature describing XLIF outcomes. Patients recover quickly, requiring minimal hospital stay, although transient hip/thigh pain and/or weakness is common. Long-term outcomes are generally favourable, with maintained improvements in patient-reported pain and function scores as well as radiographic parameters, including high rates of fusion.	Studies with more patients or longer follow-up are included. Study is included in Lehmen JA and Gerber EJ (2015).
Youssef JA, Orndorff DG, Scott MA et al. (2014) Sterile Seroma Resulting from Multilevel XLIF Procedure as Possible Adverse Effect of Prophylactic Vancomycin Powder: A Case Report. Evidence based Spine care Journal 5: 127-133	Case report n=1	**Sterile seroma** Recurrence of epidural fluid collection needing serial aspirations confounded the patients' clinical presentation. The cause of the fluid collection and formation is undetermined. With lack of bone morphogenetic protein usage, and few confounding variables accountable, an acute allergic response to topical vancomycin powder is a possible aetiology.	Complication is suggested to be an allergic response to vancomycin powder. Study is included in Lehmen JA and Gerber EJ (2015).
Yuan PS, Rowshan K, Verma RB et al. (2014) Minimally invasive lateral lumbar interbody fusion with direct psoas visualization. Journal of Orthopaedic Surgery 9: 20	Case series n=34	Preliminary evidence suggests that minimally invasive lateral interbody fusion with direct psoas visualization may reduce the risk for severe procedural complications.	Studies with more patients or longer follow-up are included.

Article	Number of patients/ follow-up	Direction of conclusions	Reasons for non-inclusion in table 2
Zils U, Youssef F, Schreiber S et al. (2011) Comparison of axial lumbar interbody fusion (axialif) of the lumbosacral level vs. Postero-Lateral-Interbody Fusion (PLIF) combined with fixateur interne: Clinical outcome and fusion rates after 18 months. European Spine Journal 20: 2026-2027	Non-randomised comparative study n=34 FU=18 months	The axial lumbar interbody fusion (AxiALIF) system is superior to Postero-Lateral-Interbody Fusion (PLIF) in reducing pain initially and to shorten length of stay. Over 18 months both behave the same concerning pain relief. A good fusion rate with AxiALIF can be achieved only after introducing a dorsal screw. Therefore a higher fusion rate can be seen in PLIF patients after 12 months.	Studies with more patients or longer follow-up are included.

Appendix B: Related NICE guidance for lateral interbody fusion in the lumbar spine for low back pain

Guidance	Recommendations
Interventional procedures	**Lateral (including extreme, extra and direct lateral) interbody fusion in the lumbar spine. NICE interventional procedure guidance 321 (2009) (current guidance)** 1.1 Current evidence on the safety and efficacy of lateral (including extreme, extra and direct lateral) interbody fusion in the lumbar spine is inadequate in quantity and quality. Therefore this procedure should only be used with special arrangements for clinical governance, consent and audit or research. 1.2 Clinicians wishing to undertake lateral interbody fusion in the lumbar spine should take the following actions. Inform the clinical governance leads in their Trusts. • Ensure that patients and their carers understand the uncertainty about the procedure's safety and efficacy and provide them with clear written information. In addition, the use of NICE's information for patients ('Understanding NICE guidance') is recommended. • Audit and review clinical outcomes of all patients having lateral interbody fusion in the lumbar spine (see section 3.1). 1.3 This procedure should only be carried out by surgeons with specific training in the technique, who should perform their initial procedures with an experienced mentor. 1.4 NICE encourages further research into lateral interbody fusion in the lumbar spine. Research outcomes should include fusion rates, pain and functional scores, quality of life measures and the frequency of both early and late complications. NICE may review

	the procedure on publication of further evidence. **Percutaneous electrothermal treatment of the intervertebral disc annulus for low back pain and sciatica. NICE interventional procedure guidance 544 (2016).** 1.1 Current evidence on percutaneous electrothermal treatment of the intervertebral disc annulus for low back pain and sciatica raises no major safety concerns. The evidence on efficacy is inconsistent and of poor quality. Therefore, this procedure should only be used with special arrangements for clinical governance, consent and audit or research. 1.2 Clinicians wishing to do percutaneous electrothermal treatment of the intervertebral disc annulus for low back pain and sciatica should: • Inform the clinical governance leads in their NHS trusts. • Ensure that patients understand the uncertainty about the procedure's efficacy and provide them with clear written information. In particular, patients should be informed about other treatment options, about the possibility that the procedure may not relieve their symptoms, and about the risk of a flare-up of their pain following treatment. In addition, the use of NICE's information for the public is recommended. • Audit and review clinical outcomes of all patients having percutaneous intradiscal radiofrequency treatment of the intervertebral disc annulus (see section 7.2). 1.3 NICE encourages further research into percutaneous electrothermal treatment of the intervertebral disc annulus. Further research should document details of patient selection, including the duration of their symptoms. It should report precise details of the technique used for treatment. Outcome measures should

	include pain relief and quality of life. Long-term follow-up data should include details of any subsequent procedures. **Percutaneous coblation of the intervertebral disc for low back pain and sciatica. NICE interventional procedure guidance 543 (2016).** 1.1 Current evidence on percutaneous coblation of the intervertebral disc for low back pain and sciatica raises no major safety concerns. The evidence on efficacy is adequate and includes large numbers of patients with appropriate follow-up periods. Therefore, this procedure may be used provided that normal arrangements are in place for clinical governance, consent and audit. 1.2 As part of the consent process, patients should be informed that there is a range of treatment options available to them and also that further procedures may be needed. **Insertion of an annular disc implant at lumbar discectomy. NICE interventional procedure guidance 506 (2014)**. 1.1 Current evidence on the safety and efficacy of insertion of an annular disc implant at lumbar discectomy is limited in quantity and quality. Therefore, this procedure should only be used with special arrangements for clinical governance, consent and audit or research. 1.2 Clinicians wishing to undertake insertion of an annular disc implant at lumbar discectomy should take the following actions: • Inform the clinical governance leads in their NHS trusts. • Ensure that patients and their carers understand the uncertainty about the procedure's safety and efficacy and provide them with clear written information. In addition, the use of NICE's information for the public is recommended.

	1.3 NICE encourages further research on insertion of an annular disc implant at lumbar discectomy, particularly comparative trials. All studies should report details of patient selection and recurrence rates. 1.4 Clinicians should enter details about all patients undergoing insertion of an annular disc implant at lumbar discectomy onto the British Spine Registry and review clinical outcomes locally. **Peripheral nerve-field stimulation for chronic low back pain. NICE interventional procedure guidance 451 (2013)**. 1.1 Current evidence on the efficacy of peripheral nerve-field stimulation (PNFS) for chronic low back pain is limited in both quantity and quality, and duration of follow-up is limited. Evidence on safety is also limited and there is a risk of complications from any implanted device. Therefore this procedure should only be used with special arrangements for clinical governance, consent and audit or research. 1.2 Clinicians wishing to undertake PNFS for chronic low back pain should take the following actions. • Inform the clinical governance leads in their Trusts. • Ensure that patients understand the uncertainty about the procedure's safety and efficacy and provide them with clear written information. In addition, the use of NICE's information for the public is recommended. 1.3 Patient selection for treatment using PNFS for chronic low back pain should be done by a multidisciplinary team, including specialists in pain management and neurosurgery. 1.4 Clinicians should enter details about all patients undergoing

	PNFS for chronic low back pain onto the UK Neuromodulation Register when it is available. They should audit and review clinical outcomes locally. 1.5 NICE encourages collaborative data collection and publication of comparative studies on PNFS for chronic low back pain. Outcomes should include measures of pain, function and quality of life, particularly in the long term. Full details of any complications and adjunctive or subsequent treatments should be recorded. **Transaxial interbody lumbosacral fusion. NICE interventional procedure guidance 387 (2011).** 1.1 Current evidence on the efficacy of transaxial interbody lumbosacral fusion is limited in quantity but shows symptom relief in the short term in some patients. Evidence on safety shows that there is a risk of rectal perforation. Therefore this procedure should only be used with special arrangements for clinical governance, consent and audit or research. 1.2 Clinicians wishing to undertake transaxial interbody lumbosacral fusion should take the following actions. • Inform the clinical governance leads in their Trusts. • Ensure that patients and their carers understand the uncertainty about the procedure's efficacy and its risks, specifically including the small risk of rectal perforation in patients with higher bowel disease, or a history of pelvic disease or previous pelvic surgery. They should provide patients with clear written information. In addition, the use of NICE's information for patients ('Understanding NICE guidance') is recommended. • Audit and review clinical outcomes of all patients having

	transaxial interbody lumbosacral fusion (see section 3.1). 1.3 This procedure should only be carried out by surgeons with expertise in the surgical management of spinal disease and specific training in the technique. They should perform their initial procedures with an experienced mentor. 1.4 NICE encourages further research into transaxial interbody lumbosacral fusion. Research outcomes should include fusion rates, pain and functional scores, quality of life measures and the frequency of both early and late complications. NICE may review this procedure on publication of further evidence. **Non rigid stabilisation techniques for the treatment of low back pain. NICE interventional procedure guidance 366 (2010).** 1.1 Current evidence on the efficacy of non-rigid stabilisation techniques for the treatment of low back pain shows that these procedures are efficacious for a proportion of patients with intractable back pain. There are no major safety concerns. Therefore these procedures may be used provided that normal arrangements are in place for clinical governance, consent and audit. 1.2 Patient selection should be carried out by specialist spinal surgeons who are able to offer patients a range of surgical treatment options. **Interspinous distraction procedures for lumbar spinal stenosis causing neurogenic claudication. NICE interventional procedure guidance 365 (2010).** 1.1 Current evidence on interspinous distraction procedures for lumbar spinal stenosis causing neurogenic claudication shows that these procedures are efficacious for carefully selected patients in

	the short and medium term, although failure may occur and further surgery may be needed. There are no major safety concerns. Therefore these procedures may be used provided that normal arrangements are in place for clinical governance, consent and audit. 1.2 Patient selection should be carried out by specialist spinal surgeons who are able to offer patients a range of surgical treatment options. **Percutaneous intradiscal laser ablation in the lumbar spine. NICE interventional procedure guidance 357 (2010).** 1.1 Current evidence on the safety and efficacy of percutaneous intradiscal laser ablation in the lumbar spine is adequate to support the use of this procedure provided that normal arrangements are in place for clinical governance, consent and audit. 1.2 Patients selected for the procedure should be limited to those with severe pain refractory to conservative treatment, in whom imaging studies show bulging of an intact disc, and who do not have neurological deficit requiring surgical decompression. **Prosthetic intervertebral disc replacement in the lumbar spine. NICE interventional procedure guidance 306 (2009)** 1.1 Current evidence on the safety and efficacy of prosthetic intervertebral disc replacement in the lumbar spine is adequate to support the use of this procedure provided that normal arrangements are in place for clinical governance, consent and audit. 1.2 A multidisciplinary team with specialist expertise in the treatment of degenerative spine disease should be involved in patient selection for prosthetic intervertebral disc replacement in

	the lumbar spine. The procedure should only be carried out in patients for whom conservative treatment options have failed or are contraindicated. 1.3 The current evidence includes studies with a maximum follow-up of 13 years, but the majority of evidence is from studies with shorter durations of follow-up. NICE encourages clinicians to continue to collect and publish data on longer-term outcomes, which should include information about patient selection and the need for further surgery. **Percutaneous endoscopic laser lumbar discectomy. NICE interventional procedure guidance 300 (2009).** 1.1 Current evidence on the safety and efficacy of percutaneous endoscopic laser lumbar discectomy is inadequate in quantity and quality. Therefore this procedure should only be used with special arrangements for clinical governance, consent, and audit or research. 1.2 Clinicians wishing to undertake percutaneous endoscopic laser lumbar discectomy should take the following actions. • Inform the clinical governance leads in their Trusts. • Ensure that patients and their carers understand the uncertainty about the procedure's safety and efficacy and provide them with clear written information. In addition, the use of NICE's information for patients ('Understanding NICE guidance') is recommended. • Audit and review clinical outcomes of all patients having percutaneous endoscopic laser lumbar discectomy (see section 3.1). 1.3 Surgeons undertaking this procedure should have specific

	training in the use of lasers and in endoscopy of the spinal canal. 1.4 NICE encourages further research into percutaneous endoscopic laser lumbar discectomy and may review the procedure on publication of further evidence. Research studies should provide long-term outcome data. **Automated percutaneous mechanical lumbar discectomy. NICE interventional procedure guidance 141 (2005).** 1.1 Current evidence suggests that there are no major safety concerns associated with automated percutaneous mechanical lumbar discectomy. There is limited evidence of efficacy based on uncontrolled case series of heterogeneous groups of patients, but evidence from small randomised controlled trials shows conflicting results. In view of the uncertainties about the efficacy of the procedure, it should not be used without special arrangements for consent and for audit or research. 1.2 Clinicians wishing to undertake automated percutaneous mechanical lumbar discectomy should take the following actions. • Inform the clinical governance leads in their Trusts. • Ensure that patients understand the uncertainty about the procedure's efficacy and provide them with clear written information. In addition, use of the Institute's information for the public is recommended. • Audit and review clinical outcomes of all patients having automated mechanical percutaneous lumbar discectomy. The Institute may review the procedure upon publication of further evidence.

NICE guidelines	**Low back pain in adults: early management. NICE clinical guideline 88 (2009).** **1.1 Assessment and imaging** 1.1.1 Keep diagnosis under review. 1.1.2 Do not offer X-ray of the lumbar spine for the management of non-specific low back pain. 1.1.3 Consider MRI (magnetic resonance imaging) when a diagnosis of spinal malignancy, infection, fracture, cauda equina syndrome or ankylosing spondylitis or another inflammatory disorder is suspected. 1.1.4 Only offer an MRI scan for non-specific low back pain within the context of a referral for an opinion on spinal fusion (see section 1.9). **1.2 Information, education and patient preferences** 1.2.1 Provide people with advice and information to promote self-management of their low back pain. 1.2.2 Offer educational advice that: • includes information on the nature of non-specific low back pain • encourages the person to be physically active and continue with normal activities as far as possible. 1.2.3 Include an educational component consistent with this guideline as part of other interventions, but do not offer stand-alone formal education programmes. 1.2.4 Take into account the person's expectations and preferences when considering recommended treatments, but do not use their expectations and preferences to predict their response to

	treatments. 1.2.5 Offer one of the following treatment options, taking into account patient preference: an exercise programme (see section 1.3.3), a course of manual therapy (see section 1.4.1) or a course of acupuncture (see section 1.6.1). Consider offering another of these options if the chosen treatment does not result in satisfactory improvement. **1.3 Physical activity and exercise** 1.3.1 Advise people with low back pain that staying physically active is likely to be beneficial. 1.3.2 Advise people with low back pain to exercise. 1.3.3 Consider offering a structured exercise programme tailored to the person: • This should comprise up to a maximum of eight sessions over a period of up to 12 weeks. • Offer a group supervised exercise programme, in a group of up to 10 people. • A one-to-one supervised exercise programme may be offered if a group programme is not suitable for a particular person. 1.3.4 Exercise programmes may include the following elements: • aerobic activity • movement instruction • muscle strengthening • postural control • stretching.

	1.4 Manual therapy The manual therapies reviewed were spinal manipulation (a low-amplitude, high-velocity movement at the limit of joint range that takes the joint beyond the passive range of movement), spinal mobilisation (joint movement within the normal range of motion) and massage (manual manipulation or mobilisation of soft tissues). Collectively these are all manual therapy. Mobilisation and massage are performed by a wide variety of practitioners. Manipulation can be performed by chiropractors and osteopaths, as well as by doctors and physiotherapists who have undergone specialist postgraduate training in manipulation. 1.4.1 Consider offering a course of manual therapy, including spinal manipulation, comprising up to a maximum of nine sessions over a period of up to 12 weeks. **1.5 Other non-pharmacological therapies** **Electrotherapy modalities** 1.5.1 Do not offer laser therapy. 1.5.2 Do not offer interferential therapy. **1.5.3 Do not offer therapeutic ultrasound.** **Transcutaneous nerve stimulation** 1.5.4 Do not offer transcutaneous electrical nerve simulation (TENS). **Lumbar supports** 1.5.5 Do not offer lumbar supports.

Traction

1.5.6 Do not offer traction.

1.6 Invasive procedures

1.6.1 Consider offering a course of acupuncture needling comprising up to a maximum of 10 sessions over a period of up to 12 weeks.

1.6.2 Do not offer injections of therapeutic substances into the back for non-specific low back pain.

1.7 Combined physical and psychological treatment programme

1.7.1 Consider referral for a combined physical and psychological treatment programme, comprising around 100 hours over a maximum of 8 weeks, for people who:

- have received at least one less intensive treatment (see section 1.2.5) **and**
- have high disability and/or significant psychological distress.

1.7.2 Combined physical and psychological treatment programmes should include a cognitive behavioural approach and exercise.

1.8 Pharmacological therapies

Both weak opioids and strong opioids are discussed in the recommendations in this section. Examples of weak opioids are codeine and dihydrocodeine (these are sometimes combined with paracetamol as co-codamol or co-dydramol, respectively). Examples of strong opioids are buprenorphine, diamorphine, fentanyl and oxycodone. Some opioids, such as tramadol, are

	difficult to classify because they can act like a weak or strong opioid depending on the dose used and the circumstances. No opioids, cyclooxygenase 2 (COX-2) inhibitors or tricyclic antidepressants and only some non-steroidal anti-inflammatory drugs (NSAIDs) have a UK marketing authorisation for treating low back pain. If a drug without a marketing authorisation for this indication is prescribed, informed consent should be obtained and documented. 1.8.1 Advise the person to take regular paracetamol as the first medication option. 1.8.2 When paracetamol alone provides insufficient pain relief, offer: • non-steroidal anti-inflammatory drugs (NSAIDs) **and/or** weak opioids Take into account the individual risk of side effects and patient preference. 1.8.3 Give due consideration to the risk of side effects from NSAIDs, especially in: • older people • other people at increased risk of experiencing side effects. 1.8.4 When offering treatment with an oral NSAID/COX-2 (cyclooxygenase 2) inhibitor, the first choice should be either a standard NSAID or a COX-2 inhibitor. In either case, for people over 45 these should be co-prescribed with a PPI (proton pump inhibitor), choosing the one with the lowest acquisition cost. [This recommendation is adapted from 'Osteoarthritis: the care and

	management of osteoarthritis in adults' (NICE clinical guideline 59).] 1.8.5 Consider offering tricyclic antidepressants if other medications provide insufficient pain relief. Start at a low dosage and increase up to the maximum antidepressant dosage until therapeutic effect is achieved or unacceptable side effects prevent further increase. 1.8.6 Consider offering strong opioids for short-term use to people in severe pain. 1.8.7 Consider referral for specialist assessment for people who may require prolonged use of strong opioids. 1.8.8 Give due consideration to the risk of opioid dependence and side effects for both strong and weak opioids. 1.8.9 Base decisions on continuation of medications on individual response. 1.8.10 Do not offer selective serotonin reuptake inhibitors (SSRIs) for treating pain. **1.9 Referral for surgery** 1.9.1 Consider referral for an opinion on spinal fusion for people who: • have completed an optimal package of care, including a combined physical and psychological treatment programme (see section 1.7) **and** • still have severe non-specific low back pain for which they would consider surgery.

	1.9.2 Offer anyone with psychological distress appropriate treatment for this before referral for an opinion on spinal fusion. 1.9.3 Refer the patient to a specialist spinal surgical service if spinal fusion is being considered. Give due consideration to the possible risks for that patient. 1.9.4 Do not refer people for any of the following procedures: • intradiscal electrothermal therapy (IDET) • percutaneous intradiscal radiofrequency thermocoagulation (PIRFT) • radiofrequency facet joint denervation.

Appendix C: Literature search for lateral interbody fusion in the lumbar spine for low back pain

Databases	Date searched	Version/files
Cochrane Database of Systematic Reviews – CDSR (Cochrane)	22/03/2016	Issue 3 of 12, March 2016
HTA database (Cochrane)	22/03/2016	Issue 1 of 4, January 2016
Cochrane Central Register of Controlled Trials (Cochrane)	22/03/2016	Issue 2 of 12, February 2016
MEDLINE (Ovid)	21/03/2016	1946 to March Week 2 2016
MEDLINE In-Process (Ovid)	21/03/2016	March 18, 2016
EMBASE (Ovid)	22/03/2016	1974 to 2016 Week 12
PubMed	21/03/2016	n/a
BLIC (British Library)	22/03/2016	n/a

Trial sources searched on 16 March 2016

- Clinicaltrials.gov
- ISRCTN
- WHO International Clinical Trials Registry

Websites searched on 16/03/2016

- National Institute for Health and Care Excellence (NICE)
- NHS England
- Food and Drug Administration (FDA) - MAUDE database
- Australian Safety and Efficacy Register of New Interventional Procedures – Surgical (ASERNIP – S)
- Australia and New Zealand Horizon Scanning Network (ANZHSN)
- EuroScan
- General internet search

The following search strategy was used to identify papers in MEDLINE. A similar strategy was used to identify papers in other databases.

1	spinal fusion/
2	((spine* or spinal*) adj4 fusion*).ti,ab.
3	(fusion* adj4 (inter-bod* or interbod*)).ti,ab
4	lumbar vertebrae/
5	intervertebral disc/
6	Thoracic Vertebrae/

7	((lumbar* or intervertebr* or thoracic*) adj4 fusion*).ti,ab.
8	Degenerative disc disease*.ti,ab.
9	Degenerative disk disease*.ti,ab.
10	(spin* adj4 arthrosi*).ti,ab.
11	(lateral* adj1 (inter-bod* or interbod*) adj1 fusion*).ti,ab.
12	or/1-11
13	(extralateral* or extra lateral* or direct lateral* or extreme lateral*).ti,ab.
14	(lateral* adj1 (inter-bod or interbod*) adj1 fusion*).ti,ab.
15	13 or 14
16	12 and 15
17	(XLIF or nuvasive).ti,ab.
18	16 or 17
19	animals/ not humans/
20	18 not 19