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Subsidence of Spinal Fusion Cages: A Systematic Review

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ABSTRACT

Background: Although many research studies investigating subsidence of intervertebral fusion cages have been published, to our knowledge, no study has comprehensively compared cage subsidence among all lumbar intervertebral fusion (LIF) techniques. This study aimed to review the literature reporting evidence of cage subsidence linked to LIF. The amount of subsidence was compared and associated with the procedures and corresponding implants used, and the effect of cage subsidence on clinical outcomes was investigated.

Methods: For this systematic review, the MEDLINE and PubMed databases were used to identify relevant studies. Search terms included lumbar, lumbar vertebrae, lumbar spine, cage, spinal fusion, prosthesis, prosthesis implantation, implantation, implants, interbody, spacer, and subsidence. Studies included in this review were those having more than 10 patients and reporting the amount of subsidence observed using computed tomography or x-ray imaging after surgery and at follow-up visits after a minimum of 6 weeks postsurgery. Data and scale definitions related to subsidence were extracted from articles for comparison of subsidence prevalence between the 5 LIF surgical procedures.

Results: Forty articles were identified for inclusion. The review included data from 390 anterior lumbar intervertebral fusions (ALIFs), 2130 lateral lumbar intervertebral fusions (LLIFs), 560 posterior lumbar intervertebral fusions (PLIFs), 245 oblique lumbar intervertebral fusions (OLIFs), and 1634 transverse lumbar intervertebral fusions (TLIFs) for a total of 4959 patients who underwent LIF surgery. The minimum and maximum percentages of the number of patients having subsidence for each procedure in the included studies were as follows: ALIF stand-alone, 6% and 23.1%; LLIF stand-alone, 8.7% and 39.6%; LLIF with posterior fixation, 3.3% and 20.7%; OLIF with posterior fixation, 4.4% and 36.9%; PLIF with posterior fixation, 7.4% and 31.8%; and TLIF, 0.0% and 51.2%.

Conclusions: The number of patients experiencing subsidence varied between studies within each fusion procedure. Our findings indicate that all 5 surgical methods are at risk of subsidence. Overall, ALIF without posterior fixation resulted in the lowest reported subsidence occurrence among the 5 surgical approaches. There is conflicting evidence on the association between subsidence and negative clinical outcomes.

Clinical Relevance: This review defines and compares subsidence incidence between all LIF procedures and investigates the risk of symptomatic clinical outcomes.

Level of Evidence: 4.

Lumbar Spine

Keywords: anterior lumbar interbody fusion (ALIF), lateral lumbar interbody fusion (LLIF), oblique lumbar interbody fusion (OLIF), posterior lumbar interbody fusion (PLIF), transverse lumbar interbody fusion (TLIF)

INTRODUCTION

Degeneration of an intervertebral disc (IVD), caused by changes in permeability and water content of annulus and nucleus pulposus, leads to a decrease of the disc space.[1] Numerous pathologies associated with IVD degeneration such as sciatica, disc prolapse, nucleus pulposus herniation, spinal stenosis, spondylolisthesis, and scoliosis, among others, require the removal of the disc followed by the fusion of the adjacent vertebrae. Surgeons may choose between 5 approaches to perform the fusion: anterior lumbar intervertebral fusion (ALIF), lateral lumbar intervertebral fusion (LLIF), posterior lumbar intervertebral fusion (PLIF), oblique lumbar intervertebral fusion (OLIF), and transverse lumbar intervertebral fusion (TLIF) (Table 1).

Each surgical approach has their own benefits and potential risks. All can lead to cage subsidence: a significant loss of disc space occurring when the implant migrates into the vertebral bodies. Complications resulting from cage subsidence can vary from loss of disc height and lumbar lordosis to the narrowing of the intervertebral foramen and foraminal stenosis. A change in the lordosis will hinder the sagittal balance and kinematics of the spine and may lead to back pain.[6–8] If the lordosis angle and height are not properly corrected, spinal nerve decompression and the strength of the fusion are compromised.[9] Subsidence can also jeopardize the alignment of the spine during fusion and lead to cyst formation.[7,10,11] All those complications can potentially result in nonunion, lead to adjacent-level

Table 1. Surgical procedure's description of the lumbar intervertebral fusion methods.

Surgical Procedure	Description
ALIF	The ALIF technique consists of an anterior retroperitoneal approach that provides access to the disc, with the patient in supine position. It involves a 3- to 5-inch midline and paramedian incision, the opening of the longitudinal ligament, and an important vascular mobilization, leaving the paraspinal muscles intact.[2,3] This approach allows the insertion of a cage that covers the entire endplate surface, including the apophyseal ring, which stabilizes the motion segments, which may not require adjunct pedicle screws.
LLIF	LLIF is performed by a lateral retroperitoneal incision on a laterally positioned patient. This creates a transpsoas corridor to access the disc space and insert the implant.[2] Like the cages used in ALIF, the LLIF implant is placed medially and has a large footprint covering parts of the apophyseal ring.
OLIF	The OLIF surgery requires patients to be positioned on their side. It involves a lateral and paramedian incision between the peritoneum and the psoas muscle to access the disc space.[2] A smaller implant than for ALIF and LLIF is inserted, covering the interior one-third portion of the endplate. It will rarely cover the apophyseal ring and mostly be used in conjunction with posterior fixations.
PLIF	PLIF, one of the first procedures used for IVD fusion surgery, accesses the IVD space from a posterior direction with the patient in a prone position. A midline incision dissecting bilateral muscle strip or splitting paramedian muscle is performed. Before inserting the cage, a laminectomy and a partial facetectomy are performed to navigate around nerve roots.[4] Depending on the cage design, 1 or 2 cages are inserted within the apophyseal ring.[2–4]
TLIF	The transforaminal TLIF provides access to the intervertebral space directly through a small unilateral incision on 1 side of the neural foramen while the patient is in prone position, minimizing nerve manipulation.[2] This may involve extensive muscle retraction and dissection with the removal of the facet joint in order to place a straight or curved cage. TLIF cages have significantly smaller footprint coverage than ALIF and LLIF cages.[3,5] Depending on the cage used and the surgeon's approach, the TLIF cage can either be placed on the interior or medial part of the endplate. TLIF does not provide enough segmental stability without the use of posterior fixation.

Abbreviations: ALIF, anterior lumbar interbody fusion; IVD, intervertebral disc; LLIF, lateral lumbar interbody fusion; OLIF, oblique lumbar interbody fusion; PLIF, posterior lumbar interbody fusion; TLIF, transverse lumbar interbody fusion.

degeneration, and/or cause recurrent symptoms requiring revision surgery.[12,13]

This study aimed to comprehensively review the available literature reporting evidence of subsidence linked to lumbar intervertebral fusion (LIF), compare the amount of cage subsidence associated with the different surgical procedures and implants used, and determine whether a procedure or type of implant causes symptomatic clinical outcomes.

The literature shows that occurrence of subsidence has been studied for specific LIF approaches,[9,14–18] few systematic reviews reported subsidence comparing 2 LIF approaches,[19,20] and multiple studies have been published to find ways to reduce subsidence.[8,21–23] No study, to our knowledge, has specifically reviewed subsidence in all the LIF techniques, and it is unclear whether cage subsidence is a significant problem that needs to be addressed in any of these approaches. This review aims to assist in the selection of surgical technique and implant type and help improve cage design.

METHODS

A systematic review of literature was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration.[24] This review was not registered with PROSPERO or any equivalent database.

The systematic search was performed using MEDLINE and PubMed databases using the following search items: ("lumbar" [all fields] or "lumbar vertebrae" [mesh] or "lumbar vertebrae" [all fields] or "lumbar spine" [mesh]) and ("cage" [all fields] or "spinal fusion" [all fields] or "spinal fusion" [mesh] or "prosthesis" [all fields] or "prosthesis implantation" [all fields] or "implantation" [all fields] or "implants" [all fields] or "implant" [all fields] or "interbody" [all fields] or "spacer" [all fields]) and ("subsidence" [all fields] or "subsidence" [mesh]), for the period including 1 January 2013 to Present. The last search run was done on 15 March 2020. Articles older than 2013 were not investigated to ensure comparability of data, considering that medical and technical advancements over time could influence results.

Articles not available in English and duplicate articles were excluded. Studies regarding cervical fusion, thoracic fusion, or corpectomy were excluded, as were single case studies and animal studies. All articles based on fewer than 10 patients, in addition to articles with the same authors overlapping patient datasets were also excluded. No discrimination was made based on age, gender, implant manufacturers, surgeons training, patients' bone mineral density (BMD), prevalence of other medical issues, and patients' body mass index (BMI).

Only results from articles respecting the following quality criteria were included: The studies must measure subsidence based on x-ray or computed tomography (CT) images taken in the first few weeks following surgery and at the final follow-up, and articles must specify the last follow-up time frame and their subsidence measuring scale. Any articles presenting data based on postoperative follow-ups earlier than 6 weeks were disregarded, since subsidence is normally seen 6 weeks postsurgery and onward.[12] Furthermore, only studies evaluating ALIF and LLIF without pedicle screws were included in the ALIF and LLIF groups, and only studies with posterior fixation were considered for the LLIF with posterior fixation (LLIF-P), OLIF with posterior fixation (OLIF-P), PLIF with posterior fixation (PLIF-P), and TLIF with posterior fixation (TLIF-P) groups.

A data extraction sheet was developed to summarize details facilitating the final comparisons between surgical methods. This sheet included information regarding the authors, number of patients, number of levels operated, follow-up rates for subsidence assessment, use of pedicle screws during surgery, implant type, subsidence occurrence, inclusion and exclusion pathology criterion, radiological and clinical assessment evaluated, as well as each article's specific definition for subsidence. A second extraction sheet was used to compile all analyses of studies evaluating possible correlation between postsurgery complications and subsidence.

Having no universal protocol to measure subsidence, a subgroup analysis was performed to evaluate the different definitions of subsidence regardless of the surgery method. The authors' definitions of subsidence were divided into 3 groups: undefined subsidence, moderate subsidence, and substantial subsidence. Undefined subsidence considers patients with more than 1 mm of subsidence or any breakage of the endplate. Since the average disc height is 8 mm, moderate subsidence includes all patients from studies considering subsidence greater than 2, 3 mm, 25% of the implant height, or a significant reduction in disc space. Substantial subsidence includes patients with subsidence greater than 4 mm, more than 50% of implant height, or symptomatic subsidence. When studies separated their results between different scales, the subsidence occurrence was divided in their respective category. Differences between groups were assessed using independent sample *t* tests.

The primary analysis of this literature review is the comparison of subsidence occurrence between the different surgical procedures. With the data collected from the included studies, a box-and-whisker graph identifying the first, median, and third quartiles of subsidence occurrence was created to visualize the distribution of the results from each study, within each LIF methods (Figure 2). Any study with a resulting occurrence of more than 1.5 times the interquartile range was considered an outlier and is displayed by a point.[25]

RESULTS

Study Selection

A search via MEDLINE (473) and PubMed (262) first provided 735 citations and left 725 without duplicates. After reading the titles and abstracts of the remaining citations, 332 did not report the targeted data and were excluded. Of the remaining studies, 289 were discarded because they discussed issues related to cervical or thoracic fusion, corpectomy, non-IVD fusion surgery, usage of expandable cages, single case or animal studies, or involved fewer than 10 patients. An additional 65 studies were excluded through full-text assessment because they involved cadaveric experiments, finite element analysis, previously reported reviews, and meta-analyses, or they did not meet all the inclusion quality criteria. A total of 40 studies were included in the review (Figure 1).

Study Characteristics

The included studies involved 390 ALIF, 1530 LLIF, 600 LLIF-P, 560 OLIF, 245 PLIF, and 1634 TLIF patients for a total of 4959 patients who received a single form of LIF surgery. When the information was provided, the number of levels treated was noted along with the number of patients because subsidence can occur on 1 or several levels for the same patient. When studies presented multiple follow-ups, all follow-ups were noted, and the subsidence occurrence of the latest period was extracted. A summary of the 40 included studies is provided in Table 2.

Risk of Bias Within Studies

This study is based on observational studies, leading to less control on the consistency of data collected. Quality criteria were established to assure that any conclusion drawn from meta-analysis relies on well-defined articles. No significant difference was found between the subsidence occurrence mean of the undefined subsidence (17.3%), moderate subsidence (20.5%), and substantial subsidence (17.7%) groups, all $P > 0.05$. However, there is still substantial variation within the scale used. Factors that can affect the amount

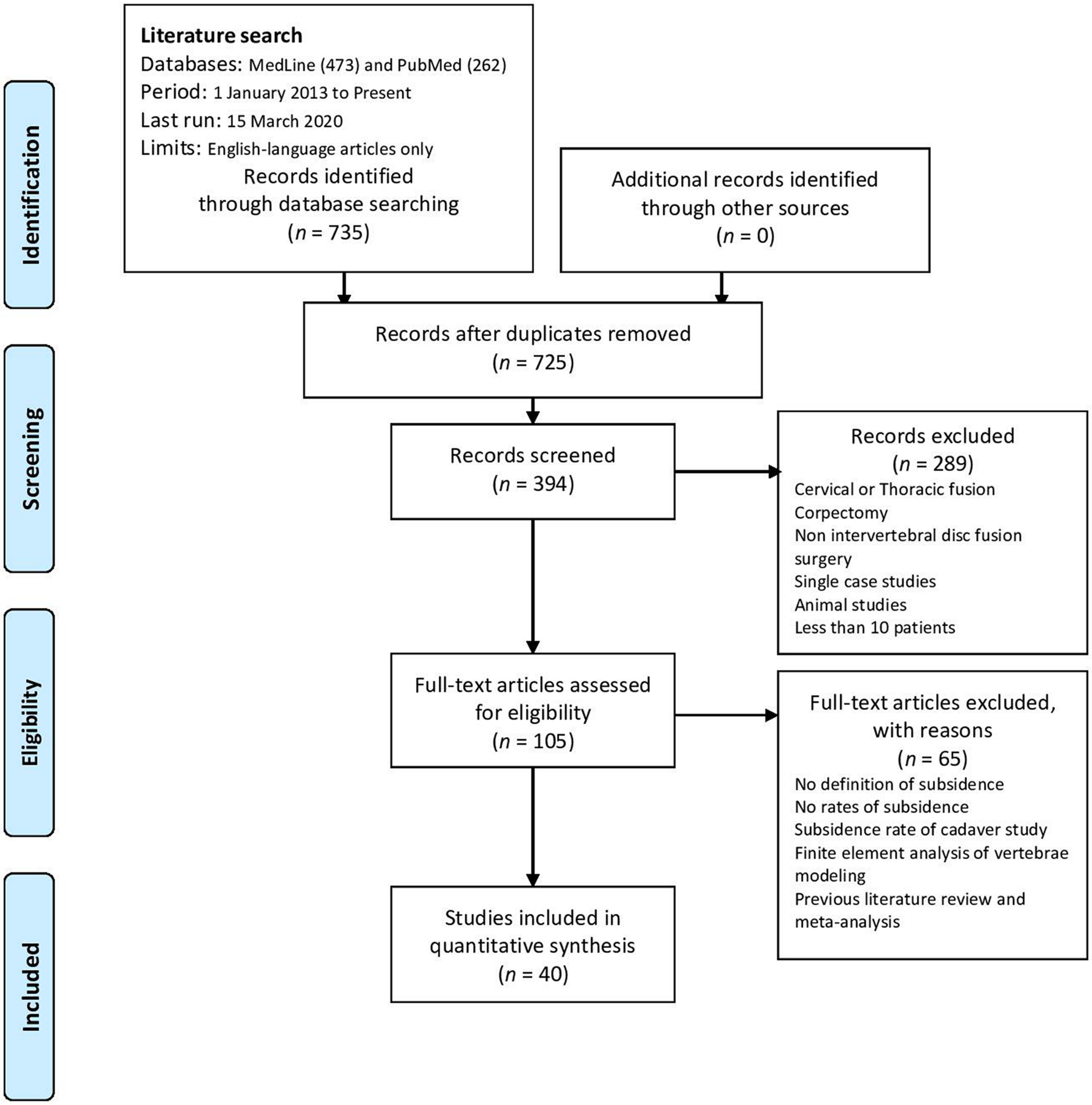

Figure 1. Flow diagram of the study selection process.

of subsidence such as patients' medical state, surgeons' specific manipulation, and preparation of the vertebra or the choice of cage size implanted cannot be controlled. Furthermore, the placement of the cage can vary, and its exact location is not described in most of the articles. Other details regarding different age groups, pathologies leading to surgery, number of levels operated, and length of follow-up periods can cause additional bias. Some articles present subsidence rate by calculating occurrence per patient and others by occurrence per levels treated, limiting the comparison.

Few studies discussed specific pathologies that could have implications on subsidence; hence, their results create the potential for bias. Studies specific to adjacent segment disease or spondylolisthesis can affect the generalization of the results included. The numbers of level fused (single- and multilevel surgery) will also affect the generalization of the results. The numbers of studies reporting on specific pathology and surgery type are summarized in Table 3. It should be noted that there is variation in the average age and BMD of patients investigated in all studies included in this article. As such, BMD and patient age have an impact on subsidence,[50] which leads to biased results.

Most equipment and implants used during surgery are standard with small variations between brands. The majority of ALIF studies used Synfix or ROI-A oblique PEEK cage, LLIF and LLIF-P used CoRoent or COUGAR (NuVasive)

Table 2. Summary of surgical procedures and resulting subsidence occurrence by study.

Authors (Year)	No. of Patients at Final Follow-Up	No. of Levels	Postoperative Follow-Up	Pedicle Screws	Implant Type	Subsidence Considered	Subsidence Occurrence	Pathology Criteria	Radiological Assessments	Clinical Assessments
ALIF										
Behrbalk et al (2013)[18]	25	32	2, 6, 12, and 18 mo	No	PEEK (Synthes SynFix-LR) cage	>1 mm	5/32 (15.6%)[a]	Only patients with grade 1 degenerative spondylolisthesis were included	CT or x-ray imaging	N/A
Kuang et al (2017)[26]	42	50	3, 12, and 24 mo	No	Self-anchored stand-alone PEEK cage (ROI-A Oblique; LDR Medical)	Any compromise to the endplate	3/50 (6%)[a]	All spinal pathology considered Excluded high BMI (≥28 kg/m^2), severe osteoporosis, spinal stenosis, disc herniation, and spondylolisthesis	CT or x-ray imaging	N/A
Lee et al (2017)[27]	26	26	12 and 24 mo	No	Synfix PEEK cage (Synthes)	Any breakage of the endplate	4/26 (15.4%)	Included patients with lower back pain, severe disc space narrowing, and moderate grade of spondylolisthesis; excluded patients with deformity, history of lumbar surgery, or ossification of the ligamentum flavum	CT	VAS
Phan et al (2017)[28]	137	N/A	6 wk	No	SynFix-LR PEEK integral cage device (Depuy)	>2 mm	<49 y old 2/45 (4.4%) 50–63 y old 2/46 (4.3%) >64 y old 10/46 (21.7%) No age consideration 14/137 (10.2%)	All spinal pathology considered	CT	ODI and SF-12
Rao et al (2017)[29]	147	N/A	6 wk and 18 mo	No	SynFix-LR PEEK integral (Depuy) for 89.1% of the patients	>2 mm	15/147 (10.2%)	All spinal pathology considered	CT and x-ray imaging	ODI, VAS, and SF-12
Tu et al (2018)[30]	13	N/A	3, 12, and 24 mo	No	PEEK cages (ROI-A Oblique; LDR Medical)	>2 mm	3/13 (23.1%)	Included patients with ASD, all patients with additional spinal pathologies that were not severe were also included	CT and x-ray imaging	VAS, ODI, SF-36, and Macnab criteria
LLIF										
Marchi et al (2013)[12]	74	98	2, 6 wk, 3, 6, and 12 mo	No	46 with standard cages (18 mm) 28 with wide cages (22 mm) (CoRoent, NuVasive)	High grade; >50% cage collapsed in the endplate	30%[a] for the standard cages and 11%[a] for the wide cages	Most spinal pathology included; excluded patients with damaged spine structure, compromised vertebral bodies, presence of neuromuscular disease, severe central stenosis, and significant instability and scoliosis	CT	VAS and ODI
Tohmeh et al (2014)[31]	140	223	12 mo minimum (average last follow-up at 15.5 mo)	Yes	18- and 22-mm PEEK cages (CoRoent; NuVasive)	>1 mm, 2–4 mm, >4 mm	>1 mm; 15/223 (6.7%)[a] 2–4 mm; 71/223 (31.8%)[a] >4 mm; 53/223 (23.8%)[a]	All spinal pathology considered	Fluoroscopy and CT	ODI, VAS, and SF-36
Kotwal et al (2015)[32]	118	237	Minimum of 24 mo (average last follow-up at 27.5 mo)	Yes	PEEK cages (Nuvasive) for 112 patients and carbon fiber cages (Depuy Spine) for 6 patients	>2 mm	34/237 (14.3%)[a]	Included neurological claudication with deformity or instability, scoliosis, spondylolisthesis, and junctional disc degeneration	X-ray imaging	VAS, ODI, and SF-12
Malham et al (2015)[33]b	128	178	6 wk and 3, 6, and 12 mo (average last follow-up at 25.1 mo)	56 without and 72 with fixations	PEEK cages with 18- and 22-mm width (NuVasive)	Compromised endplate	13/125 (10.4%) 6 had pedicle screws and 7 didn't have the posterior fixation	All spinal pathology considered	CT	VAS, ODI, and SF-36
Tempel et al (2015)[34]	335	712	12 mo	No	22-mm wide PEEK cages	A loss of more than 25% of the disc height	29/335 (8.7%) patients with subsidence	All spinal pathology considered	X-ray imaging	N/A
Isaacs et al (2016)[35]	29	36	6, 12 wk, 6, 12, and 24 mo	Yes	16 patients with 18-mm width titanium cages (CoRoent XL, NuVasive), 86 patients with 18-mm width PEEK XLIF (NuVasive)	>3 mm	1/30 (3.3%)	Only patients with grade I or II degenerative spondylolisthesis were considered	CT (12 mo)	VAS, ODI, and SF-36
Yen et al (2017)[10]	140	247	1, 3, 6, and 12 mo	37.1% No 62.9% Yes	18–22-mm wide 50–60-mm long PEEK cages	A loss of more than 25% of the disc height	22/79 (27.8%)[a] without pedicle screws, 30/168 (17.9%)[a] with pedicle screws	All spinal pathology considered	X-ray imaging	N/A

Table 2. Continued.

Authors (Year)	No. of Patients at Final Follow-Up	No. of Levels	Postoperative Follow-Up	Pedicle Screws	Implant Type	Subsidence Considered	Subsidence Occurrence	Pathology Criteria	Radiological Assessments	Clinical Assessments
Du et al (2017)[36]	39	39	6 mo	Yes	18–22-mm wide cages	Low grade; >25% cage collapsed in the endplate High grade; >50% cage collapsed in the endplate	Low grade; 2/39 (5%) High grade; 0%	All spinal pathology considered	X-ray imaging	ODI, VAS, and SF-12
Bocahut et al (2018)[9]	69	82	12 mo	No	Avenue L cage (Zimmer)	>4 mm	20/63 (32%)	All spinal pathology considered	CT imaging	VAS and ODI
Tempel et al (2018)[34]	297	623	6 wk, 3, 6, 12, and 24 mo	No	18-h and 22-mm wide PEEK	Low grade; >25% cage collapsed in the endplate High grade; >50% cage collapsed in the endplate	Low grade; 12/297 (4.04%) High grade; 22/297 (7.4%)	All spinal pathology considered	X-ray imaging and CT	N/A
Chen et al (2019)[23]	107	126	3 d, 3, 12, and 24 mo	No	PEEK cages	Low grade; >25% cage collapsed High grade; >50% cage collapsed in the endplate	High grade; (26.9%)	Included all patients with degenerative disease	X-ray imaging and CT	JOA and VAS
Jung et al (2019)[37]	84	84	1, 3, 6, 12, and 24 mo	Yes	PEEK cages	>3 mm	Patients with osteopenia 7/41 (17.1%) Patients with normal bone mineral density 4/43 (9.3%)	All spinal pathology considered	X-ray imaging	VAS and ODI
Ko et al (2019)[38]	29	29	Minimum of 12 mo (average last follow-up at 33.6 mo)	Yes	PEEK with titanium coating Clydesdale cage (Medtronic)	>2 mm	6/29 (20.7%)	Included only patients with degenerative spondylolisthesis	X-ray imaging	VAS and ODI
Park et al (2019)[39]	40	62	3 and 24 mo	No	N/A	Low grade; >25% cage collapsed in the endplate High grade; >50% cage collapsed in the endplate	Low grade; 11/62 (17.7%)[a] High grade; 8/62 (12.9%)[a]	Included only patients with ASD needing revision surgery	X-ray imaging	VAS and ODI
Rentenberger et al (2019)[40]	122	258	12 mo	No	PEEK cage Nuvasive Inc. or COUGAR system (Depuy)	High grade; >50% cage collapsed in the endplate	High grade; 69/258 (26.7%)[a]	All spinal pathology considered	X-ray imaging and CT	N/A
Agarwal et al (2020)[41]	297	623	6 wk, 3, 6, 12, and 24 mo	No	18- and 22-mm cages	Low grade; >25% cage collapsed in the endplate High grade; >50% cage collapsed in the endplate	Low grade; 10/297 (3.4%) High grade; 20/297 (6.7%)	All spinal pathology considered	X-ray imaging	N/A
Okano et al (2020)[42]	96	210	Between 6 and 12 mo	No	PEEK cage (Nuvasive) or COUGAR system (Depuy Spine)	High grade; >50% cage collapsed in the endplate	38/96 (39.6%) 58/210 (27.6%)[a]	All spinal pathology considered	X-ray imaging or CT	N/A
OLIF										
Woods et al (2017)[43]	137	340	6 mo	Yes	PEEK with titanium coating (Medtronic CLYDESDALE)	Any breach of the endplate adjacent to disc space	6/137 (4.4%)	All spinal pathology considered	CT and x-ray imaging	N/A
Lin et al (2018)[44]	25	25	6, 12, and 24 mo	Yes	PEEK Clydesdale; (Medtronic)	>2 mm	3/20 (15%)	All spinal pathology considered Excluded patients with severe canal stenosis, spinal tumor, infection, fractures, and previous L4-L5 surgery	X-ray imaging	VAS and ODI
Chang et al (2019)[45]	169	262	3, 6, and 12 mo	Yes	PEEK cages	>25% cage collapsed in the endplate	62/168 (36.9%) 85/261 (32.6%)[a]	All spinal pathology considered	X-ray imaging	ODI, SF-36, VAS, and JOA back pain evaluation questionnaire
Lin et al (2019)[13]	67	107	6, 12, and 24 mo	Yes	18–22-mm wide, 8–16-mm high, 40–55-mm long, PEEK cages Clydesdale (Medtronic)	>3 mm	19/107 (17.8%)[a]	Included all degenerative spinal disease Excluded infection, trauma, neoplasm, and patient with previous lumbar surgery	CT	VAS, ODI, and Macnab criteria

Table 2. Continued.

Authors (Year)	No. of Patients at Final Follow-Up	No. of Levels	Postoperative Follow-Up	Pedicle Screws	Implant Type	Subsidence Considered	Subsidence Occurrence	Pathology Criteria	Radiological Assessments	Clinical Assessments
Liu and Feng (2019)[46]	14	20	Minimum of 12 mo (last follow-up in the range of 12–45 mo)	Yes	(Clydesdale Spinal System, Medtronic)	>25% cage collapsed in the endplate	1/14 (7.1%)	Included all degenerative spinal disease Excluded infection, spinal tumor, vertebral fracture, hypertrophic ligamentum flavum, lesions involving L5-S1, fused facet, and patient with severe spondylolisthesis	X-ray imaging	VAS and ODI
Mun et al (2019)[47]	74	74	Minimum 6 mo (average last follow-up at 12.1 mo)	Yes	Large round PEEK cage (Perimeter, Medtronic)	>2 mm	(25.3%)	All spinal pathology considered Excluded patient with infection, tumor, and congenital anomalies	X-ray imaging	VAS and ODI
Wen et al (2019)[48]	74	74	24 mo	Yes; bilateral and uni-lateral	N/A	High grade; >50% cage collapsed in the endplate	High grade; 13/74 (17.6%)	All spinal pathology considered Excluded high BMI (≥35 kg/m^2), severe osteoporosis, lumbar infection, lumbar tumor, and patient with previous lumbar surgery	X-ray imaging	VAS and ODI
PLIF										
Suzuki et al (2013)[49]	19	19	Minimum 12 mo (average last follow-up at 54.6 mo)	Yes	2 PEEK, parallelepiped (REC) cages 16.4–14.6 wide 12.0–11.0 high (Telamon-S/-C/-, 22.0 mm length; Medtronic) or Brantigan I/F cage 11.0 mm wide, 11.0 mm height, 23.0 mm length (Depuy, Raynhem)	>2 mm	3/19 (15.8%)	Included patients with osteoporotic vertebral collapse with neurologic deficit	X-ray imaging	VAS
Lee et al (2017)[27]	30	30	12 and 24 mo	Yes	2 PEEK cages (Medtronic)	Any breakage of the endplate	3/30 (10%)	Included patients with lower back pain, leg pain, neurogenic intermittent claudication, moderate disc space narrowing, and severe grade of spondylolisthesis Excluded, patient with deformity, with history of lumbar surgery, and ossification of the ligamentum flavum	CT imaging	VAS
Oh et al (2017)[50]	129	139	3, 6, and 12 mo; Minimum of 12 mo (average last follow-up at 49.2 mo)	Yes	PEEK cage (O.I.C. cages; Stryker)	1–3 and >3 mm	>3 mm 22/139 (15.8%)[a]	All spinal pathology considered	CT imaging	VAS, ODI, and SF-36
Tu et al (2018)[30]	27	N/A	3, 12, and 24 mo	Yes	PEEK cages (Libeier; Orthopedic)	>2 mm	2/27 (7.4%)	Included patients with ASD (all patients with additional spinal pathologies who were not severe were also included)	CT	VAS, ODI, SF-36, and Macnab criteria
Park et al (2019)[39]	40	44	3 and 24 mo	Yes	N/A	Low grade; >25% cage collapsed in the endplate High grade; >50% cage collapsed in the endplate	Low grade; 10/44 (22.7%)[a] High grade; 4/44 (9.1%)[a]	Included only patients with ASD needing revision surgery	X-ray imaging	VAS and ODI
TLIF										
Kim et al (2013)[14]	104	122	Minimum 24 mo (last follow-up range from 24 to 45 mo)	Yes	Bullet-shaped PEEK cage (Capstone; Medtronic)	>2 mm	>2 mm; 10/122 (8.2%)[a] >4 mm; 8/122 (6.6%)[a]	All spinal pathology considered	X-ray imaging	N/A
Isaacs et al (2016)[35]	26	29	6, 12 wk; 6, 12, and 24 mo	Yes	PEEK cages	>3 mm	2/26 (7.7%)	Included only patients with grade I or II degenerative spondylolisthesis	CT (12 mo) and magnetic resonance imaging (3 mo)	VAS, ODI, and SF-36
Choi et al (2016)[51]	21	21	6 and 12 mo	Yes	Banana-shaped cage (Crescent, Medtronic) or straight cage (Opal, Depuy)	>2 mm	7/21 (33.3%)	All spinal pathology considered	X-ray imaging and CT	VAS, ODI, and patient satisfaction rate
Kuang et al (2017)[26]	40	48	3, 12, and 24 mo	Yes	PEEK cage (Libeier)	Any compromise to the endplate	No cage subsidence	Most spinal pathology considered Excluded high BMI (≥28 kg/m^2), severe osteoporosis, spinal stenosis, disc herniation, and spondylolisthesis	CT or x-ray imaging	

Table 2. Continued.

Authors (Year)	No. of Patients at Final Follow-Up	No. of Levels	Postoperative Follow-Up	Pedicle Screws	Implant Type	Subsidence Considered	Subsidence Occurrence	Pathology Criteria	Radiological Assessments	Clinical Assessments
Lee et al (2017)[27]	21	21	12 and 24 mo	Yes	PEEK Capstone cage (Medtronic)	Any breakage of the endplate	8/21 (38.1%)	Included patients with lower back pain, leg pain, moderate disc space narrowing, and unilateral intervertebral foraminal stenosis Excluded, patients with deformity, with history of lumbar surgery, or ossification of the ligament flavum	CT	VAS score
Lin et al (2017)[11]	76	76	3, 6, 12, and 24 mo	Yes	Banana-shaped cage or straight cage	>2 mm	14/30 (46.7%)	Included symptomatic spinal stenosis, grade I and II spondylolisthesis, herniated nucleus pulposus, and other clinical symptoms Excluded patients with previous lumbar surgery	CT	VAS and ODI
Choi et al (2018)[52]	84	84	6 and 12 mo	Yes	Banana-shaped cage (Crescent, Medtronic) Straight cage (Opal, Depuy)	>2 mm	Banana-shaped; 14/44 (31.8%) Straight cages; 7/40 (17.5%)	All spinal pathology considered Excluded patients with metabolic bone disease, infection, spinal trauma, and tumors	X-ray imaging	VAS and ODI
Lin et al (2018)[44]	25	25	6, 12, and 24 mo	Yes	PEEK Opal (Depuy) or PEEK Capstone (Medtronic)	>2 mm	6/20 (30%)	Most spinal pathology considered Excluded patients with severe canal stenosis, spinal tumor, infection, fractures, and previous L4-L5 surgery	X-ray imaging	VAS and ODI
Pereira et al (2018)[7]	117	117	6 and 12 mo	Yes	Bullet-shaped PEEK cage	>3 mm	25/117 (21.4%)	All spinal pathology considered Excluded patients with infection, tumor, trauma, and previous lumbar surgery	CT	ODI, Odom criteria, and Stanford score
Ko et al (2019)[38]	41	41	Minimum 12 mo (average last follow-up at 27.2 mo)	Yes	PEEK capstone cage (Medtronic)	>2 mm	21/41 (51.2%)	Included only patients with degenerative spondylolisthesis	X-ray imaging and CT	VAS and ODI
Mun et al (2019)[47]	74	74	Minimum 6 mo (average last follow-up at 22.3 mo)	Yes	A single (PEEK) cage (Capstone, Medtronic)	>2 mm	(25.3%)	All spinal pathology considered Excluded patients with infection, tumor, and congenital anomalies	X-ray imaging	VAS and ODI
Park et al (2019)[53]	784	881	18 mo	Yes	INNESIS PEEK cages (BK MEDITECH) Rotation-type cages (PLIVIOS PEEK cages [Depuy, Raynham]) Bullet-shaped cages (Capstone PEEK cages [Medtronic])	>2 mm	36/881 (4.1%)a	All spinal pathology considered	X-ray imaging	N/A
Zhou et al (2019)[54]	145	145	3, 6, and 12 mo	Yes	PEEK cage (Capstone, Medtronic)	>2 mm	23/145 (15.9%)	All spinal pathology considered Excluded patients with infection, tumor, trauma, and previous lumbar surgery	X-ray and CT imaging	VAS and ODI
Zhao et al (2020)[5]	76	76	60 mo	Contoured and straight rod	PEEK material and cuboid shape (arched appearance) from Stryker	Low grade; >25% cage collapsed in the endplate High grade; >50% cage collapsed in the endplate	Low grade; 9/76 (11.8%) High grade; 6/76 (7.9%)	Most spinal pathology considered Excluded patients with previous lumbar surgery history, neurological lesions, peripheral neuropathy and other diseases entities	X-ray imaging	VAS, ODI, and JOA

Abbreviations: ALIF, anterior lumbar interbody fusion; ASD, adjacent segment disease; BMI, body mass index; CT, computed tomography; JOA, Japanese Orthopaedic Association ; LLIF, lateral lumbar interbody fusion; ODI, Oswestry Disability Index; OLIF, oblique lumbar interbody fusion; PEEK, polyetheretherketone; PLIF, posterior lumbar interbody fusion; SF-12, 12-Item Short Form Health Survey; TLIF, transverse lumbar interbody fusion; VAS, visual analog scale; XLIF, extreme lateral interbody fusion.
[a]Subsidence reported by levels.
[b]Less than 80% follow-up.

Table 3. Number of studies reporting on specific pathology by surgical procedure.

Variable	ALIF	LLIF	LLIF-P	OLIF-P	PLIF-P	TLIF-P
Pathology						
Adjacent segment disease	-	1 [39]	-	-	1 [39]	-
Spondylolisthesis	1 [18]	-	2 [35,38]	-	-	2 [35,38]
No specific pathology	5 [26–30]	10 [9,10,12,23,35–40]	6 [10,31–33,36,37]	7 [13,43–48]	4 [27,30,49,50]	12 [5,7,11,14,26,27,44,47,51–54]
Levels						
Single	1 [27]	-	3 [36–38]	4 [44,47,48]	2 [27,49]	10 [5,7,11,29,31,46,49,52,53,55]
Multiple and single	2 [18,26]	11 [9,10,12,23,33,34,39–42,55]	5 [10,31–33,35]	4 [13,43,45,46]	2 [39,50]	4 [14,26,35,53]
Unspecified	3 [28–30]	-	-	-	1 [30]	-
Total number of articles reviewed	6	11	8	7	5	14

Abbreviations: ALIF, anterior lumbar interbody fusion; LLIF, lateral lumbar interbody fusion; LLIF-P, LLIF with posterior fixation; OLIF-P, oblique lumbar interbody fusion with posterior fixation; PLIF-P, posterior lumbar interbody fusion with posterior fixation; TLIF-P, transverse lumbar interbody fusion with posterior fixation.

PEEK cages, OLIF used Clydesdale (Medtronic) PEEK cages, and TLIF used Capstone or Crescent (Medtronic) PEEK cages. The cages used for PLIF were made by different suppliers including Medtronic, Zimmer, and Stryker. Other cage designs included materials such as titanium, carbon fiber, and PEEK with titanium coating. Some studies specifically compared technical alternatives such as changing the fixation method or choosing a different cage type.[5,10,33,48] In this systematic review, the subsidence occurrence of the bilateral and unilateral screws was not distinguished.

[13,23,53,55,56] The 6 studies listed in Table 4 investigated the relationship between subsidence and patient-reported outcomes.[12,29,33,45,50,57] These studies reported whether subsidence caused pain, poor quality of life, or recurrent symptoms potentially leading to revision surgery. The 5 studies listed in Table 5 discussed the impact of subsidence on the postsurgical outcome.[13,23,53,55,56] These studies evaluated the risk of non-union, positive cysts, and screw loosening to cause subsidence.

Syntheses of Results

This systematic review outlines the main observations and results related to subsidence. According to the resulting median from the data analysis, subsidence typically occurs in 13% to 27% of patients regardless of the chosen LIF method, including a range of results between 0.0% and 51.2% (Table 6). The subsidence occurrence median was 12.8% for ALIF, 13.7% for LLIF-P, 15.8% for PLIF-P, 17.6% for OLIF-P, 21.4% for TLIF-P, and 26.9% for LLIF. There is a substantial overlap between the results from the different methods. The quartile box for LLIF, OLIF-P, and TLIF-P showed wider distribution of subsidence occurrence than ALIF, LLIF-P, and PLIF-P (Figure 2).

In the ALIF studies, the lowest subsidence occurrence is 6% (3/50).[26] In a smaller patient population, Tu et al[30] registered the highest occurrence of 23.1% (3/13). Two studies with more patients reported a 10.2% occurrence (14/137 and 15/147).[28,29]

Studies of LLIF approaches show subsidence occurrences ranging from 3.3%[35] to 39.6%.[42] When cases were separated according to the use of pedicle screws or not, 2 ranges were distinguishable. Surgeries with

Table 4. Relationship between subsidence and patient-reported outcomes.

Authors (Year)	Pain Score	Disease-Specific Function	Overall Quality of Life	Other	Power Analysis
Marchi et al (2013)[12]	**Significant correlation** Higher-grade subsidence led to higher axial back pain (P = 0.029)	N/A	N/A	N/A	N/A
Lequin et al (2014)[57]	No significant correlation VAS: $r = -0.2$, $P = 0.459$	N/A	N/A	N/A	N/A
Malham et al (2015)[33]	N/A	N/A	N/A	No significant correlation MCID criteria ($P > 0.05$)	Underpowered
Oh et al (2017)[50]	No significant correlation VAS: $r = 0.017$, $P = 0.874$	No significant correlation ODI: $r = -0.006$, $P = 0.956$	No significant correlation SF-36: $r = 0.015$, $P = 0.886$	N/A	N/A
Rao et al (2017)[29]	No significant correlation VAS: $P = 0.36$	No significant correlation ODI: $P = 0.55$	No significant correlation SF-12 mental component ($P = 0.64$) SF-12 physical component ($P = 0.69$)	N/A	N/A
Chang et al (2019)[45]	N/A	**Significant correlation** Subsidence led to higher ODI: 45.4–33.8, $P = 0.02$	**Significant correlation** Subsidence led to lower SF-36: 33.6–41.4, $P = 0.01$	N/A	N/A

Abbreviations: MCID, minimum clinically important difference; ODI, Oswestry Disability Index; SF-36, Short Form 36 Health Survey Questionnaire; VAS, visual analog scale.

Table 5. Relationship between subsidence and surgical outcomes.

Authors (Year)	Nonunion	Revision Surgery	Other
Nemani et al (2014)[56]	N/A	4/12 (33.3%) patients requiring revision surgery was due to subsidence	N/A
Tempel et al (2018)[34]	N/A	**Significant correlation** between revision surgery and high-grade subsidence: ($P < 0.05$; OR: 12.95% CI: 1.29–13.6) −6.1% (18/296) required revision surgery due to subsidence (all patients with high-grade subsidence)	N/A
Chen et al (2019)[23]	No correlation between subsidence and fusion: $P = 0.242$	N/A	N/A
Lin et al (2019)[13]	**Significant correlation** Subsidence was a risk of nonunion OR: 17.24; 95% CI: 1.67–178.09	N/A	**Significant correlation** Subsidence was a risk of positive cyst OR: 8.37; 95% CI: 2.71–25.89
Park et al (2019)[53]	Fusion rate: • No cage migration = 801/825 (97.1%) • Cage migration with no subsidence = 11/20 (55%) • Cage migration with subsidence = 15/36 (41.7%)	N/A	**Significantly higher rate of screw loosening** for the group with cage migration with subsidence compared with group with cage migration with no subsidence • Cage migration with no subsidence = 2/20 (10%) • Cage migration with subsidence = 22/36 (61.1%)

pedicle screws reportedly have subsidence within the range of 3.3% (1/30)[35] to 20.7% (6/29).[38] One study evaluating LLIF with posterior fixation had a subsidence occurrence of 62.3%[31] and considered to be an outlier in the statistical analysis. Without posterior fixation, subsidence was found in the range of 8.7% (29/335)[34,41] to 39.6% (38/96).[42] Two of the 17 LLIF studies[10,33] compared the prevalence of subsidence with and without pedicle screws on 140 and 128 patients, respectively. Both studies reported higher subsidence when no posterior fixations were used.

The highest and lowest amount of subsidence in patients who underwent OLIF were found in the 2 largest patient groups. Woods et al[43] determined that 4.4% (6/137) of patients experienced cage subsidence of more than 25% the implant height, while Chang et al[45] observed 36.9% (62/169) patients with subsidence considering any breach of the endplate as their criteria.

Following the PLIF approach, a study including 27 patients showed 7.4% occurrence and considered only patients having LIF for nonsevere spinal pathologies.[30] On the other end of the range, Park et al[39] observed that 31.8% (14/44) of the levels treated met their criterion for subsidence. In a larger patient group (129 patients), 20.3% of surgeries resulted in cage subsidence.[50] Reviewed studies' definition of subsidence varied substantially, only 2 used the same criterion (>2 mm).[30,49]

Studies investigating cage subsidence after TLIF reported subsidence in the range of 0.0% (0/40)[26] to 51.2% (21/41).[38] The study that found no subsidence was the only TLIF study that considered subsidence as any compromise to the endplate instead of reporting specific measurements. Also patient age range was 18 to 65 years, and patients with a high BMI and/or suffering from severe osteoporosis were excluded.[26] Eleven out of the remaining 13 studies were found to have more than a 14.8% occurrence of cage subsidence. The larger group samplings, reported by Park et al[53] on 784 patients, identified that 4.1% (36/881) resulted in subsidence. Zhou et al[54] noted that 15.9% (23/145) of patients had subsidence. The highest occurrence of subsidence was found in elderly[11,38] patients suffering from

Table 6. Occurrence of subsidence per LIF method considering 25–50% or >2 mm migration of the cage in the endplate.

LIF Surgical Approach	Subsidence Occurrence		No. of Studies
	Minimum	Maximum	
ALIF	6% (3/50)[26]	23.1% (3/13)[30]	6
LLIF	8.7% (29/335)[34,41] (26/297)[34,41]	39.6% (38/96)[42]	11
LLIF with posterior fixation	3.3% (1/30)[35]	20.7% (6/29)[38]	8
OLIF with posterior fixation	4.4% (6/137)[43]	36.9% (62/168)[45]	7
PLIF with posterior fixation	7.4% (2/27)[30]	31.8% (11/41)[39]	5
TLIF with posterior fixation	0% (0/40)[26]	51.2% (21/41)[38]	14

Abbreviations: ALIF, anterior lumbar interbody fusion; LIF, lumbar interbody fusion; LLIF, lateral lumbar interbody fusion ; OLIF, oblique lumbar interbody fusion; PLIF, posterior lumbar interbody fusion; TLIF, transverse lumbar interbody fusion.

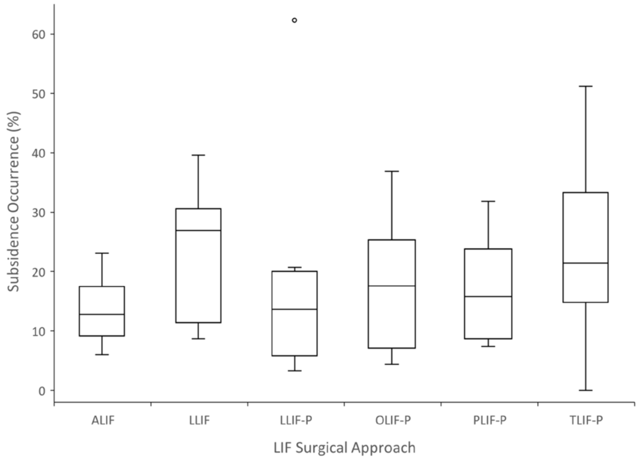

Figure 2. Box-and-whisker plots of the data presented in Table 2, including the first, median, and third quartiles of subsidence occurrence for each surgery method. The whiskers indicate the ranges. Includes results from 6 anterior lumbar intervertebral fusion (ALIF), 11 lateral lumbar intervertebral fusion (LLIF), 8 LLIF with posterior fixation (LLIF-P), 7 oblique lumbar interbody fusion with posterior fixation (OLIF-P), 5 posterior lumbar interbody fusion with posterior fixation (PLIF-P), and 14 transverse lumbar interbody fusion with posterior fixation (TLIF-P) studies.

spinal stenosis or spondylolisthesis[38,51] and patients receiving banana-shaped cages.[52] Twelve out of the 15 TLIF studies considered subsidence to be either 2 or 3 mm penetration into the endplate.[7,11,14,35,38,44,47,51–54]

Subsidence and Postsurgical Outcomes

Within all LIF studies in this systematic review, 6 studies directly compared the patient-reported outcomes of subsidence against no subsidence.[12,29,33,45,50,57] Four of the 6 studies did not show any correlation between subsidence and poor outcomes, although none of them did a power analysis.[29,33,50,57] Meanwhile, 1 of 4 studies comparing pain score showed that higher-grade subsidence led to axial back pain.[12] One of 3 studies comparing disease-specific function and 1 of 3 studies comparing quality of life found that subsidence led to higher ODI and lower quality of life, respectively.[45] Although a correlation with revision surgery and recurrent symptom was not directly made, 4 studies[43,58–60] showed subsidence was the most common complication. In another study, symptomatic subsidence was the second most prevalent surgical outcome after persistent radiculopathy leading to a revision.[56]

Four studies directly compared the surgical outcome between subsidence and no subsidence groups.[13,23,53,55] Subsidence was shown to increase the risk of nonunion in 2 of 3 studies evaluating LIF fusion rates.[13,53] While Lin et al[13] found that patients with subsidence were 17.24 times more likely to have nonunion. They showed that patients with subsidence had an 8.37 times higher risk of positive cysts. However, that result is a 2-way cause and effect relationship. Park et al[53] found that subsidence led to a higher rate of screw loosening. In the only study that compared a subsidence group with a no subsidence group for revision surgery rate, a correlation was shown between revision surgery and high-grade subsidence.[55] Studies by Nemani et al[56] and Malham et al[33] found that 3.4% and 3% of patients undergoing LIF surgery required revision surgery due to subsidence. None of the 6 studies that do not show a correlation between subsidence and the outcomes did a power analysis.

DISCUSSION

No previous systematic review compared all 5 LIF methods to determine if subsidence is more prevalent in certain methods. In this review, a collection of 40 studies revealed that subsidence remains present in numerous patients after all 5 LIF procedures (Figure 2). Comparison between methods is difficult, since there is significant overlap between the results. By comparing the medians, LLIF without pedicle screws and TLIF had the highest subsidence occurrence, 26.9% and 21.4%, respectively, while ALIF had the lowest occurrence, 12.8%.

ALIF implants cover most of the endplate, which could explain a lower rate of subsidence. For LLIF, the range and median of occurrence reported that LLIF 26.9% and LLIF-P 13.7% were higher and varied more without the usage of posterior fixation. Additionally, the box-and-whisker graph highlighted 1 LLIF-P study as an outlier with a subsidence occurrence of 62.3%, which is more than 1.5 times the interquartile range.[31] This study made in 2014 by Tohmeh et al considered all spinal pathologies regardless of the severity. The occurrence was measured in terms of the number of levels subsiding, and most patients received multiple-level fusion surgeries.[31] This could have contributed to the higher subsidence occurrence. Occurrence reported from the studies evaluating TLIF resulted in the largest variation of all methods, ranging between 0.0% and 51.2%. The results were widely spread. While most TLIF studies used the same scale, the inconsistency could be attributed to inclusion criteria related to age, BMI, diseases treated, and cage shape implanted. The occurrence reported for OLIF resulted in the second widest range (4.4% and 36.9%). As for PLIF, occurrence ranged between 7.4% and 31.8% (Figure 2). Only a few studies were available for PLIF and OLIF, and their definition of subsidence was not consistent overall, which could have led to these results.

Three studies included in this systematic review reported the occurrence of subsidence by comparing 2 or 3 approaches for LIF.[27,35,44] A comparative study published by Lin et al[44] found that TLIF had higher incidence of subsidence compared with OLIF.[44] Similar results were also revealed in a study reporting that TLIF had a significantly higher incidence of subsidence compared with ALIF and PLIF[27] (38.1% compared with 15.4% and 10%, respectively).[27] This study noted that during TLIF, positioning the cage at the optimal location on the endplate was challenging, resulting in increased subsidence. Additionally, in the third study, LLIF showed a lower amount of subsidence than TLIF.[35] A similar conclusion was drawn in a cadaver study comparing the maximum force between ALIF, LLIF, PLIF, and TLIF, and it was shown that TLIF led to the highest subsidence, whereas LLIF had the lowest subsidence.[61]

Cage's shape, size, and positioning can all play a role in the risk of subsidence.[9,12,33,62,63] Cages with a bigger surface area in contact with the endplate, such as the ALIF devices, result in less subsidence since it reduces endplate stress.[47,62,63] As for the different LLIF cage designs, the wider implants clinically reduced subsidence in all studies comparing cage sizes.[12,16,41,47,62]

Furthermore, to reduce subsidence risk, placing the implant on the periphery of the vertebrae is recommended because the endplate and vertebral body are weaker in the center.[64,65] Biomechanical cadaveric studies showed that regardless of cage type, placing the implant on the peripheral subchondral bone prevents the cage from penetrating the vertebral body interphase.[66,67] For instance, when LLIF cages are long enough to bridge both sides of the apophysis ring, resistance to subsidence is significantly increased.[67]

Taller cages are also correlated with increased subsidence, making height crucial during the implant selection.[31,62] Taller cages can cause overdistraction, and therefore higher forces are applied on the endplates,[31] which may lead to intraoperative endplate failure. Yet, inappropriate height correction will compromise the spinal nerve decompression and the fusion itself.[9] Moreover, aggressive decortication of the endplate and overdistraction could make the vertebrae more at risk of subsidence,[12,59] as confirmed by cadaveric analysis.[67] The LLIF and OLIF cages tend to be taller compared with the TLIF cages, which could lead to overdistraction and augment the risk of subsidence.

Regardless of the surgical methods, patients' pathologies and health condition influence subsidence occurrence in many studies.[11,13,18,28,30,37,38] Higher BMI as well as lower BMD increase the amount of subsidence.[18,28,37] For the elderly population, most studies showed that age is a risk factor for subsidence. A study suggested that for patients at risk of low BMD, a dual-energy x-ray absorptiometry scan would be beneficial to predict subsidence.[55] A *T* score lower than 1.0 measured with the dual-energy x-ray absorptiometry scan correlates with higher subsidence.[33,34] For patients having a *T* score lower than 1.0, posterior instrumentation relieving some of the endplate stress can be implanted.

Subsidence is one of the most common complications leading to revision surgery following LIF surgery. However, there are conflicting accounts that it is associated with poor clinical outcomes. Few studies were able to show that subsidence can lead to back pain, reduced quality of life, reduced function, screw loosening, higher nonunion, and revision surgery risk. Furthermore, many studies state that subsidence is a concern following surgery, but the extent of the problem is unclear due to lack of statistical evidence. Two of 6 studies evaluating the relationship between subsidence and patient-reported outcomes showed that patients with subsidence had significantly increased instances of negative outcomes.[12,45] The other 4 studies did not find a direct correlation.[29,33,50,57] However, they all included fewer than 22 patients with subsidence. The risk of revision surgery following subsidence was evaluated comparing a subsidence group with a no subsidence group postsurgery in only 1 study, and it was shown to increase the rate of revision surgery.

While only a total of 9 studies made statistical analysis regarding either subsidence and surgical outcomes or patient-reported outcomes, none of the studies specified if any power analysis was done. Additionally, the sample of the subsidence groups was small reducing the generalization of the results. The number of studies recording a relationship between subsidence and postsurgery outcome is limited considering that it is rarely the primary goal of surgical LIF case studies.

Since analyzing subsidence after LIF was the main goal of this systematic review, other leading causes of revision surgery such as neurologic symptoms, adjacent disc segment disease, pseudarthrosis, and hardware failure were not considered.[40] Additionally, each method has its own advantages and disadvantages in regard to operation time, patient recovery time, and total volume of blood loss.[26,30] Among the factors implicated in LIF, this analysis of subsidence provides additional evidence and might help clinicians in the selection of the approach.

Limitations

Published clinical studies investigating causes of subsidence after LIF surgery are mainly based on inconsistent analysis methods, which somewhat limit the conclusions that can be drawn. One major discrepancy was the definition of subsidence used in the studies. There is no clear consent regarding which amount of subsidence should be considered clinically relevant. Marchi et al[12] established a scale according to the percentage of postoperative disc height lost, the grades being grade 0, 0% to 24%; grade 1, 25% to 49%; grade 2, 50% to 74%; and grade 3, 75% to 100%. It has been used more frequently by researchers to evaluate subsidence occurrence. This scale helps the accuracy of the comparison between studies. The radiological assessment techniques vary, as some studies measured subsidence on plain x-ray and others used CT images. Many studies gathered both the CT and x-ray images of their patients but strictly used the plain x-ray image to measure subsidence.[31,37,41,48] With evidence that CT images allow superior accuracy when assessing spine injuries, future study should consider assessing subsidence using available CT images.[68,69] Inconsistency between studies makes it difficult for review studies to make accurate comparison and compilation of subsidence occurrences. Additionally, for the data collection and comparison of the surgical methods, a correlation between subsidence and postsurgical clinical outcomes has not been reported in most studies, which weaken any conclusion in this regard.

Even though it is stated that subsidence can be observed as soon as 6 weeks postsurgery, the varying length of the follow-up in each study can still lead to bias.[12] Not only device shape and material are same in all patients within each method, lordosis curvature due to the cages also varies. Studies from 2013 and after were chosen to emphasize postsurgical results of patients treated using the most comparable surgical approaches, equipment, and cages, considering the changes in procedure, cage design, and surgery technique would likely be up to date. However, most studies published in the last 10 years evaluate LLIF and TLIF methods. Clinical outcomes reported after ALIF and PLIF tend to include populations with specific risk factors such as low BMD, high BMI, specific pathologies, or the evaluation of new cage devices.

CONCLUSIONS

Subsidence clearly remains present in many patients after all LIF procedures. ALIF was found to have the lowest subsidence occurrence of all methods. While LLIF, LLIF-P, OLIF-P, and PLIF-P had similar ranges of subsidence and TLIF showed variable results, there are too much heterogeneity and discrepancy between studies to draw clear conclusions. There is also no consistent evidence confirming that subsidence significantly augments the risk of poor clinical outcomes. This matter should be further addressed with more powered studies. Subsidence appears to remain a clinical problem in some studies and further strategies to reduce its occurrence should be implemented.

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