Effects of intradiscal vacuum phenomenon on surgical outcome of lateral interbody fusion for degenerative lumbar disease

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OBJECTIVE The authors investigated whether the presence of intradiscal vacuum phenomenon (IVP) results in greater correction of disc height and restoration of segmental lordosis (SL).

METHODS A retrospective chart review was performed on every patient at the University of South Florida's Department of Neurosurgery treated with lateral lumbar interbody fusion between 2011 and 2015. From these charts, preoperative plain radiographs and CT images were reviewed for the presence of IVP. Preoperative and postoperative posterior disc height (PDH), anterior disc height (ADH), and SL were measured at disc levels with IVP and compared with those at disc levels without IVP using the t-test. Linear regression was used to evaluate the factors that predict changes in PDH, ADH, and SL.

RESULTS One hundred forty patients with 247 disc levels between L-1 and L-5 were treated with lateral lumbar interbody fusion. Among all disc levels treated, the mean PDH increased from 3.69 to 6.66 mm ($p = 0.011$), the mean ADH increased from 5.45 to 11.53 mm ($p < 0.001$), and the mean SL increased from 9.59° to 14.55° ($p < 0.001$). Significantly increased PDH was associated with the presence of IVP, addition of pedicle screws, and lack of cage subsidence; significantly increased ADH was associated with the presence of IVP, anterior longitudinal ligament (ALL) release, addition of pedicle screws, and lack of subsidence; and significantly increased SL was associated with the presence of IVP and ALL release.

CONCLUSIONS IVP in patients with degenerative spinal disease remains grossly underreported. The data from the present study suggest that the presence of IVP results in increased restoration of disc height and SL.

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KEY WORDS adult spinal deformity; degenerative disc disease; lateral lumbar interbody fusion; scoliosis; spondylolisthesis; vacuum phenomenon

INTRADISCAL vacuum phenomenon (IVP) refers to the radiographic appearance of gas within an intervertebral disc space. Its prevalence on conventional radiographs ranges from 2% in healthy adults to 21% in asymptomatic elderly people.²² Although IVP can occur with spinal infection or neoplasm,^{3,5,13} it is associated more commonly with advanced stages of degenerative spinal disease.^{13,19} Among patients with this condition, IVP can be seen in 52%–73% of them.^{6,27} Evidence has shown that IVP is associated with spinal instability.^{18,19,27}

In patients with IVP, the relative mobility of the disc

space might allow greater correction of sagittal and coronal deformities. If true, the presence of IVP might affect surgical planning and obviate the need for more advanced corrective maneuvers such as anterior column release or posterior osteotomy. The purpose of this study was to compare the degree of deformity correction in patients who underwent lateral lumbar interbody fusion (LLIF) with or without percutaneous posterior instrumentation and had associated IVP with that of such patients without IVP, as measured by disc-height restoration and improved segmental lordosis (SL).

ABBREVIATIONS ADH = anterior disc height; ALL = anterior longitudinal ligament; IVP = intradiscal vacuum phenomenon; LLIF = lateral lumbar interbody fusion; MIS = minimally invasive surgical; PDH = posterior disc height; SL = segmental lordosis.

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FIG. 1. A 70-year-old woman presented with back pain and leg pain (right greater than left). MRI (not shown) revealed moderate spinal canal and foraminal stenosis at the L4–5 level. **A:** Preoperative upright lateral radiograph revealing L4–5 degenerative Grade I spondylolisthesis. Also noted is IVP at the L4–5 and L5–S1 disc spaces. **B:** Postoperative Day 1 upright lateral radiograph, after L4–5 LLIF and placement of percutaneous pedicle screws and rods, showing the interbody cage and reduction of the listhesis. **C:** Lateral upright radiograph obtained 24 months after surgery revealing fusion at the L4–5 level without evidence of cage subsidence.

Methods

Patient Population

Review of a prospectively maintained database was performed to identify all patients treated with minimally invasive surgical (MIS) LLIF with or without placement of posterior percutaneous pedicle screws/rods for degenerative spinal pathology (including degenerative disc disease, degenerative spondylolisthesis, and adult degenerative deformity with coronal and/or sagittal imbalance) between October 2011 and July 2015 at the University of South Florida's Department of Neurosurgery. Patients who underwent a hybrid procedure (posterior osteotomy, instrumentation, and fusion procedure other than placement of percutaneous pedicle screws) were excluded. Preoperative plain radiographs and CT, MR, and intraoperative fluoroscopic images were reviewed for the presence of IVP. Patient demographics, including age, sex, and details of surgical procedures, were retrieved from the medical record.

Surgical Technique

The details of MIS LLIF were given previously.²⁸ In brief, patients were placed in a true lateral position. A lateral incision was made, and dissection was performed down to the abdominal wall musculature. Dilation of the abdominal musculature was then performed to create a corridor to the retroperitoneal space. The psoas muscle was then dilated under the guidance of fluoroscopy and triggered electromyography. Once a satisfactory trajectory to the disc space was created, an expandable tubular retractor was inserted. A discectomy was performed, and the cartilaginous endplates were removed. Trials were placed into the disc space for a snug fit. Ten-degree lordotic, 18- to 22-mm-wide, 8- to 12-mm-high, 50- to 60-mm-long polyetheretherketone (PEEK) cages filled with 5 ml of cadaveric cancellous bone mixed with mesenchymal stem cells (Osteocel, NuVasive) were placed according to the trials in an attempt to restore lumbar lordosis. In patients with significant sagittal imbalance, anterior longitudinal ligament (ALL) release was performed, followed by placement of

a hyperlordotic cage (20° or 30°) to correct pelvic incidence–lumbar lordosis mismatch.⁸ Placement of supplementary percutaneous pedicle screws and rod fixation were performed in patients with evidence of overt spinal instability or spondylolisthesis and in those who were undergoing long-segment LLIF.²

Postoperative Follow-Up

Patients returned to the clinic 1, 3, 6, and 12 months and then yearly after surgery for upright radiographs. The most recent postoperative radiographs were used for comparison with preoperative radiographs. Preoperative and postoperative posterior disc height (PDH), anterior disc height (ADH), and SL at the operative levels were measured digitally on standing radiographs using Centricity 3.0 workstations (GE Healthcare). The measurements were performed by 2 independent observers (C.P.Y. and K.B.), and averages were used for analysis. We arbitrarily determined that measurement disagreements greater than 15% between the 2 observers would be reviewed further by the senior author (J.S.U.). PDH and ADH were the distances between the superior and inferior endplates of the disc space at the posterior and anterior borders of the vertebrae, respectively. SL was defined as the angle between the cranial and caudal endplates of the upper and lower vertebrae of the segment subjected to surgery (Fig. 1). Deformity correction, cage subsidence, and construct integrity were assessed also. The degree of cage subsidence was classified based on loss of immediate postoperative disc height (Grade 0, 0%–24% loss; Grade I, 25%–49% loss; Grade II, 50%–74% loss; and Grade III, 75%–100% loss), as described by Marchi et al.¹⁶ Fusion was defined as the existence of bridging bone between the treated intervertebral endplates and lack of intervertebral movement on flexion/extension lateral radiographs.

Statistics

Statistical analyses were performed using the statistical software package SPSS 25.0 (SPSS IBM). Comparisons

of nominal measurements were made using the chi-square test. Continuous data were compared using the t-test. We used univariate linear regression to evaluate factors that predict changes in PDH, ADH, and SL, and then we used a multivariate analysis in which only those factors that were significant in the univariate analysis were entered. Factors evaluated include patient age and sex, procedure performed (LLIF only, ALL release, placement of percutaneous pedicle screws), level of surgery, presence of spondylolisthesis, cage subsidence, and IVP. The same factors were evaluated for their relationship with subsidence by using logistic regression. A p value of less than 0.05 was used as the limit for statistic significance.

Results

Patient Population

A total of 140 patients underwent MIS LLIF with or without placement of posterior percutaneous pedicle screws/rods. There were 61 (43.6%) males and 79 (56.4%) females; the mean age was 62 years (range 30–88 years). Seventy-six patients underwent 1-level, 29 underwent 2-level, 27 underwent 3-level, and 8 underwent 4-level LLIF(s). Ninety-two (65.7%) patients with at least 1 disc level with IVP underwent surgery (1 level in 53, 2 levels in 21, 3 levels in 13, and 4 levels in 5 patients); 48 (34.3%) patients had no IVP at any surgical level. Fifteen patients underwent at least 1-level ALL release (11 underwent 1-level and 4 underwent 2-level ALL release). Fifty-two (37.1%) patients underwent stand-alone LLIF, and 88 (62.9%) underwent placement of supplementary posterior percutaneous pedicle screws/rods. Seven-five patients had at least 1 level with spondylolisthesis. The follow-up duration ranged from 6 to 42 months (mean 12 months).

Disc Levels

A total of 247 lumbar disc levels were surgically treated, including 15 at L1–2, 47 at L2–3, 83 at L3–4, and 102 at L4–5. ALL release was performed at 19 levels (3 at L2–3, 10 at L3–4, and 6 at L4–5). Percutaneous screw fixation was performed at 168 levels. IVP was observed at a total of 155 surgical levels and not observed at 92 levels. Spondylolisthesis was observed at 100 levels.

Radiographic Outcomes

Among all disc levels treated, the mean PDH increased from 3.69 to 6.66 mm ($p = 0.011$), the mean ADH increased from 5.45 to 11.53 mm ($p < 0.001$), and the mean SL increased from 9.59° to 14.55° ($p < 0.001$). ALL release was performed at 19 disc levels; among these levels, the mean PDH increased from 3.52 to 7.04 mm ($p = 0.016$), the mean ADH from 4.57 to 15.90 mm ($p < 0.001$), and the mean SL from 2.80° to 15.48° ($p = 0.001$). For the 228 levels with LLIF only, the mean PDH increased from 3.70 to 6.62 mm, the mean ADH from 5.53 to 11.17 mm, and the mean SL from 10.15° to 14.47° ($p < 0.001$ for all) (Table 1).

Among all the levels treated, significantly increased PDH was associated with the presence of IVP, addition of pedicle screws, and lack of cage subsidence in univariate and multivariate regression analyses. Significantly in-

TABLE 1. Preoperative and postoperative PDHs, ADHs, and SL

Parameter	Preop	Postop	Change
All disc levels (n = 247)			
PDH (mm)	3.69 ± 1.97	6.66 ± 2.35	3.00 ± 2.95
ADH (mm)	5.45 ± 2.72	11.53 ± 3.77	6.13 ± 4.89
SL (°)	9.59 ± 9.35	14.55 ± 9.20	5.12 ± 8.08
LLIF only (n = 228)			
PDH (mm)	3.70 ± 1.88	6.62 ± 2.29	2.96 ± 2.77
ADH (mm)	5.53 ± 2.73	11.17 ± 3.49	5.70 ± 4.14
SL (°)	10.15 ± 9.43	14.47 ± 9.40	4.42 ± 7.62
ALL release (n = 19)			
PDH (mm)	3.52 ± 2.84	7.04 ± 2.95	3.53 ± 3.86
ADH (mm)	4.57 ± 2.63	15.90 ± 4.36	11.33 ± 5.34
SL (°)	2.80 ± 4.60	15.48 ± 6.51	13.50 ± 8.88

Values are means ± SD. All parameters improved significantly after surgery ($p < 0.001$, t-test).

creased ADH was associated with the presence of IVP, ALL release, addition of pedicle screws, and lack of subsidence in univariate and multivariate regression analyses. Significantly increased SL was associated with the presence of IVP, ALL release, and lack of subsidence in univariate analysis but with only the presence of IVP and ALL release in multivariate analysis (Table 2). Among the levels treated with LLIF without ALL release, the presence of IVP significantly increased postoperative PDH, ADH, and SL; the addition of pedicle screws and lack of subsidence significantly increased postoperative PDHs and ADHs but not SL (Table 3). In the ALL-release group, there were no associations between any of the studied patient factors and changes in PDH, ADH, or SL (Table 4). In the LLIF-only group, the mean increase in SL was 2° at the levels at which IVP was absent compared with 5.9° for the levels at which IVP was present ($p < 0.001$). In the ALL-release group, the mean increase of SL at levels at which IVP was absent was 10.3° compared with 15.0° for the levels at which IVP was present ($p = 0.301$) (Table 5).

Subsidence at the end of follow-up was observed in 52 (21.1%) levels; there was Grade I subsidence at 45 levels and Grade II subsidence at 7 levels. None of the studied patient factors (including age, sex, ALL release, presence of IVP, and length of follow-up) except the addition of pedicle screws ($p = 0.009$) affected the incidence of subsidence. Twenty-two (27.8%) of 79 levels without pedicle screws developed subsidence; 30 (17.9%) of 168 levels with pedicle screws developed subsidence. Fusion was observed in 92% of the levels treated.

Discussion

Pathogenesis of IVP

The pathogenesis of IVP is debatable and most likely multifactorial. The prevailing hypothesis for gas formation in a degenerative disc is based on the endplate-degeneration theory. As vertebral endplates degenerate, the hyaline cartilage becomes calcified, and inflammatory cytokines are produced. This combination blocks the nutritional pathways, which results in metabolic imbalance and

TABLE 2. Factors that predict changes in PDH, ADH, or SL at all disc levels

Factor	Δ PDH		Δ ADH		Δ SL	
	Univariate p Value (95% CI)	Multivariate p Value (95% CI)	Univariate p Value (95% CI)	Multivariate p Value (95% CI)	Univariate p Value (95% CI)	Multivariate p Value (95% CI)
Age	0.742 (−0.041 to 0.029)	—	0.261 (−0.023 to 0.083)	—	0.394 (−0.054 to 0.137)	—
Sex	0.458 (−0.466 to 1.031)	—	0.805 (−0.996 to 1.282)	—	0.942 (−2.216 to 1.974)	—
IVP	0.011 (0.226 to 1.739)*	0.009 (0.249 to 1.724)*	<0.001 (1.583 to 3.814)*	<0.001 (1.563 to 3.623)*	<0.001 (2.067 to 6.135)*	<0.001 (5.082 to 12.13)*
Segment†	0.319 (−0.610 to 0.200)	—	0.124 (−1.095 to 0.132)	—	0.098 (−2.033 to 0.174)	—
Spondylolisthesis	0.603 (−0.954 to 0.555)	—	0.991 (−1.142 to 1.155)	—	0.172 (−3.492 to 0.626)	—
ALL release	0.422 (−0.822 to 1.957)	—	<0.001 (3.639 to 7.625)*	<0.001 (3.102 to 6.868)*	<0.001 (5.447 to 12.71)*	<0.001 (1.908 to 5.788)*
Pedicle screws	0.001 (0.501 to 2.057)*	0.003 (0.399 to 1.949)*	0.003 (0.647 to 3.020)*	0.016 (0.256 to 2.437)*	0.066 (−0.138 to 4.182)	—
Subsidence	0.005 (−1.878 to −0.333)*	0.030 (−1.615 to 0.083)*	0.002 (−3.045 to 0.706)*	0.019 (−2.354 to 0.213)*	0.032 (−4.455 to −0.199)*	0.086 (−3.729 to 0.251)

Δ = change (postoperative value minus preoperative value).

The total number of levels was 247. The presence of IVP, addition of pedicle screws, and lack of subsidence were associated with increased PDH in multivariate linear regression analysis. The presence of IVP, addition of pedicle screws, ALL release, and lack of subsidence were associated with increased ADH. The presence of IVP and ALL release were associated with significantly increased SL.

* $p < 0.05$.

† L1–2, L2–3, and L3–4 versus L4–5.

TABLE 3. Factors that predict changes in PDH, ADH, or SL at disc levels treated with LLIF

Factor	Δ PDH		Δ ADH		Δ SL	
	Univariate p Value (95% CI)	Multivariate p Value (95% CI)	Univariate p Value (95% CI)	Multivariate p Value (95% CI)	Univariate p Value (95% CI)	Multivariate p Value (95% CI)
Age	0.415 (−0.049 to 0.020)	—	0.342 (−0.026 to 0.074)	—	0.666 (−0.072 to 0.113)	—
Sex	0.652 (−0.581 to 0.926)	—	0.643 (−0.834 to 1.348)	—	0.985 (−2.031 to 1.992)	—
IVP	0.033 (0.068 to 1.594)*	0.028 (0.089 to 1.68)*	<0.001 (1.412 to 3.548)*	<0.001 (1.442 to 3.516)*	<0.001 (1.189 to 5.875)*	<0.001 (1.189 to 5.875)*
Segment†	0.425 (−0.563 to 0.238)	—	0.189 (−0.966 to 0.192)	—	0.115 (−1.918 to 0.210)	—
Spondylolisthesis	0.999 (−0.757 to 0.758)	—	0.564 (−0.775 to 1.419)	—	0.131 (−3.559 to 0.465)	—
Pedicle screws	0.003 (0.426 to 1.974)*	0.007 (0.294 to 1.829)*	0.005 (0.479 to 2.729)*	0.007 (0.400 to 2.553)*	0.119 (−0.434 to 3.760)	—
Subsidence	0.001 (−2.026 to −0.490)*	0.007 (−1.814 to −0.289)*	0.002 (−2.850 to −0.622)*	0.011 (−2.462 to 0.322)*	0.054 (−4.118 to −0.038)	—

The total number of levels at which LLIF was performed was 228. The presence of IVP, addition of pedicle screws, and lack of subsidence were associated with increased PDH in multivariate linear regression analysis.

The presence of IVP, addition of pedicle screws, and lack of subsidence were associated with increased ADH. The presence of IVP was the only factor associated with significantly increased SL.

* $p < 0.05$.

† L1–2, L2–3, and L3–4 versus L4–5.

TABLE 4. Factors that predict changes in PDH, ADH, or SL at disc levels treated with ALL release

Factor	Δ PDH (univariate p value [95% CI])	Δ ADH (univariate p value [95% CI])	Δ SL (univariate p value [95% CI])
Age	0.392 (−0.099 to 0.241)	0.304 (−0.148 to 0.446)	0.277 (−0.236 to 0.773)
Sex	0.873 (−2.808 to 3.227)	0.451 (−7.210 to 3.349)	0.470 (−12.187 to 5.862)
IVP	0.163 (−0.922 to 5.036)	0.054 (−0.105 to 9.862)	0.301 (−4.559 to 13.864)
Segment*	0.252 (−3.291 to 0.923)	0.205 (−6.034 to 1.391)	0.216 (−10.14 to 2.467)
Spondylolisthesis	0.482 (−4.405 to 2.166)	0.839 (−5.342 to 6.503)	0.149 (−2.678 to 16.182)
Pedicle screws	0.450 (−2.981 to 6.426)	0.472 (11.212 to 5.410)	0.280 (−21.268 to 6.553)
Subsidence	0.413 (−2.125 to −4.935)	0.871 (−6.899 to −5.900)	0.940 (−11.241 to −10.451)

The total number of levels at which ALL release was performed was 19. None of the factors analyzed predicted changes in PDH, ADH, or SL.

* L1–2, L2–3, and L3–4 versus L4–5.

decreased synthesis of structural matrix proteins. As a result, the structural integrity of the disc becomes unstable, and the continuous compression-and-distraction motion creates a cleft that is filled gradually with gas.¹³ Intradiscal gas typically is composed of 90%–92% nitrogen, and the remaining fraction consists of oxygen, carbon dioxide, and other traces of gases.^{9,29} The literature shows that IVP is associated with spinal instability.^{18,19,27} Adjacent bone marrow changes have been observed on MRI when IVP is present, but the clinical significance of that finding is not clear.²⁷

Implications of IVP in Surgery

LLIF has been used to treat degenerative disc disease with instability and adult spinal deformity. Studies have found that sagittal spinopelvic malalignment from advanced degeneration is a major cause of pain and loss of function.²³ Surgeries that fail to restore normal sagittal vertical axis and spinopelvic harmony will lead to an unsatisfactory outcome, pseudarthrosis, and proximal junctional kyphosis.¹⁰ Therefore, sagittal balance should be considered carefully when deciding to perform a lumbar fusion procedure, even in patients with normal spinopelvic parameters or who are undergoing short-segment fusion, because failure to fuse the spine in a lordotic fashion can

cause failed-back surgery syndrome.¹¹ In addition, a lordotic alignment of the lumbar fusion influences the biomechanical stresses on the adjacent segments and thus affects the rate of adjacent-level degeneration.^{20,24} The presence of IVP usually indicates a more advanced stage of degeneration and is considered a sign of instability.^{18,19,27} Nevertheless, the increase in spinal mobility when IVP is present might provide greater freedom for spine reconstruction. Based on our study, there were significant increases in disc height and SL after LLIF when IVP was found in preoperative images (Table 3). There was a trend toward increased disc height and SL in patients who underwent ALL release and placement of a hyperlordotic cage, but the increase was not statistically significant, likely because of the small number of patients.

Lateral Lumbar Interbody Fusion

Since its introduction in 2006, LLIF has been popularized and used for the treatment of degenerative disc disease.²¹ The advantages of LLIF are indirect decompression and enhancement of fusion with the placement of a wide-footprint cage, achieved through an MIS approach (Fig. 1). The indications of this technique were expanded later to include spinal deformity in patients with either coronal or sagittal imbalance. Placement of a large lordotic cage provides benefits for anterior column support and spine realignment. Our study found that a single-level LLIF provided, on average, a 2.9-mm increase in PDH, 5.7-mm increase in ADH, and 4.4° increase in SL.

In patients with severe sagittal imbalance, posterior shortening or anterior lengthening procedures might be needed to restore alignment. MIS lateral-approach ALL release has become an appealing option for restoring coronal and sagittal balance in spinal deformity through releasing the anterior column and placing a large hyperlordotic interbody cage. Our early reports showed increases in SL between 10° and 17° after ALL release and placement of the 30° cage.^{7,8,15} The study presented here found that a single-level ALL release provided a mean 3.5-mm increase in PDH, 11.3-mm increase in ADH, and 13.5° increase in SL. It should be noted that a hyperlordotic cage and more anterior placement of the cage did not increase PDHs significantly. One must exercise caution with placement of a lordotic cage anteriorly, because subsequent compression of the posterior elements can cause a fulcrum effect at the

TABLE 5. Changes in PDH, ADH, and SL after LLIF or ALL release at disc levels with or without IVP

Parameter Changes	All Levels	IVP		p Value
		Absent	Present	
Δ PDH (mm)				
LLIF only (n = 228)	2.9	2.5	3.2	0.043
ALL release (n = 19)	3.5	0.9	4.8	0.065
Δ ADH (mm)				
LLIF only (n = 228)	5.7	4.2	6.6	<0.001
ALL release (n = 19)	11.3	8.5	12.6	0.012
Δ SL (°)				
LLIF only (n = 228)	4.4	2.0	5.9	<0.001
ALL release (n = 19)	13.5	10.3	15.0	0.301

Values are means. The Student t-test was used to compare the absence or presence of IVP.

posterior vertebral body and subsequent neuroforaminal stenosis, which can either exacerbate or create foraminal stenosis and subsequent radiculopathy. The resultant increased SL did not match the angle of the hyperlordotic cage in this series of patients, which is to be expected, because we did not perform any posterior column osteotomies. A posterior column osteotomy is required to achieve the desired SL, as demonstrated in computer modeling and clinical case series.^{7,26}

Addition of Posterior Instrumentation

LLIF can be performed as a stand-alone procedure or supplemented with instrumentations such as lateral plating or posterior open or percutaneous pedicle screws/rods. Because the ALL, posterior longitudinal ligament, and posterior column are not violated, spinal stability is largely maintained with a simple LLIF procedure. However, supplementary instrumentation might be required in patients with osteoporosis, listhesis greater than 3 mm as a result of pars defects or degeneration, or coronal or sagittal instability and in those in whom 3 or more levels are being treated.^{1,17} In the current study, we chose the addition of percutaneous pedicle screws/rods for patients with osteoporosis, instability, or significant deformity. With the addition of contoured rods, posterior instrumentation can maintain an increase in disc height. Biomechanical data have revealed that stability of the spinal segment with pedicle screw fixation is improved over that with the stand-alone procedure.⁴

Subsidence

Cage settling into adjacent vertebral bodies after interbody fusion is not an uncommon occurrence. Depending on the imaging modalities and criteria used to define subsidence, the rate of subsidence after MIS LLIF has been reported to be in the range of 8%–14.3%.^{12,14,16} Subsidence can lead to a loss of indirect decompression and alignment. Many factors contribute to intervertebral cage subsidence, including bone quality, cage morphology, use of biologics, application of supplemental fixation, and iatrogenic endplate violation. Despite the frequency of radiographic subsidence, clinically significant subsidence has been reported for only 2%–3% of patients.^{12,14} The results of our study show that the presence of IVP did not increase the risk of subsidence. The addition of percutaneous pedicle screws and rods reduced the incidence of cage subsidence regardless of the presence or absence of IVP.

Limitations

We acknowledge that our study was limited by its retrospective nature and relatively short follow-up duration. In addition, CT scans, which have a higher sensitivity for detecting IVP, were not obtained for every patient. Selection of cages of different sizes certainly can affect postoperative PDH, ADH, and SL. After discectomy or ALL release, trials were placed in the disc space for a snug fit, and appropriate cages were selected based on the sizes of the trials. Our practice, however, is to place the largest cage that can be inserted safely. Placement of a cage either anteriorly or posteriorly can affect the imaging outcome, although we

followed the published safe zones for placement of these cages.²⁵ In this study, 62% of the patients underwent surgery at more than 1 level. The biomechanics and configuration of the index levels affected by LLIF of the adjacent segments were not taken into consideration. Furthermore, the anatomy of the posterior column (such as facet joints and spinous processes) that could influence disc height and SL restoration was not studied. Finally, because the goals of the study were to evaluate the restoration disc height and SL, patients with more than 6 months of follow-up were included, which resulted in a cohort with wide variations in follow-up time (6–42 months).

Conclusions

IVP is a common finding in the degenerative spine. The presence of IVP can contribute positively to spinal realignment after LLIF, because its existence potentially provides an improved capacity to create SL and restore disc height. The addition of posterior instrumentation lowers the stress on the interbody cage and reduces the incidence of cage subsidence.

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Disclosures

Dr. Uribe is a consultant for and has direct stock ownership in NuVasive.

Author Contributions

Conception and design: Uribe, Yen, Beckman, Bach. Acquisition of data: Yen, Beckman, Bach. Analysis and interpretation of data: Yen, Beckman, Vivas, Bach. Drafting the article: Yen, Vivas. Critically revising the article: Uribe, Yen, Beckman, Vivas. Reviewed submitted version of manuscript: Uribe, Yen, Beckman, Vivas. Approved the final version of the manuscript on behalf of all authors: Uribe. Statistical analysis: Yen. Study supervision: Uribe.

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