Is a Persistent Vacuum Phenomenon a Sign of Pseudarthrosis After Posterolateral Spinal Fusion?

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Abstract

The purpose of this study is to evaluate whether the vacuum phenomenon (VP) resolves after posterolateral lumbar fusion, and whether persistence of VP is indicative of failed fusion. We retrospectively reviewed patients with degenerative lumbar spinal stenosis with instability with a positive VP on preoperative computed tomography (CT) who underwent posterolateral lumbar spinal fusion. Lumbar CT and radiographs were evaluated for the presence of VP and fusion at each level. Thirty-six positive VP levels were identified on the preoperative lumbar CT at the levels in the fusion in 18 patients. The mean age at surgery was 67.6 ± 9.4 years and mean follow-up was 1.6 ± 0.86 years. Fusion was seen at 32 levels (88.9%). Of the 15 levels where VP persisted, evidence of fusion was seen in 13 levels and pseudarthrosis was seen at 2. Of the 21 levels where VP disappeared, fusion was seen at 19 levels and pseudarthrosis was seen at 2 .There was no significant difference between the 2 groups ($P > .05$). We did not find an association between persistence of VP and pseudarthrosis. Persistence of VP after spinal fusion may not be an indicator of pseudarthrosis, and should not be misinterpreted as an indication for additional surgery.

The spinal vacuum sign or vacuum phenomenon (VP) is the radiographic finding of an air-density linear radiolucency in the intervertebral disc or vertebral body. The result of a gaseous accumulation, it is often a diagnostic sign of disc degeneration as well as a rare sign of infection, Schmorl node formation, or osteonecrosis.[1,2] Although the VP was first described on plain radiographs, it is better seen on computed tomography (CT).[3] Multiple studies have found a possible association between the VP and nonunion in diaphyseal fractures,[4] ankylosing spondylitis,[5,6] and lumbar spinal fusion.[7]

To our knowledge, no one has studied whether the intervertebral VP resolves after posterolateral lumbar spinal fusion in adults with degenerative spinal pathology, and no one has investigated the association between the persistence of the intervertebral VP and pseudarthrosis after posterolateral spinal fusion.

We conducted a study to determine whether the VP resolves after posterolateral lumbar spinal fusion procedures and whether persistence of the VP after fusion surgery is indicative of pseudarthrosis.

Materials and Methods

After obtaining Institutional Review Board approval for this study, we retrospectively reviewed the medical records of patients who had degenerative spinal stenosis with instability and the intervertebral vacuum sign on preoperative digital lumbar spine CT scans and who underwent posterolateral lumbar spinal fusion with or without instrumentation. Study inclusion criteria were lumbar spine CT at minimum 6-month follow-up after spinal fusion and preoperative and postoperative lumbar spine radiographs. Exclusion criteria were any type of interbody fusion procedure (anterior, posterior, transforaminal, lateral) at a level with the VP, age under 21 years, follow-up of less than 6 months, and incomplete radiographic records. As this was a retrospective study, patient consent was not required.

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CT was performed with a 16-, 64-, or 128-slice multidetector CT scanner with effective tube current set at 250 to 320 mA, voltage set at 120 to 140 kV, and pitch set at 0.75 to 0.9. After axial acquisition of 3×3-mm isometric voxels, sagittal and coronal multiplanar images were reconstructed with a slice thickness of 2 mm. Patient demographics, diagnoses, and surgical details were recorded. All digital lumbar spine CT scans and radiographs were initially screened on PACS (picture archiving and communication system) by the orthopedic spine surgery fellow at an academic medical institution; then they were reviewed on a radiology reading room monitor by 3 observers (senior radiologist, senior orthopedic spine surgeon, orthopedic spine surgery fellow). Axial images and sagittal and coronal reconstructed images of the preoperative and postoperative follow-up lumbar CT scans—together with the lateral and anteroposterior lumbar spine radiographs—were evaluated for the intervertebral VP. Mean (SD) follow-up (with CT to assess fusion) was 1.6 (0.86) years (range, 0.75-3.38 years). Fusion at each level was evaluated on the postoperative follow-up CT on axial images and sagittal and coronal reconstructed images; criteria for fusion were continuous bridging bone across posterolateral gutters and facets on one or both sides at each intervertebral level.[8] Pseudarthrosis was recorded if there was no continuity of bridging bone across both posterolateral gutters and facets, a complete radiolucent line on both sides across a level, or lysis or loosening around screws. All recordings were made by consensus, or by majority decision in case of disagreement.

Presence of the VP at the lumbar levels not included in the fusion was also recorded on the preoperative and follow-up CT scan and radiographs.

Descriptive and inferential statistical tests were performed as applicable. Pearson χ^2 test and Fischer exact test were used to evaluate if there was a significant association between the groups where the VP disappeared and persisted and fusion and pseudarthrosis. Significance was set at $P < .05$. Statistical analysis was performed with Stata Version 10.0.

Table 1. **Radiologic Details at Lumbar Intervertebral Levels of Fusion**

Radiologic Details	n
Preoperative	
Levels with vacuum phenomenon on CT	36
Levels with vacuum phenomenon on radiograph	20
Follow-up	
Levels with vacuum phenomenon on CT	15
Levels with vacuum phenomenon on radiograph	2
Fusion levels on CT	32
Pseudarthrosis levels on CT	4

Abbreviation: CT, computed tomography.

Table 2. **Relationship of Vacuum Phenomenon and Fusion Levels on Computed Tomography at Follow-Up**[a]

	Vacuum Phenomenon		
	Disappeared	Persisted	n
Fusion	19	13	32
Pseudarthrosis	2	2	4
Total	21	15	36

[a]Fischer exact test, $P = .99$.

Results

Using the preoperative lumbar spine CT scans of 18 patients (10 men, 8 women), we identified 36 cases of intervertebral levels exhibiting the VP (median positive vacuum sign levels per patient, 2; minimum, 1; maximum, 5) at the levels included in the fusion (**Table 1**). Mean (SD) age at surgery was 67.6 (9.4) years (range, 46.5-79.6 years). Mean (SD) radiologic follow-up was 1.6 (0.86) years (range, 0.75-3.38 years). All patients underwent lumbar fusion with local autograft, allograft, and recombinant human bone morphogenetic protein 2. Spinal instrumentation was used in 16 of the 18 patients.

On preoperative CT, positive VP was diagnosed in the 36 cases as follows: L5–S1 (11 cases), L4–L5 (9 cases), L3–L4 (4 cases), L2–L3 (6 cases), L1–L2 (4 cases), and T12–L1 (2 cases). On follow-up CT, 15 cases showed persistence of the VP, and 21 cases showed disappearance of the VP (Table 1).

Evidence of spinal fusion was identified on follow-up CT in 32 (88.9%) of the 36 cases. In 3 of the 18 patients, nonunion was diagnosed. Of the 15 intervertebral cases in which the VP persisted, 13 (86.7%) showed evidence of fusion on CT, and 2 (13.3%) showed evidence of pseudarthrosis. Of the 21 intervertebral cases in which the VP disappeared, 19 (90.5%) showed evidence of fusion on CT, and 2 (9.5%) showed evidence of pseudarthrosis (**Table 2**). There was no significant difference in fusion rate or pseudarthrosis rate in the groups in which the VP persisted or disappeared (Fischer exact test, $P = .99$). There was no significant association between VP persistence or disappearance and

sex, primary or revision surgery, or intervertebral level (Fischer exact test, $P > .05$). A case example is shown in the **Figure**.

At levels not included in spinal fusion, CT identified the VP at 6 lumbar intervertebral levels before surgery and 11 levels at follow-up. The VP did not disappear at any level not included in the fusion. At follow-up, no new VP was identified in a segment included in fusion. Results are summarized in **Table 3**.

Discussion

The association of radiologic intervertebral VP and disc degeneration, first recognized by Knutsson[1] in 1942, refers to the presence of gas, mainly containing nitrogen, in the crevices between or within vertebrae.[2] The VP is more often seen in patients older than 50 years, on plain radiographs in hyperextension.[9] CT is more sensitive than radiography in detecting the VP; Lardé and colleagues[3] found it in about 50% of 50 patients on CT scans but in only 12% of patients on radiographs. The VP is visible because of the nitrogen gas that accumulates when there is a negative pressure within the disc space. Nitrogen emerges from the blood and moves into the disc space; perhaps the disc space opens, causing the negative pressure.[1-3] On T1- or T2-weighted magnetic resonance imaging (MRI), the VP is visible as a signal void. MRI, however, is less accurate than CT.[10] In a study of 10 patients who had low back pain and more than 1 level of intradiscal VP, and who underwent supine MRI examinations at 0, 1, and 2 hours, Wang and colleagues[11] found that, after prolonged supine positioning, the signal intensity of the vacuum was replaced by hyperintense fluid contents. D'Anastasi and colleagues,[12] in a study of 20 patients who had lumbar vacuum phenomenon on CT and underwent MRI examinations, found a significant correlation between presence of intradiscal fluid and amount of bone marrow edema on MRI and degenerative endplate abnormalities on CT. In the present study, we found that, after the spinal fusion vacuum phenomenon disappeared in 58.3% of the lumbar levels and persisted in 41.7% on follow-up CT at the levels included in posterolateral fusion, there were 5 new levels, adjacent to the lumbar fusion, where the VP was seen on the follow-up CT.

We studied whether evidence of a persistent vacuum sign on CT is indicative of pseudarthrosis. Other authors have reported an association between the VP and nonunion in fractures[4] and ankylosing spondylitis.[5,6] In a study of 19 patients with diaphyseal fractures, Stallenberg and colleagues[4] found that, in 7 of the 10 patients with nonunion, the VP was detected on CT at the nonunion site. Martel[5] first reported on the intervertebral VP in a case of ankylosing spondylitis with spinal pseudarthrosis. Ten years later, in a study of 18 patients with advanced ankylosing spondylitis with spinal pseudarthrosis, Chan and colleagues[6] identified the intervertebral VP on CT in 7 patients. Edwards and colleagues[7] studied 15 patients with prior lumbar fusion with 17 positive intervertebral VP levels on CT and found that the vacuum disc sign was a strong predictor of lumbar nonunion as determined by surgical exploration. Mirovsky and colleagues[13] identified the intravertebral vacuum cleft in 26 patients with an osteoporotic vertebral fracture treated with vertebroplasty and concluded that nonunion of the vertebral fracture could be identified by presence of the intravertebral vacuum cleft on radiography. In the present study, there was radiologic evidence of lumbar spinal fusion in 89% of disc levels with a preoperative positive intervertebral VP and pseudarthrosis in 11% of disc levels. The rate of fusion at levels with the VP was comparable to the rate at intervertebral levels without the phenomenon. These findings indicate that persistence of the VP after spinal fusion is not an indication that fusion has not been achieved. Preoperative VP also did not predispose to failure of fusion. That there is a persistent vacuum disc might imply that,

We did not find an association between the vacuum phenomenon and pseudarthrosis. In addition, VP persistence on follow-up CT was not indicative of pseudarthrosis

Table 3. **Summary of Results at Follow-Up**

Mode and Results	n/N	%
Computed tomography		
Levels where vacuum phenomenon disappeared	21/36	58.3
Levels where vacuum phenomenon persisted	15/36	41.7
Fusion levels	32/36	88.9
Pseudarthrosis levels	4/36	11.1
Fusion % when vacuum phenomenon disappeared	19/21	90.5
Pseudarthrosis % when vacuum phenomenon disappeared	2/21	9.5
Fusion % when vacuum phenomenon persisted	13/15	86.7
Pseudarthrosis % when vacuum phenomenon persisted	2/15	13.3
Radiography		
Sensitivity of radiograph in detection of vacuum phenomenon	21/42	50

even after successful fusion as seen on CT, some motion may be occurring at the disc level to cause a negative pressure phenomenon. Even in cases of facet fusion with bridging bone, there may still be motion at the disc level, as fusions can plastically deform (even with screws in), particularly in elderly osteopenic bone. We found no association between a persistent vacuum sign and pseudarthrosis. Our study findings are clinically useful even if the benefits are limited. These findings may help surgeons avoid misinterpreting this sign as an indication for additional surgery.

Figure. Man (age, 54 years) with lumbar canal stenosis. (A) Preoperative lumbar spine lateral radiograph shows positive vacuum phenomenon at L4–L5 and L5–S1. (B) Preoperative lumbar spine sagittal computed tomography (CT) shows positive intervertebral vacuum phenomenon at L4–L5 and L5–S1. (C) At 2.4-year follow-up, lumbar spine lateral radiograph shows no vacuum phenomenon and no evidence of implant loosening. (D) At 2.4-year follow-up, lumbar spine sagittal CT shows no resolution of vacuum phenomenon at L4–L5 and L5–S1. (E) Postoperative lumbar spine coronal reconstruction CT shows posterolateral fusion from L3 to S1.

This study had some limitations. First, radiographs were used to determine presence or absence of fusion. Although CT is widely considered the gold standard for noninvasive assessment of fusion,[14] even when both posterolateral gutters and facets have been found to be fused on CT, the probability of a solid fusion on exploration ranges from 69% to 96%.[8,15] Second, detection of the VP on radiographs and CT may be affected by patient position.[11] Third, this was a retrospective series with a small number of patients and limited follow-up with CT. Arthrodesis and the VP may take years to fully evolve. It is possible that fusion rates could be higher on longer follow-up, and resolution of the VP may occur with longer follow-up. Fourth, clinical outcomes were not evaluated, as there are other confounding factors, apart from successful fusion, that could affect clinical outcomes. A larger prospective controlled study would be helpful.

Conclusion

The radiologic intervertebral VP may persist after posterolateral lumbar spinal fusion. We did not find an association between the VP and pseudarthrosis. In addition, VP persistence on follow-up CT was not indicative of pseudarthrosis, and VP disappearance was not indicative of fusion. The vacuum sign should not be misinterpreted as an indication for additional surgery.

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References

1. Knutsson F. The vacuum phenomenon in the intervertebral discs. *Acta Radiol*. 1942;23:173-179.
2. Resnick D, Niwayama G, Guerra J Jr, Vint V, Usselman J. Spinal vacuum phenomenon: anatomical study and review. *Radiology*. 1981;139(2):341-348.
3. Lardé D, Mathieu D, Frija J, Gaston A, Vasile N. Spinal vacuum phenomenon: CT diagnosis and significance. *J Comput Assist Tomogr*. 1982;6(4):671-676.
4. Stallenberg B, Madani A, Burny F, Gevenois PA. The vacuum phenomenon: a CT sign of nonunited fracture. *AJR Am J Roentgenol*. 2001;176(5):1161-1164.
5. Martel W. Spinal pseudarthrosis: a complication of ankylosing spondylitis. *Arthritis Rheum*. 1978;21(4):485-490.
6. Chan FL, Ho EK, Chau EM. Spinal pseudarthrosis complicating ankylosing spondylitis: comparison of CT and conventional tomography. *AJR Am J Roentgenol*. 1988;150(3):611-614.
7. Edwards CE, Antonoiades SB, Ford L, Crabster E. CT vacuum disc sign: a highly specific predictor of lumbar nonunion. Poster presented at: 41st Annual Meeting of the Scoliosis Research Society; September 2006; Monterey, CA.
8. Carreon LY, Djurasovic M, Glassman SD, Sailer P. Diagnostic accuracy and reliability of fine-cut CT scans with reconstructions to determine the status of an instrumented posterolateral fusion with surgical exploration as reference standard. *Spine*. 2007;32(8):892-895.
9. Goobar JE, Pate D, Resnick D, Sartoris DJ. Radiography of the hyperextended lumbar spine: an effective technique for the demonstration of discal vacuum phenomena. *Can Assoc Radiol J*. 1987;38(4):271-274.
10. Grenier N, Grossman RI, Schiebler ML, Yeager BA, Goldberg HI, Kressel HY. Degenerative lumbar disk disease: pitfalls and usefulness of MR imaging in detection of vacuum phenomenon. *Radiology*. 1987;164(3):861-865.
11. Wang HJ, Chen BB, Yu CW, Hsu CY, Shih TT. Alteration of disc vacuum contents during prolonged supine positioning: evaluation with MR Image. *Spine*. 2007;32(23):2610-2615.
12. D'Anastasi M, Birkenmaier C, Schmidt GP, Wegener B, Reiser MF, Baur-Melnyk A. Correlation between vacuum phenomenon on CT and fluid on MRI in degenerative disks. *AJR Am J Roentgenol*. 2011;197(5):1182-1189.
13. Mirovsky Y, Anekstein Y, Shalmon E, Peer A. Vacuum clefts of the vertebral bodies. *AJNR Am J Neuroradiol*. 2005;26(7):1634-1640.
14. Selby MD, Clark SR, Hall DJ, Freeman BJ. Radiologic assessment of spinal fusion. *J Am Acad Orthop Surg*. 2012;20(11):694-703.
15. Kanayama M, Hashimoto T, Shigenobu K, Yamane S, Bauer TW, Togawa D. A prospective randomized study of posterolateral lumbar fusion using osteogenic protein-1 (OP-1) versus local autograft with ceramic bone substitute: emphasis of surgical exploration and histologic assessment. *Spine*. 2006;31(10):1067-1074.