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CLINICAL GUIDELINES

Fusion Analysis on CT Spine Exams

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Introduction

Multidetector computed tomography (MDCT) is a first line study in the evaluation of fusion patients. (Burkus, Epstein, Gruskay, Goldstein, Patel) CT is useful to evaluate for healing of a fusion although some authors advocate CT only in cases in which plain radiographic evaluation is indeterminate. (Buchowski, Rhee)

It is important for the radiologist to evaluate the status of a spinal fusion. It is insufficient to merely report the presence of a fusion. A nonunion or pseudarthrosis may be a source of pain or may contribute to the patient's symptoms. In addition, the integrity of a spine fusion is an important factor in surgical planning in patients undergoing fusion revision, adjacent segment disease or adjacent segment deformity.

Multidetector Computed Tomography (MDCT) with sagittal and coronal reconstructions is the most accurate examination to assess to integrity of a fusion. (Burkus, Epstein, Gruskay, Goldstein, Patel) MDCT accurately displays bony anatomy, produces high resolution images of bony reconstructions and allows for direct visualization of the fusion bed.

CT has limited soft tissue contrast however, and has limited ability to directly visualize neurologic structures. CT has difficulty differentiating post-operative fibrosis from recurrent disc herniation following dorsal decompression surgery and discectomy. CT also has difficulty accurately grading central and subarticular recess stenosis within or adjacent to a fusion. While the reported accuracy of CT for stenosis is similar to that with MRI, in practice, delineation of the dural sac within an area of central or subarticular stenosis can be difficult. Finally, metal artifact frequently obscures soft tissue detail. If moderate or severe, metal artifact from instrumentation may even obscure the fusion bed itself. (Williams, Lee) MRI or CT myelography may be necessary in patients being evaluated for significant radicular pain or neurological deficits.

CT technique

It is important to optimize CT technique in order to limit metal artifact in patients with instrumented spinal fusions. The degree of metal artifact can vary substantially depending on the type of alloy and may be marked in patients with stainless steel or CoMoCr implants or instrumentation. (Williams, Lee, Stradiotti) Metal artifact is typically marked in patients with total disc replacement devices.

Several adjustments have been shown to decrease the severity of metal artifact: (Lee, Barrett, Stradiotti)

- Increased kVp (140) and increased the tube current (mas);
- Thin (1.25mm) sections to minimize partial voluming of artifact;
- Sagittal and coronal reconstructions using a soft kernel; and
- Extended window widths for viewing bone and the fusion mass.

Most modern CT scanners have automatic dose control software which modulates the CT dose relative to the patient's anatomy. The CT dose is automatically maximized in the region of the fusion and decreased in areas of normal anatomy decreasing the overall radiation dose delivered to the patients.

The orientation of metal implants also affects image quality. In general, the patient should be positioned so that the x-ray beam traverses the smallest cross-sectional area of the construct possible. The opposite strategy can be used to visualize segments adjacent to an instrumented fusion. In these cases, the tube is angled parallel to the long axis of the pedicle screws projecting metal artifact off of the adjacent segment. With this technique, metal artifact is concentrated at the level of the pedicle screws however obscuring soft tissue detail on the caudal margin of supra-adjacent discs and on the cephalad margins of infra-adjacent discs.

Nomenclature

Dorsal decompression defects. Fusion patients have often undergone prior or concurrent dorsal decompressions within or adjacent to the construct. In the lumbar spine, the nomenclature used to describe dorsal decompressions includes:

- Laminotomy,
- Laminectomy,
- Medial, subtotal or complete facetectomy, and/or
- Foraminotomy.

In the cervical spine the following terms are used:

- Laminoforaminotomy,
- Laminectomy, or
- Open-door laminoplasty (often performed with small malleable plates and screws).

Interbody fusions. Several surgical approaches can be used to perform an interbody fusion. It is acceptable to use the general term "interbody fusion" with or without interbody instrumentation and/or implants. If you are confident of the surgical approach, more specific terminology can be used:

- Anterior spinal fusion (Patients typically having an anterior plate or a large interbody implant such as a femoral ring allograft),
- XLIF (Extreme lateral interbody fusion),
- TLIF (Transfacet lumbar interbody fusion typically with resection of the ipsilateral facet joint), or
- PLIF (Posterior lumbar interbody fusion).

Interbody implants are used to distract the disc space and stabilize the segment until the interbody fusion heals. The surgeon may use bone implants such as femoral ring allografts, radiolucent polyetheretherketone ketone (PEEK) implants, or metal cages. More recently, surgeons have been utilizing combination interbody implants with endplate screws to achieve immediate stability.

Anterior spinal fusions can be performed with or without instrumentation. Anterior plates and vertebral screws are often used in the cervical and lumbar spine. Lateral plates or rods are typically used in the thoracic spine.

Posterior fusions. It is acceptable to use the general term posterior fusion with or without instrumentation. With posterior fusions, graft is often placed within the posterior facet joint, adjacent posterior paraspinous soft tissues, interlaminar space or lateral gutter (between the transverse processes). In the United States, posterior fusions are typically performed with instrumentation.

In the cervical spine, posterior fusions may be performed using lateral mass screws and rods or plates. In the lumbar spine, pedicle screw and posterior rod instrumentation is most commonly used. In previous years, posterior lumbar fusions were performed using translaminar facet screws, Steffee plates and Luque rods. Long segment constructs may use a combination of rods (Harrington rods), laminar wiring, pedicle screws and hooks (typically placed over the lamina or transverse processes).

Immediate or early fusion evaluation on MDCT

In immediate or early post-op period, CT is useful to evaluate for iatrogenic stenosis, fracture, hematoma and post-operative infection. (Ohaski, Allouni) Iatrogenic stenosis may result in radicular symptoms and most commonly arises from aberrant screw or implant placement, graft extrusion or implant extrusion.

Peri-operative fractures can result in severe and prolonged post-operative pain and are more common in patients with osteoporosis. Pars interarticularis or inferior articular process fractures or defects most commonly develop following laminotomy or laminectomy with or without medial facetectomy. (Figure 1)

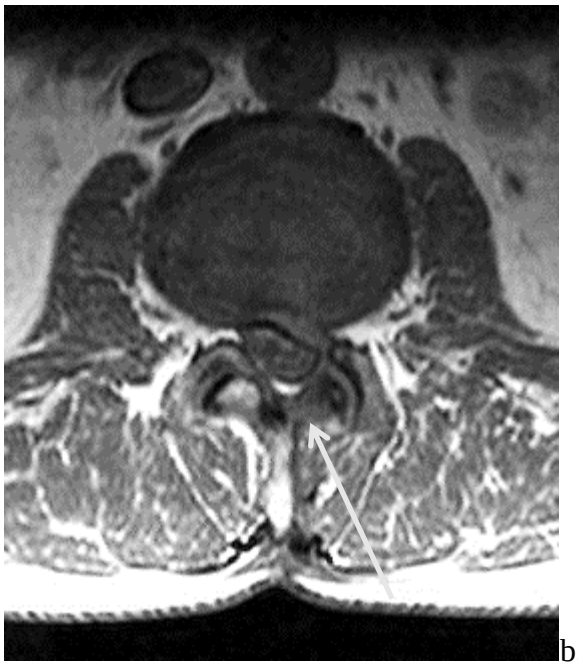
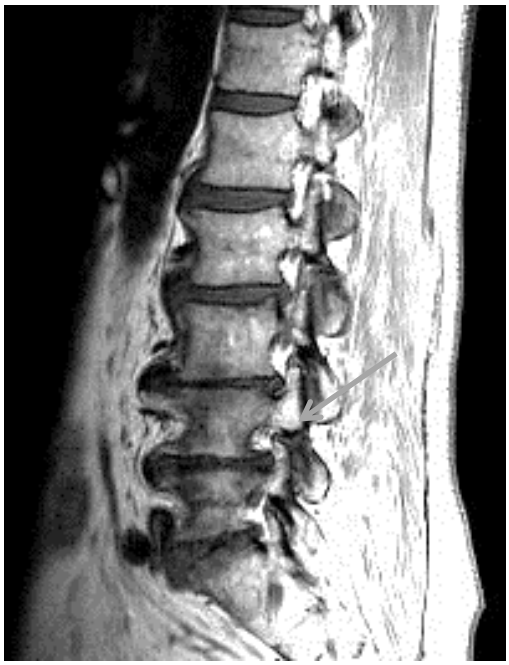
a.  b. 

Figure 1: Iatrogenic defect in the left L4 par interarticularis (arrow in b) following laminotomy/medial facetectomy (arrow in a).

Pedicle fractures typically result from pedicle screw placement and can extend into the adjacent vertebral body or neural foramen. (Figure 2)

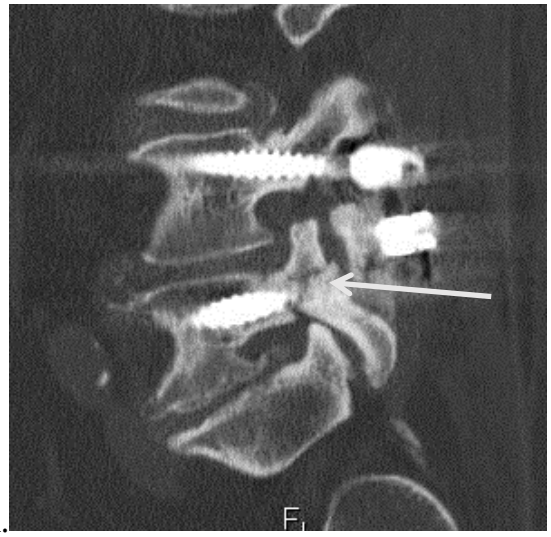
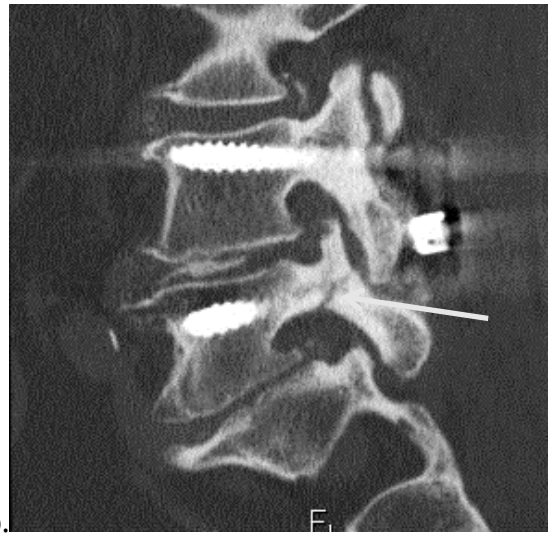
a.  b. 

Figure 2 (a,b): Iatrogenic pars/pedicle fracture following screw placement in a patient with post-operative radiculopathy

Vertebral fractures may occur following anterior spinal fusions and are most commonly seen at S1. Post-operative hematomas are common and are not symptomatic unless they result in mass effect on the dural sac or nerve roots.

Post-operative infection may develop following spine surgery of any type. MRI is indicated to detect post-operative spondylodiscitis, septic facet joint arthritis and osteomyelitis given its inherent sensitivity to marrow inflammation. MRI imaging with and without IV contrast is useful in differentiating phlegmon from abscess in the epidural, paraspinous or psoas muscular compartments. CT can be may be useful in cases with equivocal findings on MRI and is useful to detect and characterize endplate erosions. Endplate erosions associated with disc degeneration are typically sharply demarcated with adjacent medullary sclerosis, while erosions associated with infection are poorly demarcated with resorption of adjacent medullary bone. Equivocal MRI and CT finding should be correlated with the patient history, white blood cell count, C-reactive protein and sedimentation rate.

Endplate erosions, marrow edema and cystic changes can also be seen in the early post-operative spine following fusion with bone morphogenic proteins. (Licina, Rihn) Endplate erosions and marrow edema will typically resolve over a period of months as the fusion matures however cystic changes can persist within medullary bone. Heterotopic ossification is often seen in the inferior neural foramen following TLIF or PLIF procedures and can be associated with post-operative radiculopathy. (Chrastil) Heterotopic bone within the neural foramen typically shows high signal intensity fluid on MRI surrounded by a thin shell of bone on CT.

Routine fusion evaluation on MDCT

In symptomatic fusion patients, CT is useful to evaluate for fusion nonunion, fusion breakdown, recurrent stenosis and/or adjacent segment degeneration.

MDCT is more accurate for fusion evaluation and correlates better with surgical findings than does static radiography and dynamic radiography. (Buchowski, Ploumis) CT allows for direct visualization and assessment of the fusion mass and has increased sensitivity for complex, transverse or obliquely oriented plate-like radiolucencies within areas of graft. (Burkus, Patel) MDCT also allows for bridging trabecular bone to be differentiated from continuous bony density. (Selby) MDCT consistently shows a higher pseudarthrosis rate than static radiographs. (Santos, Ploumis) MDCT also shows a higher pseudarthrosis rate than dynamic radiography in most studies. (Santos, Epstein, Ploumis, Buchowski) Ghiselli et al. however showed that dynamic radiographs using Quantitative Motion Analysis and a threshold of 1 mm of interspinous motion was more predictive of pseudarthrosis than CT. (Ghiselli)

Despite these advantages, most studies overstate the fusion rate on MDCT because they do not explicitly distinguish between bridging trabecular and *continuous bony density.* Fusions with bridging trabecular bone are solid. Fusions with continuous bony density are indeterminate as CT is unable to distinguish between a developing fusion mass and packed avascular graft in these cases. (Cook) Patients with continuous bony density need to be evaluated using a preponderance of evidence including the presence of absence of marginal radiolucencies and secondary signs of motion.

Signs of a fusion on CT

Bridging trabecular bone (BTB). Bridging trabecular bone is the primary sign of a solid fusion. (Goldstein, Gruskay) BTB is defined as continuous bony density with remodeling. With remodeling, density within an area of continuous bony density decreases becoming isodense with

adjacent medullary bone, trabeculation develops and the vertebral endplate or subchondral bone resorbs. (Figures 3, 4) In many cases, demarcation between the fusion mass and adjacent medullary bone is lost.

If bridging trabecular bone is present, a fusion is judged to be solid. Solid interbody fusions in the cervical spine typically incorporate the bulk of the disc as well as the uncovertebral joints, while interbody fusion masses within the lumbar spine may remain localized to one or more quadrants of the disc.

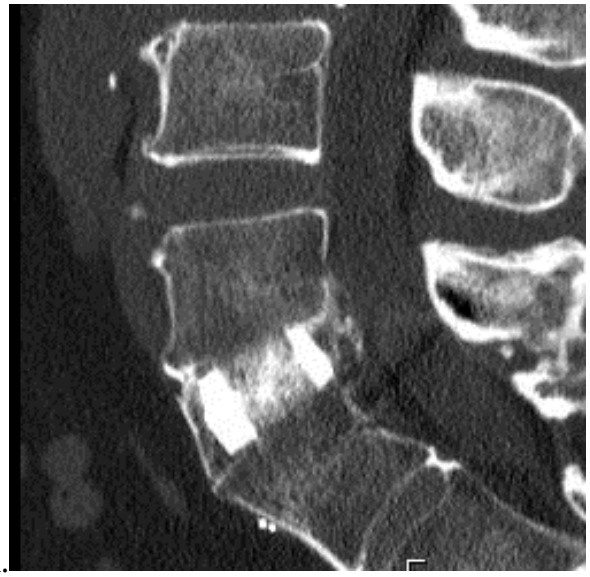
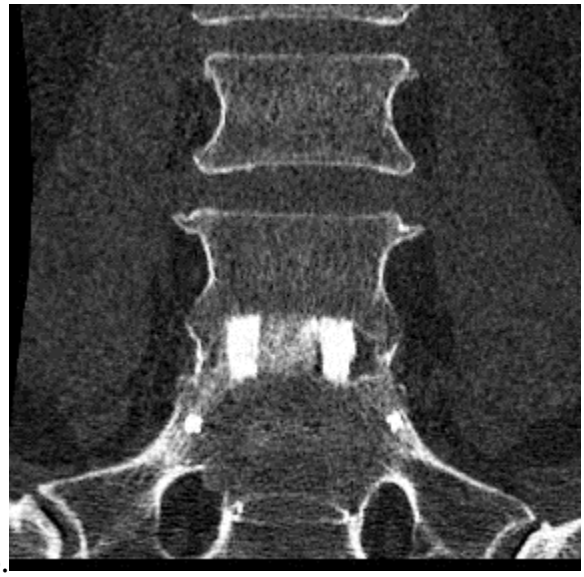
a.  b. 

Figure 3(a,b): Solid interbody fusion with bridging trabecular bone. Note resorption of the vertebral endplates and trabeculation of graft lateral to the implant.

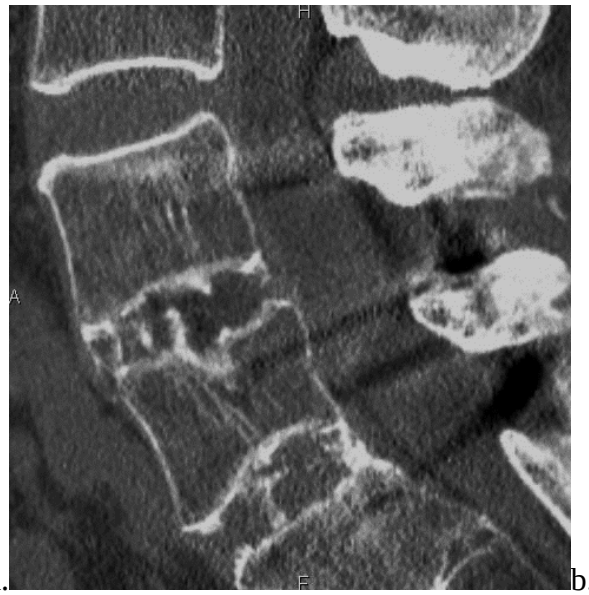
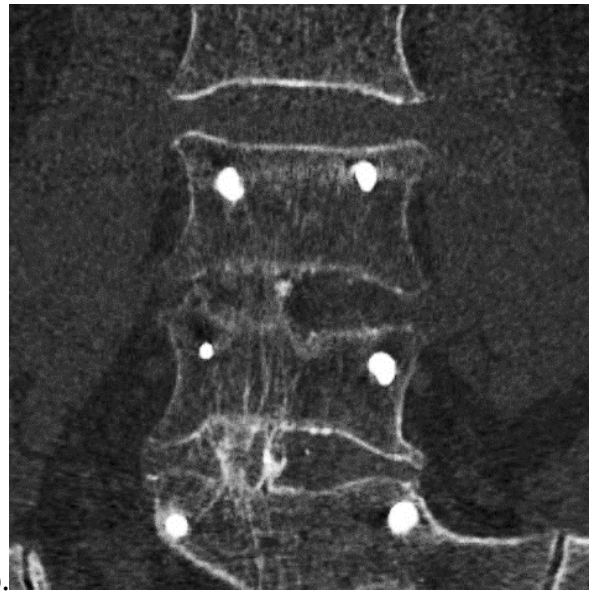
a.  b. 

Figure 4(a,b): Solid interbody fusions at L5-S1 and L4-5 with fatty density within the disc space at L4-5 and continuity of trabecular struts on coronal views.

Continuous bony density (CBD). Continuous bony density is a sign of healing in that plate-like or complex radiolucencies are absent. If continuous bony density without remodeling is present the fusion is indeterminate. (Figure 5, 6)

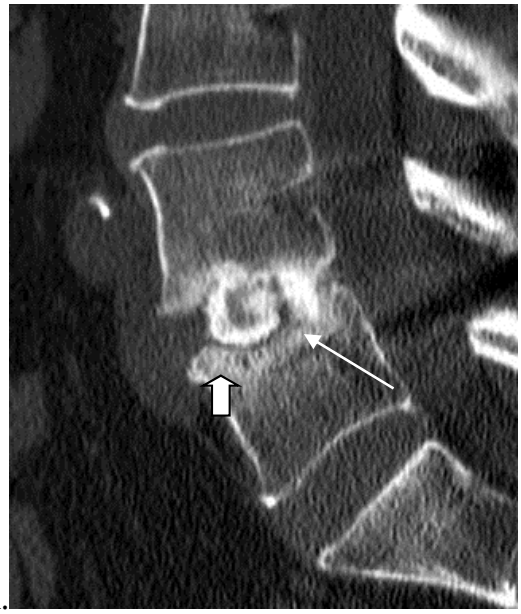
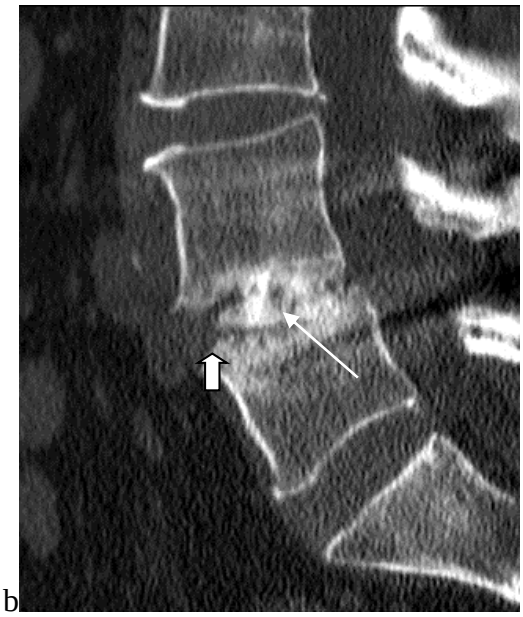
a.  b 

Figure 5(a,b): Continuous bony density within the posterior aspect of an interbody fusion bed is indeterminate for a developing fusion versus packed avascular graft. The presence of sclerosis and microcystic changes within the adjacent L5 vertebrae (bold arrows) indicates persistent interbody motion and is worrisome for developing pseudarthrosis.

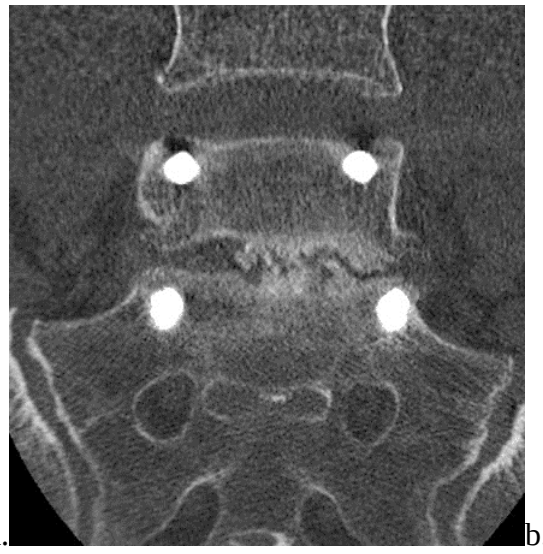
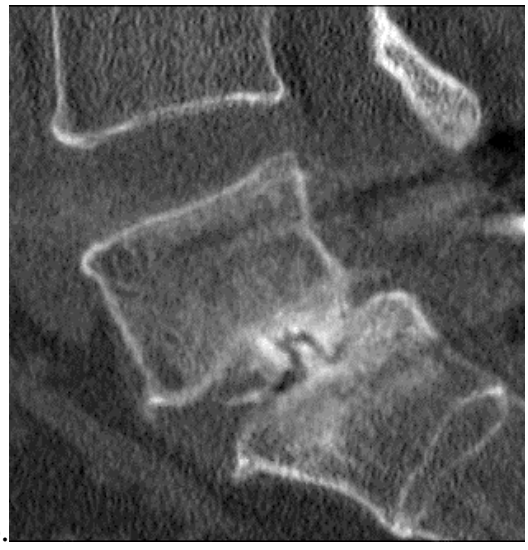
a.  b. 

Figure 6(a,b): Complex radiolucencies within the interbody fusion indicate that the fusion has not yet healed. Small collections of gas indicate persistent interbody motion and may portend the development of an interbody pseudarthrosis.

CBD is not diagnostic of a solid fusion as it can be seen with both packed avascular graft and a developing fusion mass. (Cook, Song) The significance of continuous bony density needs to be assessed relative to other observations such as the presence or absence of marginal radiolucencies, intradiscal gas, endplate microcystic changes, adjacent medullary sclerosis and the presence or absence of motion on dynamic radiography.

Continuous bony density within an interbody cage is an especially unreliable sign of fusion. Song et al. reported that continuous bony density within a cage had a low specificity (53.2%) and a low negative predictive value (35.5%) for solid fusion. (Song) Areas of continuous bony density within an interbody cage should be viewed as suspect, and attention should be paid to the presence or absence of areas of CBD or BTB outside the cage. In this regard, Carreon et al. showed that the accuracy of the anterior and posterior sentinel signs was 61% and 74% respectively. (Carreon) Continuous bony density outside the cage has moderate predictive value for a solid fusion and its significance should be graded relative to the presence of absence of marginal radiolucencies and secondary signs of motion.

Marginal Radiolucencies. Radiolucencies on the margins of interbody implants are noted if they extend along more than 50% of the superior or inferior implant margins. Marginal radiolucencies indicate a failure of the implant to incorporate and correlate with delayed union and pseudarthrosis. (Burkus) They are not diagnostic of nonunion; however, as fusion masses can develop around the implant.

The significance of marginal radiolucencies also varies depending on the type of implant used. Allograft and autograft bone are osteointegrative and are directly incorporated into the fusion mass. Ti and Ta implants are also osteointegrative. Surface oxides form on the surfaces of the Ta and Ti implants and serve as the substrate for the formation of a hydroxyapatite layer, subsequent appositional bone growth and eventual incorporation into the fusion mass. Radiolucencies on the margins of these implants may indicate a developing nonunion or pseudarthrosis.

PEEK implants are not osteointegrative and do not incorporate into fusion masses. A thin fibrous rim develops on the margins of the implant. Fusion masses develop around PEEK interbody implants and radiolucencies on the margins of the implant are an expected finding.

The significance of marginal radiolucencies needs to be assessed relative other findings. If bridging trabecular bone is present within the more peripheral disc, the fusion is solid. If continuous bony density is present within the more peripheral disc, the fusion is indeterminate. Secondary signs of motion adjacent to the implant may indicate a developing pseudarthrosis. (Figure 7, 8)

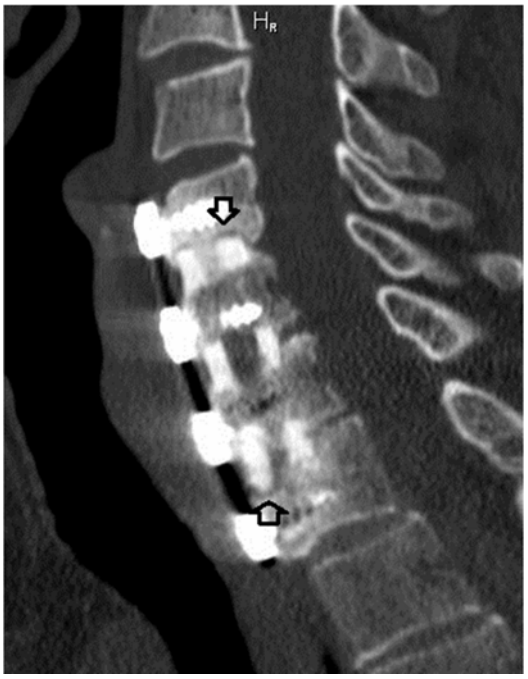
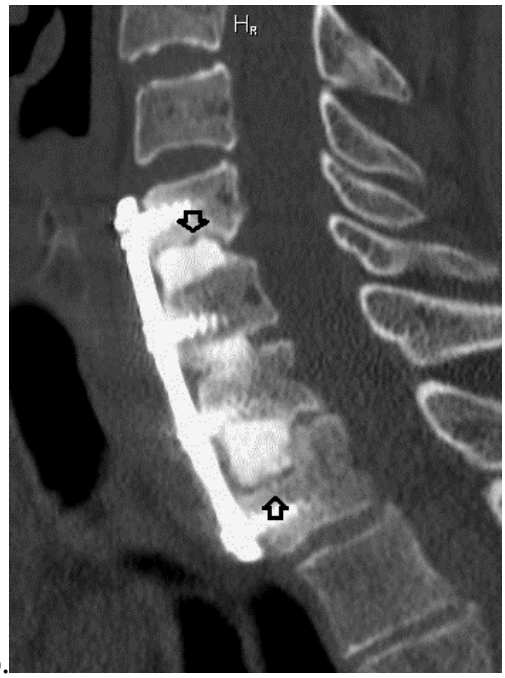
a.  b. 

Figure 7(a,b): Radiolucencies are seen on the margins of the C6-7 and C4-5 interbody implants (open arrows). While areas of continuous bony density are seen at each level, sclerosis is seen within adjacent medullary bone indicating an indeterminate fusion. The C5-6 interbody fusion is solid.

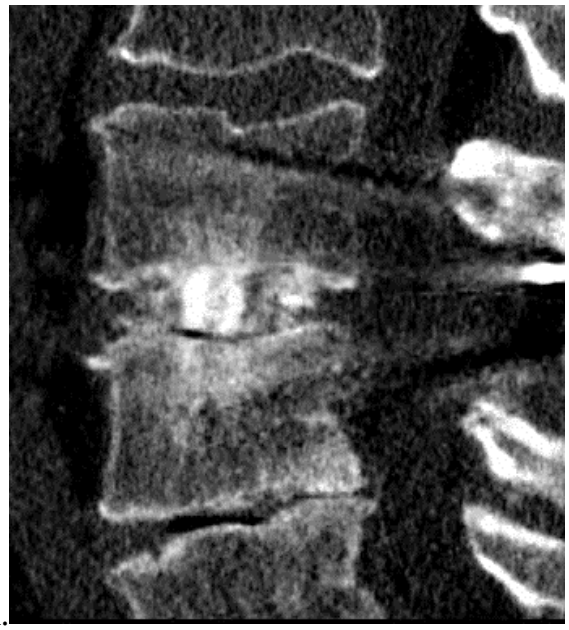
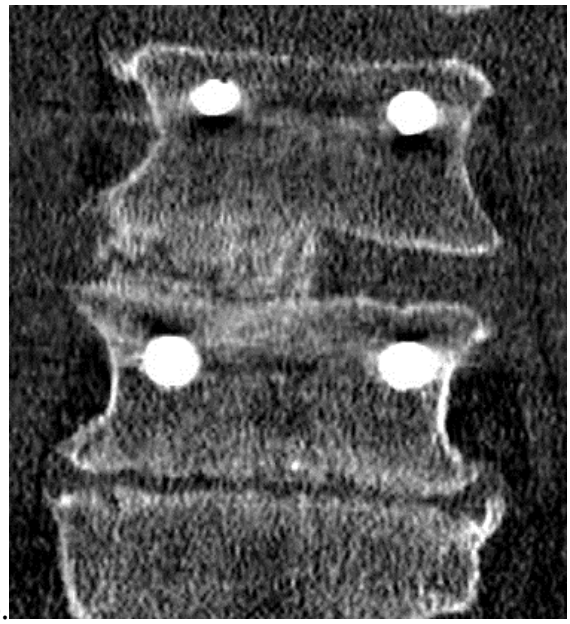
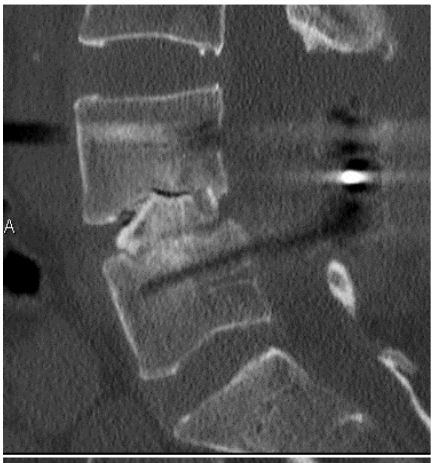
a.  b. 

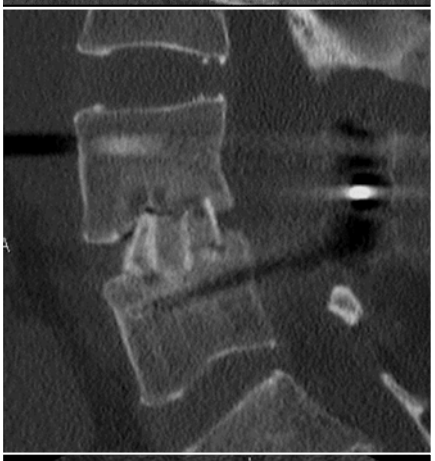
Figure 8(a,b): Radiolucency on the inferior margins of the interbody implant is associated with a complex radiolucency throughout adjacent graft indicating that there is no healing as of yet. Intradiscal gas and adjacent medullary sclerosis indicates persistent interbody micromotion and may indicate a developing interbody pseudarthrosis.

Secondary signs of motion. Intradiscal gas, adjacent medullary sclerosis and endplate cystic changes are each secondary signs of persistent interbody micromotion. (Williams, Burkus) (Figure 9) Secondary signs of motion may indicate that continuous bony density is secondary to packed avascular graft rather than to a developing fusion mass, and may indicate that marginal radiolucencies are associated with a nonunion or developing pseudarthrosis. The presence of gas within an interbody fusion 2 or more years after surgery would indicate a nonunion in most cases.

a.



b.



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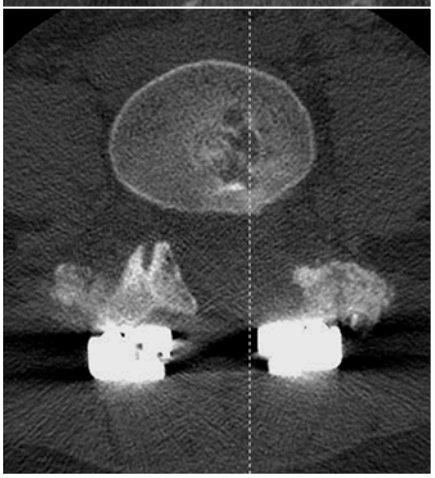


Figure 9: Secondary signs of motion. Intradiscal gas is seen in a, and both endplate microcystic changes and adjacent medullary sclerosis in b & c.

Hardware loosening and fatigue. Radiolucencies on the margins of pedicle, vertebral or lateral mass screws indicate persistent intersegmental motion and may indicate a developing or established pseudarthrosis. (Williams, Patel, Tokuhashi) (Figure 10) Hardware fatigue refers to the fracture of screws, plates or rods, indicates instrumentation failure and correlates with pseudarthrosis. (Patel)

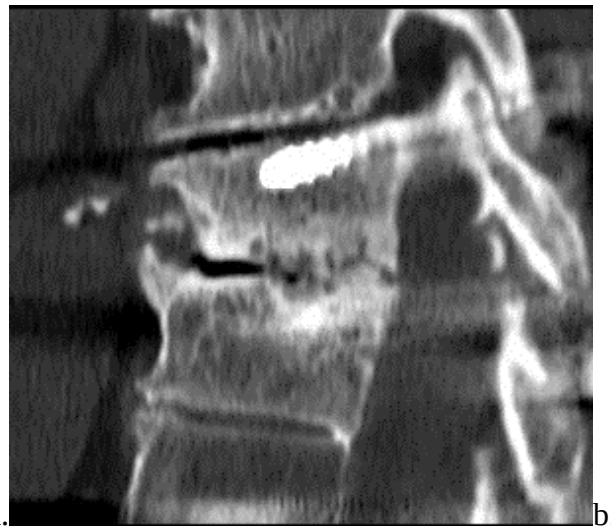
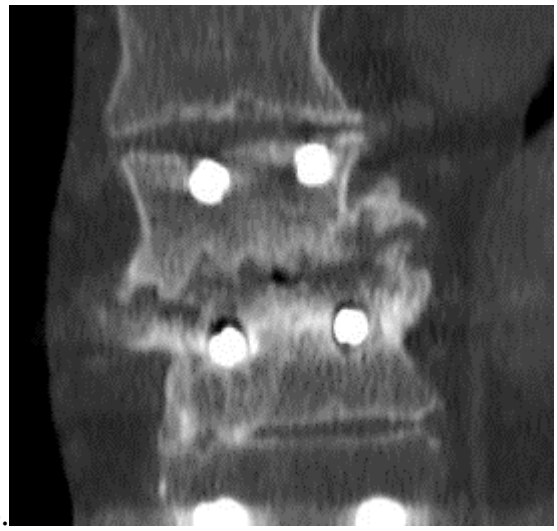
a.  b. 

Figure 10: Radiolucencies are seen on the margins of the more caudal of the pedicle screws (b). Radiolucency persists throughout the disc space with intradiscal gas, endplate cystic changes and adjacent medullary sclerosis indicating an interbody pseudarthrosis (a).

Radiolucencies on the margins of screws can be seen in patients with a solid or solid appearing fusion, presumably representing the sequelae of a delayed union. Radiolucencies may also persist on the margins of screws following revision or augmentation surgery. Similarly, fractured screws may also be left in patients who have undergone revision or augmentation surgery.

Subsidence. Subsidence of an interbody implant into an adjacent vertebral body is associated with delayed union and nonunion. With the placement of an interbody device, there is distraction of the disc space and increased tension on the annular ligaments resulting in immediate mechanical stabilization. (Williams, McAfee) With subsidence, there is loss of disc space height and loss of early interbody stability which may delay or preclude healing.

With placement of an interbody device, there is also distraction of the pedicles decompressing the neural foramina in the up-down direction. With subsidence, distraction is decreased or lost and up-down foraminal stenosis can reoccur.

Subsidence should be commented on if moderate or marked. Recurrent up-down foraminal stenosis should also be noted particularly if the patient complains of ipsilateral radicular symptoms.

Report terminology

Early fusion evaluation. In clinical practice, it is frequently necessary to assess a fusion at some time prior to the fusion endpoint. In these patients the MDCT should be examined for evidence of healing. Bridging trabecular bone, if present, indicates a solid fusion. Continuous bony density, if present, indicates healing particularly if there is consolidation and remodeling of graft.

If no BTB or CBD is present, there is no evidence of healing. Intradiscal gas, adjacent medullary sclerosis and endplate cystic changes indicate persistent interbody micromotion. Screw loosening may indicate a developing pseudarthrosis, and hardware fracture/fatigue is a sign of pseudarthrosis.

The following terminology is recommended within the first year of the fusion procedure:

- **Solid union** with bridging trabecular bone;
- **Evidence of healing** with continuous bony density;
- **No evidence of healing** with no bridging bone or continuous bony density;
- **Persistent interbody micromotion** with intradiscal gas, adjacent medullary sclerosis and/or endplate cystic changes;
- **Developing pseudarthrosis** with screw loosening or endplate cystic changes.

Endpoint fusion evaluation. At 1 year, most fusions will have healed if they are going to heal. Caution should still be exercised, however, as delayed unions can occur and may take up to 2 years to heal. Bridging trabecular bone (BTB) remains the primary sign of a solid fusion. If continuous bony density (CBD) is present, the fusion should be evaluated using a preponderance of evidence technique as illustrated in Table 1 below.

Grading Scale – CT			
	Marginal radiolucency[1]	2° signs of motion[2]	Status
BTB			Fused
CBD	None	None	Probably Fused
CBD	None	Yes	Indeterminate
CBD	Yes	None	Indeterminate
CBD	Yes	Yes	Probably not fused
None	None	None	Probably not fused
None	None	Yes	Not fused/Nonunion
None	Yes	+/-	Not Fused/Nonunion

Table 1 – Fusion assessment on CT

In clinical practice, you will most likely simply refer to the fusion as:

- **Fused**,
- **Indeterminate**, or
- **Not fused**.

Additional terminology includes:

- **Nonunion** indicating a failure of healing after an interval of time during which healing would normally be expected (1-2 years) or no evidence of progressive healing on one or more follow-up examinations over a period of 3-6 months.
- **Locked pseudarthrosis** (Brantigan) indicating bone growing into the implant (no marginal radiolucencies or secondary signs of motion) and persistent radiolucencies within bone graft and disc peripheral to the implant (no BTB or CBD).
- **Pseudarthrosis** referring to a nonunion with persistent interbody motion as indicated by the presence of endplate cystic changes/sclerosis and/or hardware loosening or fatigue. This may portend ultimate breakdown of the fusion construct.

Interbody and posterior spinal fusions should be evaluated and reported separately, and both the location and quality of a posterior spinal fusion should be reported. While large robust posterior fusion masses can be reported as such, more limited posterior spinal fusions should be reported with specific reference to continuous bony density or bridging bone in the facet joint, interlaminar space, interspinous process space, or intertransverse process space if present.

References

1. Allouni AK, Davis W, Mankad K, Rankine J, Davagnanam I. Modern spinal instrumentation. Part 2: multimodality imaging approach for assessment of complications. Clin Radiol. 2013 Jan;68(1):75-81.
2. Barrett JF, Keat N. Artifacts in CT: Recognition and avoidance. RadioGraphics 2004;24:1679-1691.
3. Buchowski JM, Lie G, Bunmaprasert T, et al. Anterior cervical fusion assessment. Surgical exploration versus radiographic evaluation. Spine 2008;33(11):1185-91.
4. Burkus JK, Foley K, Haid R & Le Huec J-C. Surgical Interbody Research Group – radiographic assessment of interbody fusion devices: Fusion criteria for anterior lumbar interbody fusion. Neurosurg Focus 2001;10(4):1-9.
5. Carreon LY, Glassman SD, Schwender JD, Subach BR, Gornet MF, Ohno S. Reliability and accuracy of fine-cut computed tomography scans to determine the status of anterior interbody fusions with metallic cages. Spine J. 2008 Nov-Dec;8(6):998-1002.
6. Cook SD, Patron LP, Christakis PM, et al. Comparison of methods for determining the presence and extent of anterior lumbar interbody fusion. Spine 2004;29(10):1118-1123.
7. Chrastil J[1], Low JB, Whang PG, Patel AA. Complications associated with the use of the recombinant human bone morphogenetic proteins for posterior interbody fusions of the lumbar spine. Spine 2013 Jul 15;38(16):E1020-7.
8. Epstein NE, Silverglade RS, Black K. Computed tomography validating bony ingrowth into fibula strut allograft: a criterion for fusion. Spine J 2002;2:129-133.
9. Ghiselli G, Wharton N, Hipp JA, et al. Prospective Analysis of Imaging Prediction of Psudarthrosis after Anterior Cervical Discetomy and Fusion. Spine 2011;36(6):463-468.
10. Goldstein C, Drew B. When is a spine fused? Injury. 2011 Mar;42(3):306-13.
11. Gruskay JA, Webb ML, Grauer JN. Methods of evaluating lumbar and cervical fusion. Spine J. 2013 Oct 31. doi:pii: S1529-9430(13)01380-6. 10.1016/j.spinee.2013.07.459.
12. Lee M, Kim S, Lee S, et al. Overcoming artifacts from metallic orthopedic implants at high field-strength MR imaging and multidetector CT. RadioGraphics 2007;27:791-803.
13. Licina, P. Early complications associated with BMP in lumbar interbody fusions. Journal of Bone & Joint Surgery, British Volume 91.SUPP III (2009): 437-437.
14. McAfee PC, Boden SD, Brantigan JW, Fraser RD, Kuslich SD, Oxland TR, Panjabi MM, Ray CD, Zdeblick TA. Symposium: A critical discrepancy-criteria of successful arthrodesis following interbody spinal fusions. Spine (Phila Pa 1976). 2001 Feb 1;26(3):320-34. Review. Erratum in: Spine 2001 May 1;26(9):1103.
15. Ohashi K, El-Khoury GY, Bennett DL, et al. Orthopedic hardware complication diagnosed with multi-detector row CT. Radiology 2005; 237:570-577.

16. Patel AA and Spiker WR. Update on the diagnosis and treatment of lumbar nonunions. Semin Spine Surg 2008;20:20-26.

17. Ploumis A, Mehbod A, Garvey T, et al. Prospective assessment of cervical fusion status: Plain radiographs versus CT-scan. Acta Orthop Belg 2006;72(3):342-6.
18. Rhee JM, Chapman JR, Norvell DC, et al. Radiologic determination of postoperative cervical fusion: A systematic review. Spine 2015;40(13):974-991.

19. Rihn JA, Gates C, Glassman SD, et al. The Use of Bone Morphogenetic Protein in Lumbar Spine Surgery. J Bone Joint Surg Am. 2008;90:2014-25.

20. Santos ER, Goss DG, Morcom RK, Fraser RD. Radiologic assessment of interbody fusion using carbon fiber cages. Spine (Phila Pa 1976). 2003 May 15;28(10):997-1001.

21. Selby MD, Clark SR, Hall DJ, Freeman BJ. Radiologic assessment of spinal fusion. J Am Acad Orthop Surg. 2012 Nov;20(11):694-703.

22. Song KS, Chaiwat P, Kim HJ, Mesfin A, Park SM, Riew KD. Anterior cervical fusion assessment using reconstructed computed tomographic scans: surgical confirmation of 254 segments. Spine (Phila Pa 1976). 2013 Dec 1;38(25):2171-7.
23. Stradiotti P, Curti A, Castellazzi G, Zerbi A. Metal-related artifacts in instrumented spine. Techniques for reducing artifacts in CT and MRI: State of art. Eur Spine J 2009;19(Suppl 1):S102-S108.
24. Tokuhashi Y, Matsuzaki H, Oda H, and Uei H. Clinical course and significance of the clear zone around the pedicle screws in the lumbar degenerative disease. Spine 2008;33(8):903-908.

25. Williams AL, Gornet MF, Burkus JK. CT evaluation of lumbar interbody fusion: current concepts. AJNR Am J Neuroradiol. 2005 Sep;26(8):2057-66. Review.