Imaging of spinal fusion

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Introduction
Surgical spinal fusion is a procedure where two or more of the vertebrae of the spine are “fused” together in an attempt to achieve solid arthrodesis and to potentially eliminate painful movement or to correct deformity. The purpose of the spinal hardware is to provide additional spinal stability while helping the fusion set up. The first successful surgical fusion procedures were described by Hibbs in 1911 for prevention of progressive deformity from Pott disease.1

Spinal fusion surgeries have increased markedly in frequency in recent decades. In fact, according to a report by the Agency for Healthcare Research and Quality (AHRQ), there has been growth of 70 per cent from 2001.2

Spinal fusion is an accepted management for spinal instability secondary to trauma, infection, tumour, congenital anomalies such as scoliosis and for progressive spinal deformity.

The purpose of this review is to highlight the basic concepts of surgical spinal fusion and to consider the most common radiological methods of spinal fusion assessment including their strengths and limitations at demonstrating post-surgical complications.

Methods of spinal fusion
Stabilisation and fusion of the lumbar spine may be performed by using various anterior and posterior surgical techniques and a wide range of devices, including screws, spinal rods, artificial ligaments, vertebral cages and artificial discs. For example, pedicle screws grip each vertebral segment and act as a firm anchor point for the rods providing early stability, and aid early recovery, optimising an environment for fusion. Interbody cages aim to restore height, improve axial loading ability, tension ligament structures and allow graft material centrally and peripherally around the cage. As spinal procedures are increasingly common, a variety of different devices are seen more frequently in everyday radiologic practice. In-depth knowledge of each of these varied devices is not possible but generic understanding of their concepts and aims is paramount to accurate imaging assessment.

The nomenclature used can be quite daunting but for interbody fusion devices in the lumbar spine it is straightforward, with the prefix to LIF (lumbar interbody fusion) representing the approach taken by the surgeon, for example ALIF – anterior; PLIF – posterior (figure 1); TLIF – transforaminal; DLIF – direct lateral.3 Dynamic stabilisation devices can also be used as an alternative to fusion by attempting to alter load bearing.

The choice of device depends on the clinical problem, the anatomic location and the surgeon’s preference. A posterior approach allows posterior canal decompression while placing posterior fusion hardware. It has relatively poor canal visualisation which is one of the advantages of an anterior approach. Historically, an anterior approach had associated morbidity but recent advances in laparoscopic procedures have reduced this and the post-operative recovery time. An anterior approach can be utilised when pain is predominantly discogenic and posterior decompression is not required. This approach is reported to have accelerated rates of fusion4 and increased axial load bearing ability but is contraindicated with concomitant facet joint disease in the motion segments to be fused.

Rigid internal fixation is necessary to promote bone fusion, which occurs within four to five months after spinal fusion surgery and to prevent pseudoarthrosis.3

Bone graft material is vital to aid bridging across the motion segments for arthrodesis to take place. Ideally this material should be osteogenic (bone forming) and have osteoconductive and osteoinductive (recruiting and moving of the bone forming cells) properties. The ‘gold standard’ graft material is autograft (from the same individual, eg iliac crest) but this has limited volume. Therefore, it is often supplemented with synthetic graft material. Today, several artificial bone graft materials have been developed to both augment and supplement autograft material. These include:

1. Demineralised bone matrices (DBMs). Calcium is removed from cadaveric bone to create DBMs. Without the mineral, the bone can be changed into a putty or gel-like consistency. DBMs are usually combined with other grafts and may contain proteins that help in bone healing.

2. Bone morphogenetic proteins (BMPs). These are very powerful synthetic bone-forming proteins and are the only synthetic protein known to be osteoconductive. They are approved by the USA Food and Drug Administration for use in the spine in certain situations. Autografts may not be needed when BMPs are used. Imaging reviewers should be aware that this is radiolucent at the time of surgical insertion, with widely reported osteolytic defects demonstrated in adjacent osseous structures in the early post-operative period, but the vast majority go on to fusion.6

3. Ceramics. Synthetic calcium/phosphate materials that are similar in shape and consistency to autograft bone.

Methods of imaging spinal fusion
Technical success of fusion has been defined as the presence of bridging trabecular bone across vertebral bodies (anterior), facet joints and transverse processes and sacral ala (posterior).

Post-operative imaging is typically performed for several reasons:
• to confirm the correct positioning and the integrity of instrumentation
• to assess the progress of osseous fusion
• to detect suspected complications (eg infection or haematoma)
• to detect new disease or disease progression.

The modality and protocol used to image the post-operative spine depends on the site, the clinical question, and the type of instrumentation. There is currently no reference standard for non-invasive imaging evaluation of fusion.7 It should be noted that the gold standard assessment for fusion is surgical and therefore, correlation between surgical exploration and imaging tests has been the best method to assess for diagnostic accuracy.

figure 1
Radiography/computed tomography (CT)

Radiography is the non-invasive modality most commonly used for the assessment of fusion due to low cost, low dose and widespread availability, although CT is reported to be more accurate due to its 3D imaging capabilities. It has been documented that plain radiographs overestimate fusion compared with CT.

Radiographic features of fusion include progressive consolidation of graft material with a ‘pebble-like’ appearance to bridging trabecular bone at the site of intended fusion (figure 2). This includes across endplates in anterior interbody fusion and across facet joints and transverse processes for posterior fusion (figure 3).

One group has suggested that linear lucency centrally across bone graft within an interbody device or cage without osteolysis at the end plate interface represents a ‘locked’ pseudoarthrosis that may represent a mechanically stable construct (figure 4). This they classified as BSF-2 which represents intermediate fusion success. A BSF-1 pseudoarthrosis is indicated by collapse of the construct, loss of disc height, vertebral slip, broken screws, displacement of cage, resorption of bone graft or visible lucency around periphery of graft or cage. BSF-3 defines radiographical fusion of bone bridging at least half the fusion area, with at least the density originally achieved at surgery.

Therefore, radiographic features associated with non-union include primary features at the graft site such as graft resorption or secondary features involving the hardware or alignment. These include:

- radiolucency around metalwork (increasing over time or persisting at two years) (figure 5)
- lucency between cage and vertebral endplate (figure 5)
- pseudoarthrosis (figure 4)
- vacuum phenomenon (figure 4)
- implant fracture (figure 6)
- migration/subsidence of implant (figure 6)
- loss of graft height
- progressive deformity on loading.

CT is the modality of choice for imaging bony detail in the spine to enable accurate assessment of the degree of bridging trabeculae. The quality of CT images may be severely degraded by starburst-type artefact due to metallic implants (figure 4), which cause marked x-ray attenuation (hollow projections) in selected planes. Titanium has a lower x-ray attenuation coefficient than stainless steel and therefor causes less severe artefact. New high speed multi-detector CT with thin slice 0.5mm acquisitions, reconstruction algorithms and multi-planar reformation may help minimise starburst-type artefacts.

Dynamic radiography

Flexion and extension radiographs are often used to assess fusion but debate exists as to their utility as a diagnostic tool due to multiple different measurement techniques, effects of instrumentation on spinal motion and disagreement regarding cut-offs for acceptable motion even before considering inter-observer error.

Magnetic resonance imaging (MRI)

MRI has limited added benefit in assessing for fusion, however, MRI is useful for evaluating sequential post-operative changes in the spine and for better visualisation of intra-spinal or neural contents. It is particularly useful for evaluating early or late complications including dural injuries and for detecting and monitoring infection or post-operative collections, such as an epidural haematoma (figure 8).

A limitation is the susceptibility artefact, particularly in the presence of stainless steel devices (figure 8). Sequences have been developed to reduce the artefact, but their use may necessitate increased image acquisition time and may result in image distortion. Gradient-echo sequences are more vulnerable to magnetic susceptibility artefact than are spin-echo (SE) sequences and are best avoided. Reduction of the echo time may lead to an increase in the signal-to-noise ratio while minimising artefact. Increasing the bandwidth also helps to significantly reduce the artefact magnitude with SE and turbo SE sequences, although this method also leads to a decrease in the signal-to-noise ratio.

Nuclear medicine, single photon emission computed tomography (SPECT) and SPECT/CT

Bone scintigraphy may be performed to assess fusion (the fused segment should be ‘cold’ after 6-12 months) and it is also useful for detecting infection. A study has shown a higher accuracy in SPECT/CT versus planar SPECT which utilises additional CT spatial correlation in diagnosing back pain in patients with previous spinal surgery. There is also increased specificity using SPECT/CT for detection of non-union of interbody devices compared to CT alone (figure 5). Complications

Potential early and late complications of spinal fusion are outlined in table 1.

Conclusion

Various fixation devices may be implanted during lumbar spine fusion procedures to prevent segmental motion while bone fusion occurs. A basic understanding of the types of devices and graft materials used in these procedures and their differing roles is necessary when considering optimising biologic fusion. Attempting to address malalignment and reduce motion is paramount, while for those involved in diagnostic assessment of spinal fusion, familiarity with the normal post-operative appearances is essential if complications are to be recognised.

CT alone and in combination with SPECT appears to have greater sensitivity when assessing for successful fusion. However, radiography, dynamic radiography, CT, MRI and SPECT/CT all appear to have a role in the diagnostic pathway of fusion and its potential complications at differing stages of the post-operative period. Primary resorption of bone graft is consistent with non-union while metalware changes are secondary signs of motion. Further close working with spinal surgeons and further research into improving diagnostic assessment of fusion to negate the gold standard of surgical exploration is required in the future.

References

10, Goldstein C, Drew B. When is a spine fused? Injury 2011;42(3):306-13

Further reading

Figure 1
Vendor image of PLIF device and its surgical route of insertion.

Figure 2
Anterior-posterior radiographs of lumbar spine three months (A), nine months (B) and two years (C) with coronal reconstruction CT at two years (D) following PLIF from L4 to S1, with ‘pebble’ like graft material (white arrows) progressing to solid bridging trabecular bone across transverse processes (black arrows). At 18 months the posterior fusion was extended proximally due to junctional disc degeneration with removal of existing posterior metalwork secondary to confirmed posterior osseous fusion.

Figure 3
Sagittal CT reformat and SPECT/CT reformat demonstrating solid osseous fusion or trabecular bridging both anteriorly across the endplates and posteriorly across the facet joints, with physiological uptake noted at both sites.
**Figure 4**
Sagittal CT reformat and sagittal SPECT/CT demonstrating lucent cleft through the central and posterior bone graft struts/columns (white arrows) of the anterior cervical discectomy and fusion, with corresponding marked radiotracer uptake representing a ‘locked’ pseudoarthrosis. Note the adjacent vacuum phenomenon (hypodense gas locule). There is solid bony bridging across the central component of the interbody disc device at two disc levels lower (blue circle) with no significant osteoblastic activity. There is significant ‘streak’ metal artefact from the interbody device one disc level lower (black arrow) which renders interpretation for fusion here impossible.

**Figure 5**
Sagittal, coronal reformats and axial acquisitions demonstrating multilevel peri-screw lucency suggestive for screw loosening. Note also the erosive change involving the interbody devices on coronal view with minor subsidence of devices into endplates.

**Figure 6**
Axial CT image demonstrating right pedicle screw fracture (white arrow) and anterior migration of interbody device (black arrow).

**Figure 7**
Axial CT images (A and B – different patients) demonstrating pedicle screw insertion into the aorta (A – white arrow) and into the right side of the spinal canal transgressing the medial pedicle cortex (B – white arrow) with risk for nerve and dural injury.

**Figure 8**
Sagittal T1 (A) and T2-weighted (B) images demonstrating a large isointense T2 and high T1 signal intensity subacute extradural haematoma – intracellular methaemoglobin – (white arrows) following posterior stabilisation. Note the anticipated metalwork artefact from the L4-5 interbody device between (blue arrows).

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**TABLE 1**
Potential early and late complications of spinal fusion.