# 20 Degenerative Lumbar Spondylosis

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## Core Messages

- ✔ Morphological abnormalities in the lumbar spine are frequent in asymptomatic individuals, but severe endplate (Modic) changes and severe facet joint osteoarthritis are rare in healthy individuals less than 50 years of age
- ✔ Specific back pain related to degenerative lumbar spondylosis (disc degeneration, facet joint osteoarthritis) is rare (10–15%)
- ✔ Proinflammatory cytokines seem to play an important role in the generation of discogenic back pain and pain in facet joint osteoarthritis
- ✔ Segmental instability is defined clinically and lacks objective criteria
- ✔ Clinical findings in patients with painful lumbar spondylosis are rare
- ✔ Facet joint blocks and provocative discography in diagnosing specific back pain must be interpreted with care
- ✔ Cognitive behavioral treatment is key for a successful conservative treatment approach
- ✔ Spinal instrumentation with pedicle screw fixation enhances fusion rate but not clinical outcome to an equal extent
- ✔ Combined interbody and posterolateral fusion provides the highest fusion rate
- ✔ Non-union and adjacent level degeneration are frequent problems related to spinal fusion
- ✔ Minimally invasive techniques have so far not been shown to provide better clinical outcome than conventional techniques
- ✔ Total disc arthroplasty is not superior to spinal fusion
- ✔ There is limited scientific evidence to favor spinal fusion over an intensive rehab program including cognitive behavioral treatment

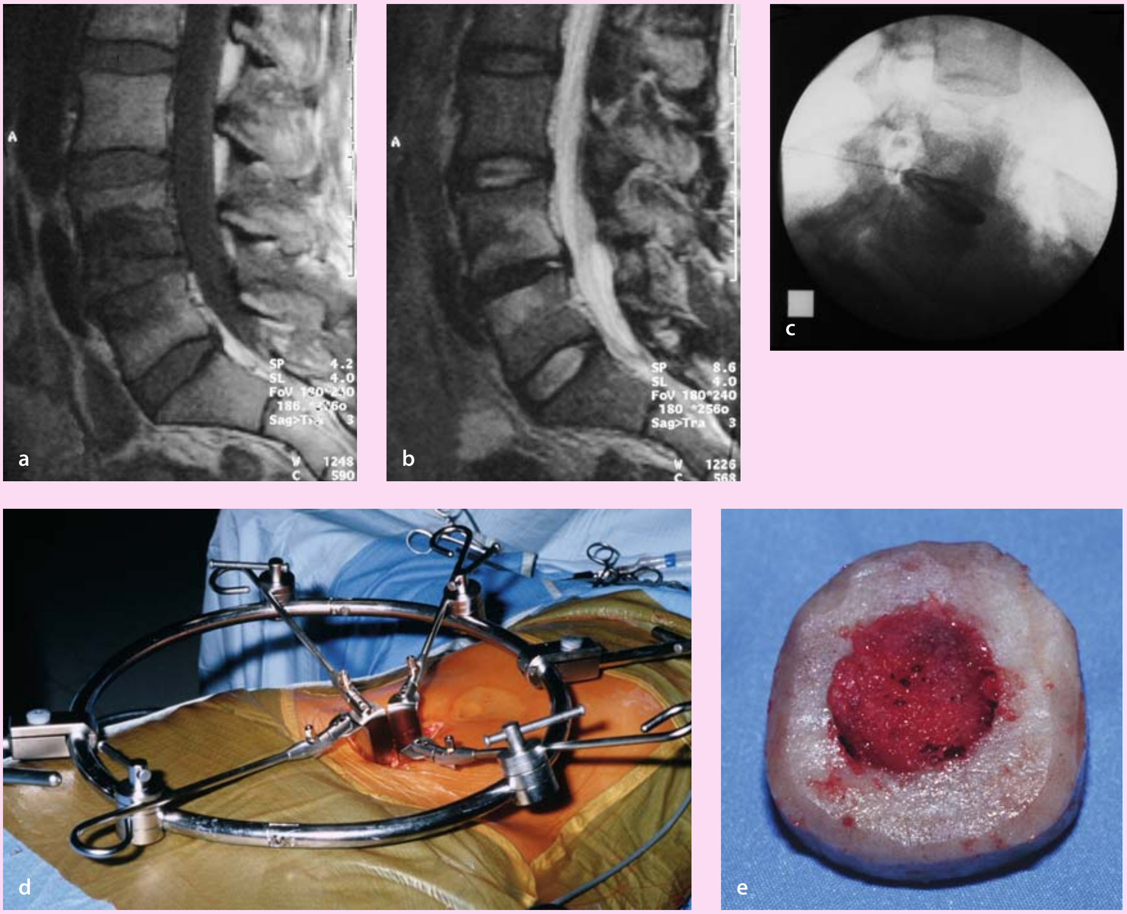
## Epidemiology

**Degenerative lumbar spondylosis** refers to a mixed group of pathologies related to the degeneration of the lumbar motion segment and associated pathologies or clinical syndromes of discogenic back pain, facet joint osteoarthritis, and segmental instability [102]. Lumbar spondylosis and degenerative disc disease can be regarded as one entity whether or not they result from aging, are secondary to trauma or "wear and tear", or degenerative disease, and whether or not they involve the intervertebral discs, vertebrae, and/or associated joints [103]. This group of disorders also includes spinal stenosis with or without degenerative spondylolisthesis, degenerative scoliosis and isthmic spondylolisthesis with secondary degenerative changes. The latter pathologies are separately covered in Chapters 19, 26 and 27, respectively.

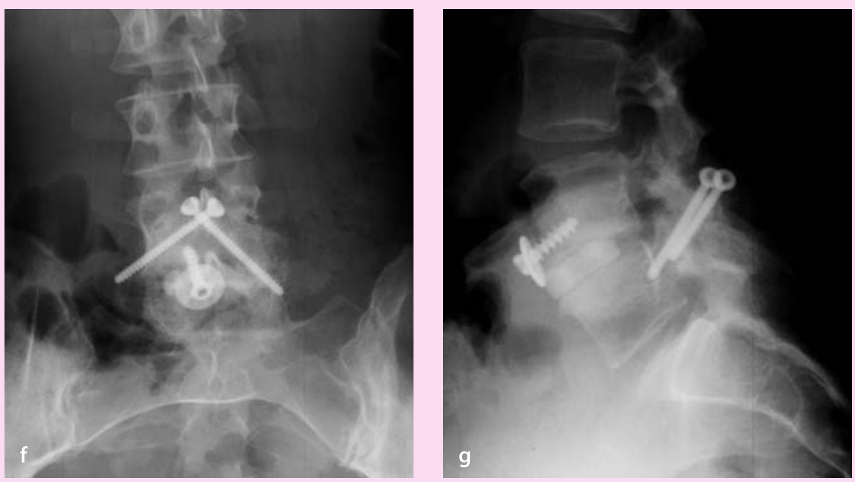
Degenerative lumbar spondylosis is a mixed group of lumbar disorders

The prevailing symptom of lumbar spondylosis is back pain. However, it is often difficult to reliably relate back pain to specific alterations of the motion segment. In the vast majority of cases (85–90%), no pathomorphological correlate can be found for the patient's symptoms and the pain remains **non-specific** [66]. We have dedicated a separate chapter to this entity (see Chapter 21). In this chapter, we focus on degenerative alterations **without neural compromise** as spe-

Specific back pain is relatively rare (10–15%)




## Case Introduction




A 37-year-old female presented with severe incapacitating back pain when sitting and during the night. The pain was so severe that the patient had to stop her work as a secretary. Pain could be provoked by a sit-up test. The pain was radiating to the anterior thigh but the patient did not have any neurological deficits. Sagittal MRI scans showed disc degeneration at the level of L4/5 with severe Modic Type I changes: decreased signal in the T1W (a) and increased signal in T2W (b) images. The remaining discs were unremarkable. Provocative discography (c) at the target level produced the typical pain worse than ever. Injection at the adjacent MR normal levels only produced a slight pressure. The intervertebral disc was assumed to be the source of the back pain. The patient underwent posterior translaminar screw fixation and posterolateral fusion with autologous bone harvested from the iliac crest. Subsequently, the patient underwent a minimally invasive retroperitoneal approach. A retractor frame facilitates the exposure (d). After disc excision, a femur ring allograft filled with autologous spongiosa (e) was used to replace the disc. The graft was secured with an anti-glide screw with washer (f, g). The patient reported immediate pain relief after surgery, which was still present at 5 year follow-up. The patient returned to work 2 months after surgery and was able to enjoy unlimited physical and leisure activities.

cific sources of back pain (i.e. symptomatic disc degeneration, symptomatic facet joint osteoarthritis and segmental instability).

Morphological abnormalities are frequent in asymptomatic individuals

Cadaveric studies [119, 192, 193, 266] indicated a strong correlation of degenerative changes to age, but correlation to symptoms was problematic for obvious reasons. By the age of 47 years, 97% of all discs studied already exhibited degenerative changes [193]. For many years, epidemiologic studies on lower back pain (LBP) were hampered by the inability to non-invasively assess the relation of morphological alterations and clinical symptoms. Studies were sparse until the advent of magnetic resonance imaging (MRI). In 1953, Splithoff et al. [243] compared the radiographs of 100 patients with and without back pain. A similar incidence of transitional vertebrae, spondylolisthesis, and retrolisthesis was reported for both groups. There was a slight tendency for a higher incidence of osteoarthritis in the symptomatic group. Comparing 200 individuals with and without low-back pain, Fullenlove and Williams [95] reported that transitional anomalies were equally frequent in symptomatic and asymptomatic individuals. However, disc height loss with spurs showed a much higher incidence in symptomatic patients (25% vs. 9%), while no significant difference in the incidence of other degenerative lesions was found. Magora and Schwartz [181] explored the prevalence of degenerative osteoarthritic changes in the lumbar spine of 372 individuals with low-back pain and in 217 matched asymptomatic controls. They found an even higher prevalence of degenerative findings in the asymptomatic (66.4%) than in the symptomatic group (58.3%).

Asymptomatic morphological abnormalities frequently occur in MRI

These early findings are corroborated by later MRI studies. The high prevalence of degenerative alterations in asymptomatic individuals demonstrated by MRI underlined the missing link of degenerative alterations of the motion segment and low-back pain [14, 23, 140, 218, 274]. In patients younger than 50 years, however, disc extrusion (18%) and sequestration (0%), endplate abnormalities (Modic changes, 3%), and osteoarthritis of the facet joints (0%) are rare [274], indicating that these findings may be associated with low-back pain in symptomatic patients [274]. Despite the weak correlation of imaging findings and pain, there is no doubt that degenerative alterations of the motion segment can be a pain source in some patients. Research has recently focused on the **molecular mechanisms**, which may explain why particular degenerative changes are symptomatic in some patients but not in healthy controls despite the identical morphological appearance of the alteration. However, screening tools will not become available in the foreseeable future, which may allow for epidemiologic studies exploring the true incidence of symptomatic alterations of the motion segment.

The natural history of LBP is benign

The **natural history of LBP** related to degenerative lumbar spondylosis is benign and self-limiting. In an RCT, Indahl et al. [133] have even shown that low-back pain has a good prognosis when left untampered.

## Pathogenesis

A prerequisite for normal spinal function is the coordinated interplay of the spinal components, i.e.:

- intervertebral disc
- facet joints and capsules
- spinal ligaments
- spinal muscles (extrinsic, intrinsic)

The three-joint complex is key to understanding the degenerative alterations

Schmorl and Junghanns [236] coined the term **functional spinal unit** (FSU) to describe the smallest anatomical unit, which exhibits the basic functional characteristics of the entire spine. On a macroscopic basis, Kirkaldy-Willis [155, 156]

Disc degeneration will finally lead to facet joint osteoarthritis and vice versa

described the sequences of age-related changes leading to multisegmental spondylosis based on the concept of the "**three-joint complex**" (Chapter 19, Table 1). Basically, this concept implies that disc degeneration will finally lead to facet joint osteoarthritis and vice versa. Both alterations can cause segmental instability but hypermobility may also result in disc degeneration and facet joint osteoarthritis. There is ongoing debate about the **temporal sequences** of these relationships. While there is increasing evidence that the age-related changes start in the intervertebral disc in the vast majority of cases [25, 35, 94, 110, 206], there are patients who predominantly exhibit facet joint osteoarthritis without significant disc degeneration. Anecdotal observations also highlight the existence of a painful segmental "**hypermobility**" without evidence of advanced disc or facet joint degenerations. A detailed overview of the biomechanics of the motion segment and age-related changes is provided in Chapters 2 and 4, respectively.

All spinal structures can be a source of pain

All structures in the lumbar motion segment, i.e. vertebrae, intervertebral discs, facet joints, muscles, ligaments and muscles, can be **sources of pain** [41]. While there is good scientific evidence that disc-related nerve root compression and spinal stenosis is correlated with pain, the evidence for spondylosis is limited [203]. The evidence for muscle related back pain, myofacial pain and sacroiliac joint syndromes is poor. From a clinical perspective, three additional pathomorphological alterations can be identified which show some correlation to clinical symptoms although the scientific evidence for this relationship is still weak and very controversial [41] (Table 1).

**Table 1.** Putative sources of specific back pain

| Pathomorphological correlate | Syndrome |
|---|---|
| • disc degeneration | • discogenic back pain |
| • facet joint osteoarthritis | • facet syndrome |
| • segmental instability | • instability syndrome |

## Disc Degeneration and Discogenic Back Pain

Discogenic back pain may be caused by proinflammatory cytokines

The presence of so-called "discogenic back pain" is critically related to the innervation of the intervertebral disc. While the normal adult intervertebral disc is only innervated at the outer layers of the anulus fibrosus [18, 19, 114, 182], the innervation in the degenerative intervertebral disc is less clear. Some researchers provided data suggesting that there is a neo-innervation and/or nerve ingrowth into deeper layers of the anulus fibrosus and even into the nucleus pulposus during disc degeneration [57, 58, 85–87, 141, 279]. Furthermore, there is some evidence that neo-innervation is preceded by neovascularization of the disc [86, 141]. However, these findings could not be confirmed by studies precisely investigating the temporospatial distribution of blood vessels [204] and neural innervation of the disc (Boos et al., unpublished data).

The **impaired nutritional supply** has been identified as one of the key factors in triggering the changes in the extracellular matrix with aging (see Chapter 4). Nutritional deficits result in an **increase in lactate** and **decreased pH**. The altered metabolism of the disc leads to **cellular changes** and **matrix degradation**. The cleavage of collagenous support structures may result in structural damage macroscopically seen as tear and cleft formation. The phenotypic change of disc cells in conjunction with degradation processes may prompt the initiation of a **proinflammatory cascade** which could become the decisive factor in producing pain. In this context, proinflammatory cytokines have been identified in degenerated intervertebral discs such as [7, 32, 33, 146, 216, 222, 271]:

Cellular changes and matrix breakdown may initiate a proinflammatory cascade

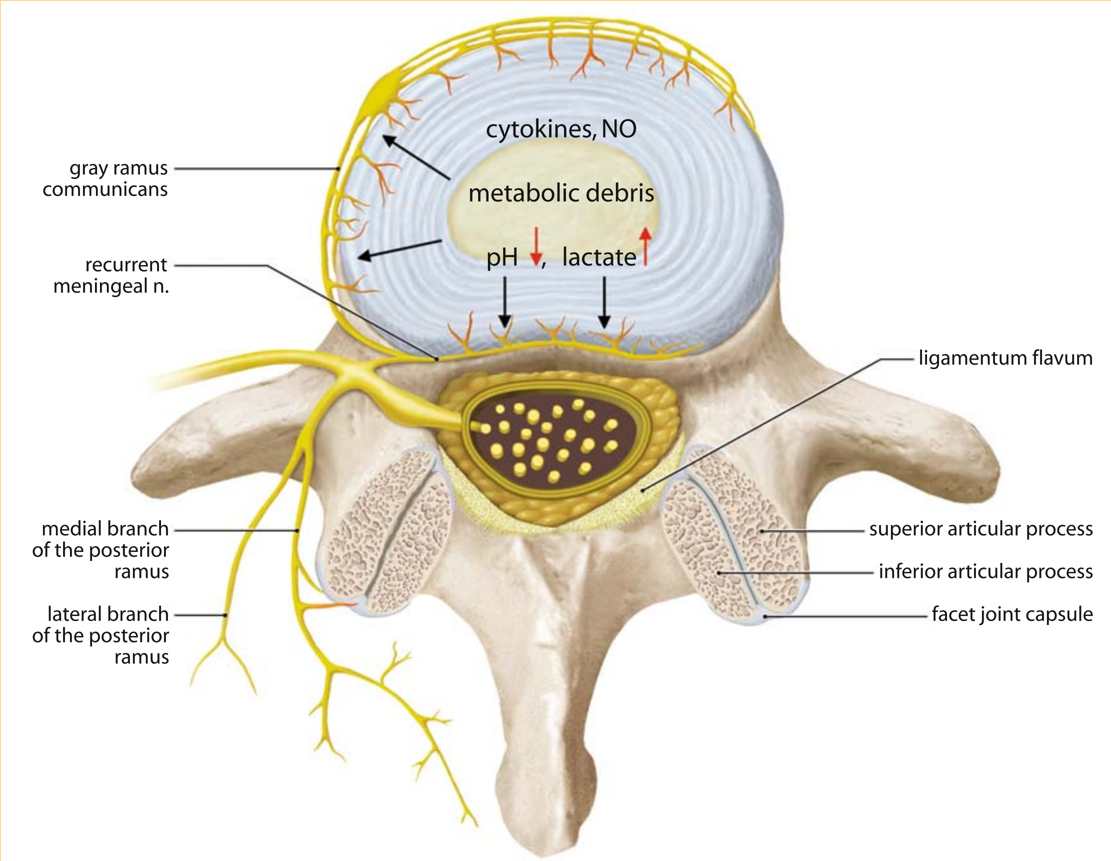



**Figure 1. Current concept of discogenic facet joint pain**

Proinflammatory cytokines, nitric oxide, metabolic debris, low pH or high lactate levels may diffuse out of the disc and cause nociception at the outer annular fibers.

- tumor necrosis factor (TNF)-α
- interleukin (IL)-1β
- interleukin (IL)-6
- prostaglandins (PG)-$E_2$

A current working hypothesis is that these proinflammatory cytokines along with other substances (e.g. nitric oxide, metabolite, waste products) diffuse out of the disc and cause nociception at the outer annular disc fibers which are innervated. The presence of **tear and cleft formations** appears to facilitate proinflammatory cytokine diffusion (Fig. 1).

Discogenic back pain may be caused by proinflammatory cytokines

## Facet Joint Osteoarthritis

The facet joints are synovial joints with a hyaline cartilage surface, a synovial membrane, and a surrounding fibrous capsule similar to a diarthrodial joint. Bogduk extensively studied the neural innervations of the facet joints [18]. The lumbar facet joints are innervated by nociceptive fibers of the medial branch of the dorsal ramus, whereas the disc, the posterior longitudinal ligament and the dura are innervated by the recurrent meningeal nerve, a branch of the ventral primary ramus (Fig. 1). As is the case for any true synovial joint, the facet joints

Facet joint cartilage is often retained in severe OA

Malalignment of the facet joints may predispose to OA

may undergo degenerative changes and develop **osteoarthritis** (OA). Similar to large synovial joints, **malalignment** of the facet joints was suspected to be a predisposing factor for OA. A significant association was found between the sagittal orientation and OA of the lumbar facet joints, even in patients without degenerative spondylolisthesis [94]. Facet joint OA appears to be the pathoanatomic feature that is associated with **sagittal orientation** of the facet joints in patients with degenerative spondylolisthesis [94]. In contrast to OA of large synovial joints (e.g. hip joint), an intact covering of hyaline cartilage is frequently retained by the articular surfaces even when large osteophytes have formed [265].

It can be hypothesized that this preservation of articular cartilage may result from changing joint stresses [265]. However, Swanepoel et al. [250] found that the apophyseal cartilage of the facet joint surfaces exhibits a greater extent and prevalence of cartilage fibrillation than large diarthrodial joints, with significant damage in specimens younger than 30 years. In late stages of OA, the facet joints also demonstrate the **classic features**, i.e. complete loss of articular cartilage, cysts and pseudocysts in the bone, dense bone sclerosis, and large osteophyte formation. Of note, spontaneous fusion of the facet joints is very rare in the absence of ankylosing spondylitis or ankylosing hyperostosis [265]. Recently, inflammatory cytokines in facet joint capsule were observed at high levels in degenerative lumbar spinal disorders [132]. These inflammatory cytokines had a higher concentration rate in lumbar spinal canal stenosis than in lumbar disc herniation. This finding suggests that inflammatory cytokines in degenerated facet joints may play an important role in symptomatic facet joint OA [132].

Spontaneous facet joint ankylosis is rare

Facet joint OA is a veritable source of back pain

Facet joint alterations were first identified as a source of low-back pain by Goldthwait in 1911 [108]. Ghormley coined the term "**facet joint syndrome**" in 1933 [101], but it only gained widespread attention after Mooney's clinical paper in 1976 [197]. Since that time, debate has continued on the relevance of this clinical entity because it was not possible to reliably attribute clinical symptoms to joint abnormalities [134, 135]. Nevertheless, there is no doubt that facet joint OA can be related to severe back pain in some patients.

## Segmental Instability

Excessive segmental motion is a potential pain source

Although there is no serious doubt that excessive mobility within a motion segment can occur which results in pain, a valid definition of segmental instability has not been satisfactorily established and remains somewhat enigmatic [217]. The current working hypothesis is (Table 2):

**Table 2.** Definition of segmental instability

- Segmental instability is a loss of stiffness of a motion segment which causes pain, has the potential to result in progressive deformity, and will place neurogenic structures at risk

According to Pope et al. [217]

No objective definition of segmental instability is available

This definition implies that forces applied to a motion segment produce greater displacement due to decreased stiffness than would be seen in a normal segment [217] and that this effect is related to pain. Various attempts were made to measure segmental instability by imaging studies. Since the diagnostic criteria for segmental instability are unclear, a proper definition of a reference standard is obviously problematic.

The range of normal (painless) lumbar motion is large

Stokes et al. [248] reported on 78 patients who had a clinical diagnosis of putative segmental instability. The authors found that the forward-backward translation movement in intervertebral discs did not differ significantly at the affected levels from those at unaffected levels. However, the ratio between translation motion and angular motion was somewhat elevated in the affected levels. It was concluded that flexion/extension radiography was not useful in the diagnosis of lumbar instability. Hayes [124] examined the angulatory and translational lumbar spine intervertebral motion using flexion-extension radiographs from 59 asymptomatic individuals. There was 7–14 degrees of angulatory motion present in the lumbar spine with such a large variation that norms of angulatory motion could not be more precisely defined. **Translational motion** was 2–3 mm at each lumbar level. Some of the asymptomatic subjects (20%) had 4 mm or more translational motion at the L4–5 interspace and at least 10% had 3 mm or greater motion at all levels except L5–S1. The diagnostic value of flexion-extension views has also been questioned in conditions where a segmental instability (e.g. spondylolisthesis) is expected [212]. The problem may lie in the inability of functional views to properly depict instability rather than in the fact that there is no instability detected with the applied tests.

Functional views do not differentiate normal and painful motion

So far, radiological criteria for instability (in terms of certain excessive motion) have failed to diagnose instability in a reliable way [214]. Boden and Wiesel [17] have indicated that it is more important to measure the dynamic vertebral translation than a static displacement on a single view. This was corroborated by an experimental animal study [143]. From these results, it was concluded that the maximum range of motion, which must be measured using a dynamic technique, was a more sensitive parameter for identifying changes in segmental kinematics caused by chronic lesions than was the end range of motion. The lumbar musculature was found to be less efficient overall in stabilizing the motion segment, possibly because of altered mechanisms in the neuromuscular feedback system [143]. The hypothesis that the motion per se and not the endpoints are unstable was explored by dynamic lumbar flexion-extension motion using videofluoroscopy [207]. While segmental instability was found to influence the whole lumbar motion in patients with degenerative spondylolisthesis, patients with chronic low-back pain did not show a significant difference when compared with volunteers [207].

Segmental instability appears to be related to the motion itself

Despite refined assessment methods, no substantial progress has so far been achieved in exploring the predisposing pathomorphological or biomechanical factors or reliably diagnosing segmental instability. Therefore, the entity of segmental instability remains a clinical diagnosis without scientific confirmation. The classic clinical entity of a segmental instability is spondylolisthesis, which is covered in Chapter 27.

## Clinical Presentation

In **specific spinal disorders,** a pathomorphological (structural) correlate can be found which is consistent with the clinical presentation, while the diagnosis of **non-specific spinal disorders** is reached by exclusion (see Chapter 8). Typical radicular leg pain and claudication symptoms can be attributed to morphological alterations (i.e. nerve root compromise, spinal stenosis) in the vast majority of patients with leg pain; less than 15% of individuals with isolated or predominant back pain can be given a precise pathoanatomical diagnosis [66].

In this chapter, we focus on clinical syndromes related to specific structural alterations such as disc degeneration, facet joint OA, or segmental instability. Despite the dilemma of unproven efficacy of diagnostic tests for isolated back pain, a practical approach appears to be justifiable until more conclusive data is available from the literature [66, 203]. We acknowledge that this approach is anecdotal rather than solidly based on scientific evidence, but it appears to work in our hands.

## History

Although we focus here on specific syndromes, the patient should undergo a thorough assessment of the whole spine as outlined in Chapter 8.

### Discogenic Pain Syndrome

Discogenic pain originating from the thoracolumbar spine manifests as deep aching pain located in the lower lumbar spine.

The **cardinal symptoms** of discogenic back pain are:

- predominant low-back pain
- pain aggravation in flexion (forward bending, sitting)
- non-radicular pain radiation in the anterior thigh

Discogenic back pain increases during sitting and forward bending

The pain is often increased after **prolonged sitting** or **bending** with the spine in a semi-flexed position. Patients often report that sitting is the worst position (caused by disc compression). The pain increases when the patient tries rising from the supine position with their knees straight (sit-up). In severe cases [often associated with endplate (Modic) changes], the pain intensity resembles the complaints of a low grade infection or a tumor and can hurt during the night (Case Introduction). However, none of these signs has been shown to closely correlate with a positive pain provocation test during discography. Therefore, these findings must be regarded as non-specific and non-sensitive.

### Facet Joint Syndrome

The term "facet joint syndrome" comprises clinical symptoms related to the facet joints such as dysfunction and osteoarthritis.

The **cardinal symptoms** of facet joint pain are:

- predominant low-back pain
- osteoarthritis pain type (improvement during motion)
- pain aggravation in extension and rotation (standing, walking downhill)
- non-radicular pain radiation in the posterior thigh

**Backward bending** and **rotation** compresses the facet joints and may therefore provoke the pain. The pain is often located in the buttocks and groin and infrequently radiates into the posterior thigh. However, it is non-radicular in origin.

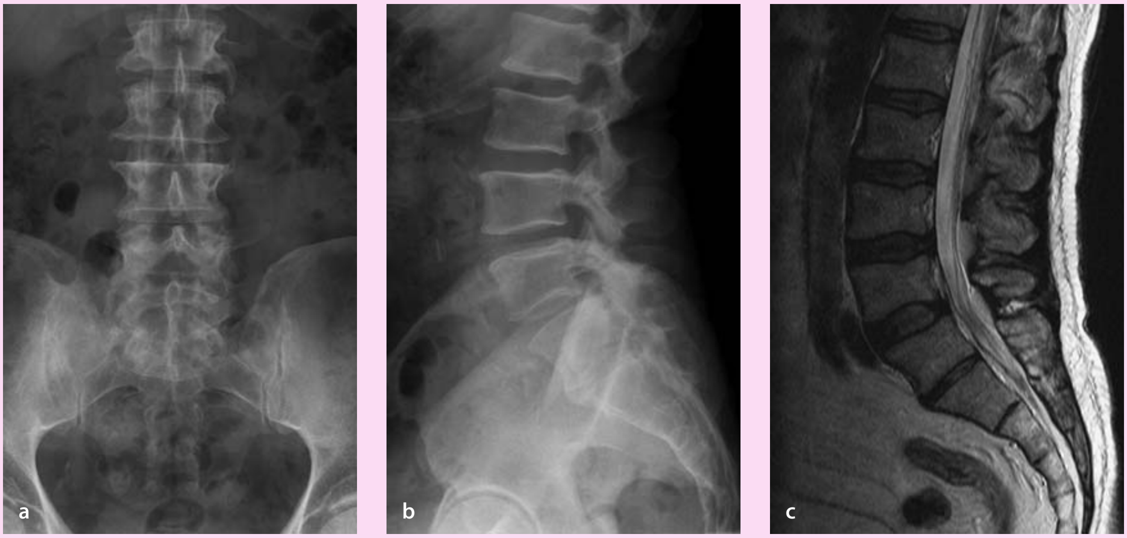
Facet joint pain improves during movement (early stages)

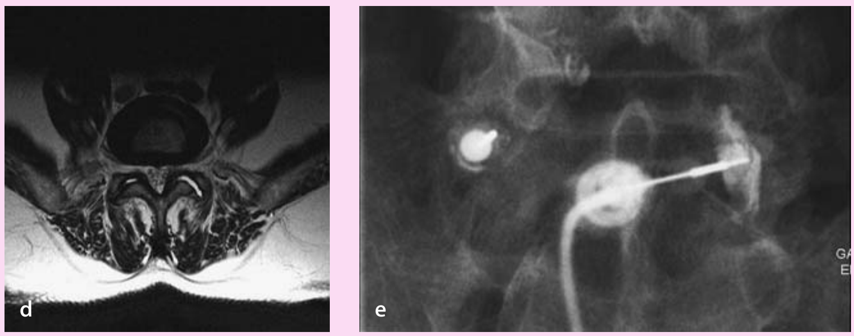
The pain usually resembles that of an osteoarthritis (OA) type with **improvement by motion** and aggravation by rest. However, in late stages of OA this alleviation may vanish. Patients often feel stiff in the morning and have a "**walk in**" period. They sometimes complain about pain in the early morning of such intensity that they have to get out of bed. Similarly, patients report that they wake up when turning. Occasionally, they have to get out of bed and move around until they can continue their sleep (Case Study 1).

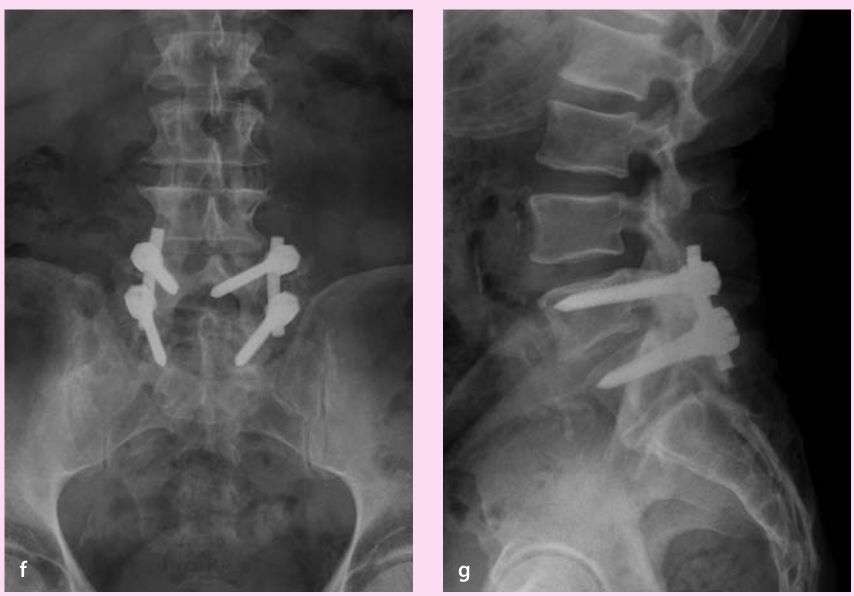
When comparing the outcome of facet joint injections with clinical symptoms, no reliable clinical signs could be identified which predicted pain relief during injection. Therefore, it is difficult to define a so-called "facet joint syndrome" [134, 135, 197].

### Instability Syndrome

The definition of spinal instability remains enigmatic because a gold standard test is lacking. So far, the definition is purely descriptive (Table 2) and therefore the clinical signs are vague (Case Study 2).




## Case Study 1

A 58-year-old male presented with recurrent episodes of back pain radiating to the posterior thigh. The pain was worse during the morning and on backward bending with rotation. The patient reported that forward bending relieved his pain. Standard radiographs (a, b) showed a lumbosacral transitional anomaly with sacralization of L5. Sagittal T2W MRI scan revealed normal discs at all lumbar levels (c). Axial T2W image (d) revealed a moderate to severe osteoarthritis of the facet joint. A gap is visible between the articular surfaces of the facet joints L4/5 filled with fluid. An intra-articular facet joint block (e) relieved the symptoms completely for 10 weeks but then the symptoms recurred. Two repeated facet joint injections relieved the pain for 6 and 4 weeks, respectively. The patient was diagnosed with a symptomatic facet joint osteoarthritis and underwent pedicle screw fixation and posterolateral fusion (f, g). At 1-year follow-up the patient was symptomfree and fully active.

The **cardinal symptom** of a segmental instability is:

- mechanical low-back pain

Instability pain worsens during motion and improves during rest

Mechanical LBP can be defined as pain which is provoked by motion and improves or disappears during rest. **Vibration** (e.g. driving a car, riding in a train) may aggravate the pain. Pain is also felt when sudden movements are made. The resulting muscle spasm can be so severe that the patients experience a lumbar catch ("**blockade**"). Pain usually does not radiate below the buttocks. Some patients benefit from wearing a brace.

### Non-specific Back Syndromes

Within this group, the **sacroiliac joint (SIJ) syndrome** deserves special attention because the pain can occasionally be attributed to a joint dysfunction or inflammation. Patients with pain originating from the SIJ locate their pain unilaterally deep over the SIJ. Sometimes the pain radiates to the dorsal aspect of the thigh or to the groin. There is no specific provocation pattern.

## Physical Findings

Physical findings rarely help to identify the pain source

The physical assessment of the spine is often hampered by strong muscle spasm and therefore does not allow for a passive examination as for large diarthrodial joints. With the exception of neurological signs, the physical assessment does not permit a reliable pathoanatomic diagnosis to be made in patients with predominant back pain. The physical examination should follow a defined algorithm so as to be as short and effective as possible (see Chapter 8). We focus here on the physical findings, which may at least give a hint as to the source of the back pain.

In patients with **discogenic pain syndrome,** physical findings are:

- pain provocation on repetitive forward bending
- pain provocation during a sit-up test (with legs restrained by the examiner)

In patients with **facet syndrome,** physical findings are:

- pain provocation on repetitive backward bending
- pain provocation on repetitive side rotation
- hyperextension in the prone position

In patients with **instability syndrome,** physical findings are:

- abnormal spinal rhythm (when straightening from a forward bent position)
- hand-on-thigh support

The hand-on-thigh support can be seen when pain is severe on forward bending. The patient needs the support with hands on thighs when straightening out of the forward bent position by supporting the back.

## Diagnostic Work-up

Diagnostic tests differentiate symptomatic and asymptomatic alterations

None of the aspects of the patient's history or physical examination allows the symptoms to be reliably attributed to structural abnormalities in patients with predominant back pain. The imaging studies are hampered by the high prevalence of asymptomatic alterations in the lumbar spine as outlined above. Further diagnostic tests are needed to differentiate between symptomatic and asymptomatic morphological alterations.

## Imaging Studies

Debate continues about the need for standard radiographs for the initial evaluation of patients with predominant back pain. MRI has become the imaging modality of choice in evaluating LBP patients. However, **lumbosacral transitional anomalies** can be missed when only sagittal and axial views are obtained. In our center, we only omit standard radiographs in the presence of recent anteroposterior and lateral radiographs. A detailed description of the imaging modalities for the lumbar spine is included in Chapter 9.

### Standard Radiographs

Standard radiographs are rarely diagnostic

Standard radiographs are helpful in diagnosing lumbosacral transitional anomalies which may be overlooked on MRI in cases without coronal sequences. Standard radiographs are rarely helpful in reliably identifying the pain source. However, **non-specific findings** indicating a painful disc degeneration or facet joint osteoarthritis are:

- disc space narrowing with endplate sclerosis
- severe facet joint osteoarthritis

#### *Flexion/Extension Films*

Flexion/extension views cannot reliably distinguish between normal and symptomatic lumbar motion

Functional views are generally regarded as unreliable for the diagnosis of a segmental instability because of the wide range of normal motion [248]. However, excessive segmental motion (>4 mm) or subluxation of the facet joint that is rare in asymptomatic individuals, and is not even observed in patients who exhibit extreme ranges of motion (e.g. contortionists) [120]. However, the inability to reliably diagnose or attribute segmental instability to a specific level by imaging studies prompts the taking of great care with this diagnostic label (Case Study 2).

### Magnetic Resonance Imaging

MRI has surpassed computed tomography (CT) because of its tissue contrast and multiplanar capabilities. MRI is a very sensitive but less specific imaging modality because of the vast majority of alterations which can be observed in asymptomatic individuals [22]. There are only very few alterations which are uncommon in asymptomatic individuals younger than 50 years [272], i.e.:

Severe Modic changes and facet joint OA are uncommon in asymptomatic individuals

- severe facet joint osteoarthritis
- endplate changes (so-called Modic changes) [195]

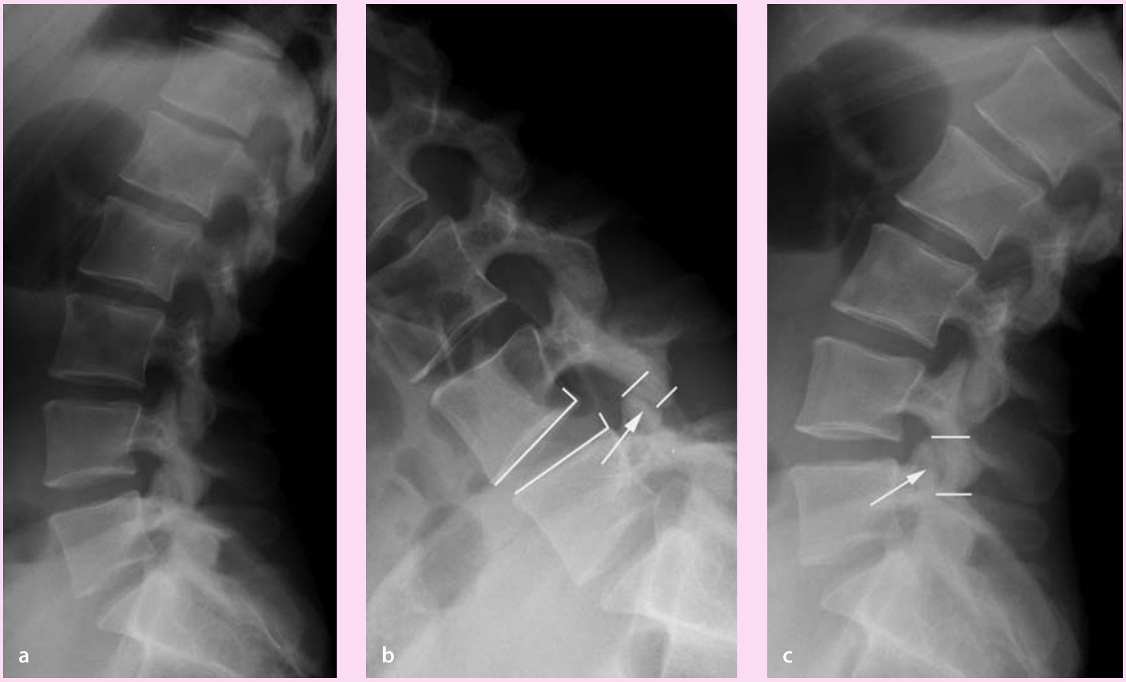
On the contrary, **annular tears** can be found in up to 30 % of asymptomatic individuals and are therefore not a good predictor.

In the context of lumbar spondylosis with predominant back pain, MR scans should be graded specifically with regard to:

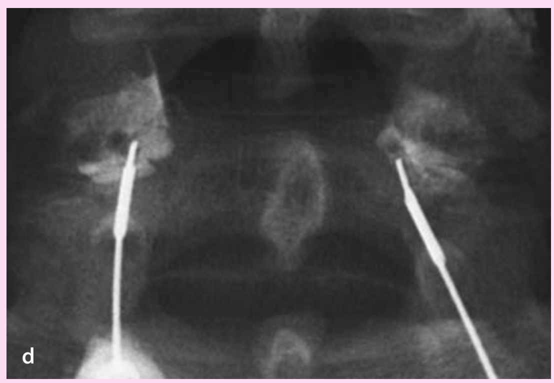
- disc degeneration [215]
- vertebral endplate changes [195]
- facet joint osteoarthritis [273]

In particular, Type I Modic changes are considered to be related to discogenic LBP [195]. However, Weishaupt et al. [275] have demonstrated that moderate to severe **Type I and II Modic changes** are correlated with discogenic LBP based on provocative discography (Case Introduction). Although CT provides better imaging of bone, MRI does not provide less information regarding facet joint osteoarthritis than CT [273].

Moderate to severe Modic changes correlate with positive provocative discography




## Case Study 2




A 28-year-old female presented with severe LBP which had been persistent for 4 months. The pain became worse during the day while moving and was better during rest and at night. In the morning, the patient was symptom-free. The patient reported frequent sensations of sharp pain in her lumbar spine during motion but no pain radiation into the legs. Lateral radiograph showing a normal spine (a). Functional views (b, c) demonstrated increased motion (compared to adjacent levels) at L4/5 with increased segmental kyphosis, slight anterior displacement of L4, and subluxation of the facet joints (*arrow*). The MRI was unremarkable (not shown). A facet joint block (d) at L4/5 resulted in a symptom-free period for several weeks. The patient was diagnosed with mechanical LBP (instability syndrome). Although very suggestive, the increased motion at L4/5 should only tentatively be attributed to the increased mobility at L4/5 because of the large variation in segmental motion in asymptomatic individuals. She was admitted to an intensive rehab program with emphasis on stabilizing exercises which resolved her symptoms. At 1 year follow-up, the patient was completely painfree and unrestricted for all activities.

### Computed Tomography

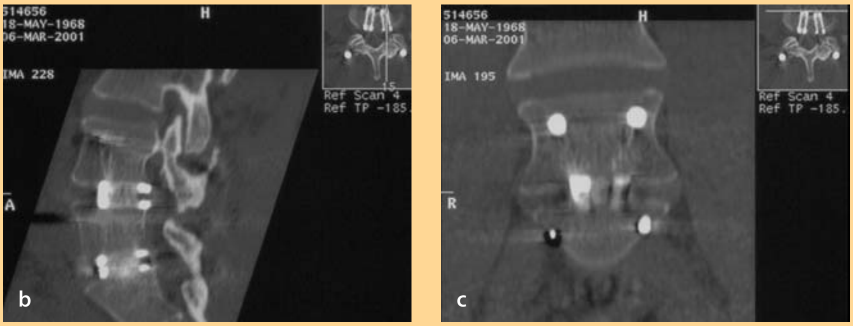
The current role of CT in the evaluation of patients suffering from lumbar spondylosis is the assessment of fusion status and for patients with contraindications for MRI (e.g. pacemaker). In the latter case, MRI is often combined with myelography (myelo-CT) to provide conclusions on potential neural compression.

CT is the method of choice for the assessment of spinal fusion

Computed tomography (Fig. 2) is the method of choice for the assessment of the fusion status [228]. However, CT in conjunction with 2D coronal and sagittal image reformation is more sensitive in diagnosing lumbar fusions than non-union (Fucentese and Boos, unpublished data).

**Figure 2. Computed tomography**

Computed tomography is the imaging modality of choice for the assessment of spinal fusion. Even in the presence of implants, the bony bridges are well visualized. Bony bridges outside a fusion cage are a more reliable sign of solid fusion than when they appear inside. **a** Axial view; **b** sagittal reformation; **c** coronal reformation


## Injection Studies

The high prevalence of asymptomatic disc alterations prompts the need for further diagnostic tests to confirm that a specific structural abnormality is the source of the pain. Spinal injections play an important role, although the scientific evidence in the literature for their diagnostic efficacy is poor. Furthermore, the predictive power of an injection study to improve patient selection for surgery is poorly explored and documented [169]. A detailed description of the strength and weaknesses of these diagnostic studies is included in Chapter 10.

Injection studies are helpful in identifying the pain source

### Provocative Discography

Discography was introduced to image intervertebral disc derangement [172]. Currently, discography predominantly serves as a pain provocation test to differentiate symptomatic and asymptomatic disc degeneration. The diagnostic efficacy of this test remains a matter of debate [43, 202, 269] (see Chapter 10). The assessment of the diagnostic accuracy of provocative discography for discogenic LBP is problematic since no gold standard is available [43].

Discography remains the only method to verify discogenic LBP

A reasonable practical approach is to include an adjacent MR normal disc level as internal control [169, 275]. Accordingly, a positive pain response would include an exact pain reproduction at the target level and no pain provocation or only pressure at the normal disc level (**Case Introduction**). In our center, patients are only selected for provocative discography if they are potential candidates for surgery, i.e. when the diagnostic test will influence treatment strategy. However, careful interpretation of the findings is still mandatory with reference to the clinical presentation [43]. Furthermore, provocative discography has failed to improve patient selection to obtain better clinical outcome after surgery [177].

Always include an MR normal level as internal control

### Facet Joint Injections

Diagnosis of painful facet joints by injections must be made cautiously

The differentiation between symptomatic and asymptomatic facet joint osteoarthritis based on imaging studies alone is impossible [169]. So far, facet joint injections have been used for this purpose but are not without shortcomings (see Chapter 10). Some authors suggest that a facet joint syndrome can be diagnosed based on pain relief by an intra-articular anesthetic injection or provocation of the pain by hypertonic saline injection followed by subsequent pain relief after injection of local anesthetics [44, 173, 185, 199]. Interpretation of the pain response is difficult because the facet joints are innervated by two to three segmental posterior branches and the local anesthetic may diffuse to adjacent levels if the injection is done non-selectively (i.e. without prior contrast medium injection) [169]. We recommend using contrast injection to document the correct needle position and filling of the joint capsule (Case Study 1). Uncontrolled diagnostic facet joint blocks exhibit a false-positive rate of 38 % and a positive predictive value of only 31 % [239]. It is therefore mandatory to perform repetitive infiltrations to improve the diagnostic accuracy [239]. However, there are no convincing pathognomonic, non-invasive radiographic, historical, or physical examination findings that allow the reliable identification of lumbar facet joints as a source of low-back pain and referred lower extremity pain [69, 70].

## Temporary Stabilization

Temporary stabilization does not predict fusion outcome

The diagnosis of segmental instability remains a matter of intensive debate. However, it would be unreasonable to assume that abnormal segmental mobility is non-existent or cannot be painful. Imaging studies, particularly functional views, have failed to reliably predict segmental instability because of the wide normal range of motion. The correct identification of the unstable level(s) is challenging. The temporary stabilization with a **pantaloon cast** [223] has the drawback of being unselective and requires further diagnostic testing, e.g. by facet joint blocks. Stabilization of the putative abnormal segments by an **external transpedicular fixator** has been suggested by several authors [74, 237, 254] with mixed results in terms of outcome prediction. Based on an analysis of 103 cases, Bednar [10] could not support using the external spinal skeletal fixation as a predictor of pain relief after lumbar arthrodesis.

## Patient Selection for Treatment

The important role of **non-biological factors** for the outcome of surgical procedures particularly for patients with predominant LBP is well documented. We have therefore dedicated Chapter 7 to this topic. Various domains must be considered, i.e.:

- medical factors
- psychological factors
- sociological factors
- work-related factors

Non-biological factors are important outcome predictors

In clinical practice, however, it is extremely difficult to identify and systematically assess risk factors that can be used to accurately predict the outcome of surgery. So far, there is insufficient evidence to exclude patients from surgery on the grounds of specific risk factors [183]. Nonetheless, in the presence of selected factors (see Chapter 7), surgery should at least be delayed until attempts have been made to modify risk factors that are amenable to change and all possible conservative means of treatment are exhausted.

## Non-operative Treatment

Most patients with predominant low-back pain without radiculopathy or claudication symptoms can be managed successfully by non-operative treatment modalities (Case Study 2). The general objectives of treatment are (Table 3):

**Table 3.** General objectives of treatment

| | |
|---|---|
| • pain relief | • improvement of social activities |
| • improvement of health-related quality of life | • improvement of recreational activities |
| • improvement of activities of daily living | • improvement of work capacity |

When the diagnostic assessment has identified a specific source of back pain (Table 1), the conservative treatment option does not differ from those applied to non-specific disorders, which are extensively covered in Chapter 21. The **mainstay of non-operative management** rests on three pillars:

- pain management (medication)
- functional restoration (physical exercises)
- cognitive-behavioral therapy (psychological intervention)

Cognitive behavioral interventions are necessary to address fears and misbeliefs

Pharmacologic pain management is outlined in Chapter 5. Spinal injections (e.g. facet joint blocks) may be a reasonable adjunct in controlling the pain for a short term period [109, 169]. The first important aspect is a multidisciplinary functional restoration program and psychological interventions to influence patient behavior (see Chapter 21). The second important aspect is the **timeliness** of the treatment intervention. The longer pain and functional limitations persist, the less likely is pain relief, functional recovery and return to work (see Chapter 6). Patients presenting with specific degenerative back pain usually experience their pain and functional limitations for more than 3 months. These patients should promptly be included in a multidisciplinary functional work conditioning program. There is increasing evidence that patients with chronic LBP benefit from a **multidisciplinary treatment** with a functional restoration approach when compared with inpatients or outpatient non-multidisciplinary treatments [263]. Two recent high quality randomized controlled trials (RCTs) demonstrated that such a program is equally effective as surgery in treating patients with lumbar spondylosis [31, 77].

It is as simple as it is obvious that the outcome of any treatment is critically dependent on patient selection and this is also valid for non-operative treatment (see Chapter 7). Favorable indications for non-operative treatment include (Table 4):

**Table 4.** Favorable indications for non-operative treatment

| | |
|---|---|
| • minor to moderate structural alterations | • short duration of persistent symptoms (<6 months) |
| • LBP of variable intensity and location | • absence of risk factor flags |
| • intermittent symptoms | • highly motivated patient |

## Operative Treatment

### General Principles

Spinal fusion is thought to eliminate painful motion

Spinal fusion is the most commonly performed surgical treatment for lumbar spondylosis [66]. The **paradigm of spinal fusion** is based on the experience that painful diarthrodial joints or joint deformities can be successfully treated by arthrodesis [66, 121]. Since its introduction in 1911 by Albee [3] and Hibbs [127], spinal fusion was initially only used to treat spinal infections and high-grade spondylolisthesis. Later this method was applied to treat fractures and deformity. Today approximately 75 % of the interventions are done for painful degenerative disorders [66]. Despite its frequent use, spinal fusion for lumbar spondylosis is still not solidly based on scientific evidence in terms of its clinical effectiveness [66, 102, 103, 264]. For a long time it was hoped that outcome of spinal fusions could be significantly improved when the fusion rates come close to 100 %. However, it is now apparently clear that outcome is not closely linked to the fusion status [24, 90, 91, 102, 103, 256].

The **standard concept** advocated in the literature is that surgical treatment is indicated when an adequate trial of non-operative treatment has failed to improve the patient's pain or functional limitations [122, 264]. However, there is no general consensus in the literature on what actually comprises an adequate trial of non-operative care. Based on a meta-analysis, van Tulder et al. [264] concluded that fusion surgery may be considered only in carefully selected patients after active rehabilitation programs for a period of 2 years have failed. The general philosophy that surgery is only indicated if long-term non-operative care has failed is challenged by the finding that the longer pain persists the less likely it is that it will disappear. This notion is supported by recent advances in our understanding of the pathways and molecular biology of persistent (chronic) pain (see Chapter 5). It has also been known for many years that returning to work becomes very unlikely after 2 years [268].

Surgery if needed should be done in a timely manner

We therefore advocate a more **active approach in patient selection** for surgery, i.e. not only offering surgery as the last resort after everything else has failed because of the adverse effects of pain chronification. Patients should be evaluated early (i.e. within 3 months), searching for a pathomorphological abnormality which is likely to cause the symptoms. This evaluation must be based on a thorough clinical assessment, imaging studies and diagnostic tests. If a pathomorphological alteration in concordance with the clinical symptoms can be found, the patient should be selected for potential surgery. Prior to surgery, the patient should then be integrated in a fast track aggressive functional rehabilitation program (not longer than 3 months). If this program fails, the structural correlate should be treated surgically if multilevel (>2 levels) fusion can be avoided. In multilevel degeneration of the lumbar spine requiring more than two-level fusion, the clinical outcome is less satisfactory in our hands and we are more conservative. We acknowledge that this approach is anecdotal and not yet based on scientific evidence, but it seems to be reasonable and works satisfactorily in a large spine referral center.

**Favorable indications for surgery** include (Table 5):

**Table 5.** Favorable indications for operative treatment

| | |
|---|---|
| • severe structural alterations | • short duration of persistent symptoms (<6 months) |
| • one or two-level disease | • absence of risk factor flags |
| • clinical symptoms concordant with the structural correlate | • highly motivated patient |
| • positive pain provocation and/or pain relief tests | • initial response to a rehab program but frequent recurrent episodes |

Only a few morphological imaging abnormalities have been identified which rarely occur in a group of asymptomatic individuals below the age of 50 years [274] and may therefore predict the pain source when occurring in symptomatic patients. Severe structural alterations which may predict a **favorable outcome** of surgery include:

- severe facet joint osteoarthritis
- disc degeneration with severe endplate abnormalities (Modic Types I and II)

These abnormalities represent favorable predictors for surgery, particularly when present at only one or two levels with the rest of the thoracolumbar spine unremarkable, cause concordant symptoms and consistently respond to pain provocation and relief test. As outlined above, the duration of symptoms should be short to avoid the adverse effects of a chronic pain syndrome. It has been our anecdotal observation that patients have a favorable outcome if they had responded successfully to a **multidisciplinary restoration program** but have frequent recurrent episodes.

## Biology of Spinal Fusion

A basic understanding of the general principles of bone development and bone healing as well as the biologic requirements for spinal fusion in the lumbar spine are a prerequisite to choosing the optimal fusion technique [13]. A comprehensive review of this topic is far beyond the scope of this chapter and the reader is referred to some excellent reviews [13, 92, 93, 209, 232, 240].

In contrast to fracture healing, the challenge in spinal fusion is to bridge an anatomic region with bone that is not normally supported by a viable bone [34]. **Spinal arthrodesis** can be generated by a fusion of:

- adjacent laminae and spinous processes
- facet joints
- transverse processes
- intervertebral disc space

Vascular supply to the fusion area is important

An osseous **fusion of the transverse processes** is the most common type of fusion performed in the lumbar spine [16]. MacNab was one of the first to realize that the success of intertransverse fusion over posterior fusion (i.e. bone apposition on the laminae and spinous processes) was based on the blood supply to the fusion bed which allowed for a revascularization and reossification of the graft [176]. The early interbody fusion technique (inserting bone into the intervertebral disc space after discectomy) was hampered by graft subsidence or graft failure because of the heavy loads in the lumbar spine and did not provide favorable results without instrumentation (see below).

The prerequisite of successful spine fusion is **three distinct properties** of the applied graft material, i.e. [164, 259]:

- osteogenesis
- osteoconduction
- osteoinduction

The optimal graft material should be osteogenic, osteoconductive and osteoinductive

**Osteogenicity** is the capacity of the graft material to directly form bone and is dependent on the presence of viable osteogenetic cells. This property is only exhibited by fresh autologous bone and bone marrow. **Osteoconduction** is the process of living tissue to grow onto a surface or into a scaffold, which results in new bone formation and incorporation of that structure [59]. Particularly cancellous bone with its porous and highly interconnected trabecular architecture allows easy ingrowth of surrounding tissues. Osteoconduction is also observed in fabricated materials that have porosity similar to that of bone structure, e.g. coralline ceramics, hydroxyapatite beads, combinations of hydroxyapatite and collagen, porous metals and biodegradable polymers [59]. **Osteoinduction** indicates that primitive, undifferentiated and pluripotent cells are stimulated to develop into bone-forming cells [4]. Urist [257, 258] coined the term "**bone morphogenetic proteins**" (BMPs) for those factors that stimulate cells to differentiate into osteogenic cells.

### Bone Grafts

Autologous bone is still the gold standard

**Autologous bone** is generally considered the "gold standard" as a graft material for spinal fusion and exhibits osteogenetic, osteoconductive and osteoinductive properties [115]. Autologous bone for spinal fusion is harvested from the anterior or posterior iliac crest as cancellous bone, corticocancellous bone chips or tricortical bone blocks. The drawback of autologous bone is related to the limited quantity and **potential donor site pain** [63, 80, 125].

Allografts potentially transmit infectious disease

These drawbacks have led to the use of **allograft bone** early in the evolution of spinal fusion. Allografts are used in different forms for spinal fusion. They are predominately used as **structural allografts** (e.g. femoral ring allografts) but are available in other forms (e.g. corticocancellous bone chips). Bone allografts exhibit strong osteoconductive, weak osteoinductive but no osteogenetic properties [152, 232]. Fresh allografts elicit both local and systemic immune responses diminishing or destroying the osteoinductive and conductive properties. Freezing or freeze-drying of allografts is therefore used clinically to improve incorporation [107], but mechanical stability of the graft is reduced by freeze drying (about 50 %) [232]. However, the major drawback of those allografts is the potential transmission of infections (particularly hepatitis C, HIV) [64]. **Gamma irradiation** of at least 34 kGy is recommended to substantially reduce the infectivity titer of enveloped and non-enveloped viruses [220]. However, screening procedures remain mandatory. Autologous or allogenic cortical grafts are at least initially weight-bearing but all bone grafts are finally resorbed.

Cancellous allografts are completely replaced by autologous bone or resorbed

Cancellous grafts are completely replaced in time by **creeping substitution**, whereas cortical grafts remain as an admixture of necrotic and viable bone for a prolonged period of time [107]. Bone graft incorporation within the host, whether autogenous or allogeneic, depends on various factors [152]:

- type of graft
- site of transplant
- quality of transplanted bone and host bone
- host bed preparation
- preservation techniques
- systemic and local disease
- mechanical properties of the graft

Although the role of cancellous allograft as a delivery vehicle for other osteoinductive factors is conceptually reasonable, data is lacking to support this application at this time [162]. Femoral ring allografts for anterior interbody fusions have gained increasing popularity because of their capability for an initial structural support [191]. The decreased fusion rate associated with allografts becomes more significant in multilevel surgery and in patients who smoke [65].

### Bone Graft Substitutes

Bone graft substitutes are increasingly being used for spinal fusion because of the minimal but inherent risk of a transmission of infectious disease with allografts

[115]. Among the **characteristics** of an **optimal bone graft substitute** are:

- high degree of biocompatibility
- lack of immunogenicity and toxicity
- ability for biodegradation
- ability to withstand sterilization
- availability in different sizes, shapes and amounts
- reasonable cost

The most **commonly used bone graft substitutes** in spinal fusion are:

- calcium phosphates
- demineralized bone matrix (DBM)

### *Calcium Phosphates*

Calcium phosphate materials can be classified by chemical composition and origin [i.e. natural or synthetic (ceramic) forms] and include:

- hydroxyapatite (HA)
- tricalcium phosphate (TCP)
- natural coralline

This group of materials closely resembles the mineral composition, properties and microarchitecture of human cancellous bone and has a high affinity for binding proteins [162]. **HA** is relatively inert and biodegrades poorly. Due to its brittleness and slow resorption, remodeling may be hindered and the material can become a focus of mechanical stress [232]. In contrast, **TCP** composites exhibit greater solubility than HA and typically undergo biodegradation within approximately 6 weeks, which may be too early for a maturation of the fusion mass [162, 232]. **Coralline HA** (CHA) was developed in 1971 with the aim of providing a more consistent pore size and improved interconnectivity [198]. These natural ceramics are derived from sea corals and are structurally similar to cancellous bone. The coral calcium carbonate undergoes a hydrothermal reaction where calcium carbonates are transformed into HA [162].

Calcium phosphates are of limited effectiveness

These materials are available in various preparations including putty, granular material, powder, pellets or injectable calcium phosphate cement [20]. In contrast to early reports suggesting the capability for osteogenic stimulation, it is now believed that calcium phosphates have only osteoconductive properties [232]. Purely osteoconductive substitutes are less effective in posterolateral spine fusion, but may be suitable for interbody fusion when it is rigidly immobilized [13]. Although selective data both from animal and clinical studies appears promising, there is still only limited evidence for the clinical effectiveness of these materials to generate or at least enhance spinal fusion [232].

### *Demineralized Bone Matrix*

A group of low-molecular-weight glycoproteins contained in the organic phase (particularly BMPs) are responsible for the bone inductive activity [166]. DBM is produced through a mild acid extraction of cortical bone and is processed to reduce risk of infection and immunogenic host response. The mild demineralization removes the mineral content of the bone, leaving behind collagen and non-collagenous proteins including the BMP, which becomes locally available to the cellular environment [166]. DMB is supplied in a variety of forms such as gel, malleable putty, flexible strips or injectable bone paste. Lee et al. [166] have pointed out that the amount of osteoinductive ability may rely on its preparation and the type of carrier with which it is combined.

DBM predominantly is a bone graft extender

Even though DBM is considered osteoinductive, this effect is much weaker as compared with commercially available recombinant BMPs. The use of current available DBMs is primarily as a bone graft extender or enhancers but caution is necessary as bone graft substitutes [5, 13].

### Bone Promoters

Since their discovery by Urist in 1965 [257], BMPs have been the focus of intensive research and clinical testing aiming to develop treatment strategies to enhance bone healing and generate arthrodesis. The role of BMPs in bone formation during development and in fracture healing is now well established [225]. BMPs are members of the transforming growth factor-β supergene family [40] and so far more than 15 BMPs have been identified [225]. BMPs function as a differentiation factor and act on mesenchymal stem cells to induce bone formation [34].

The majority of preclinical and clinical studies for spinal fusion (interbody and posterolateral) have been done using [15, 68, 106, 139, 142, 145, 260, 261]:

- BMP 2
- BMP 7 (osteogenic protein-1, OP-1)

BMPs promote fusion but cost-effectiveness is unclear

The BMPs are delivered to the fusion site on carriers, e.g. HTA/TCP [15] or collagen matrix [145]. When used at an optimized concentration and with an appropriate carrier, BMPs can be successfully used as bone graft replacement [34]. However, only increasing experience and longer term follow-up will show whether these new fusion techniques will surpass the level of safety and clinical feasibility and can be established as a cost-effective treatment.

## Surgical Techniques

For a long time, spinal fusion has been the treatment of choice when addressing symptomatic lumbar spondylosis. Motion preserving implant technologies have emerged which offer theoretical advantages over fusion. The early motion preserving technologies such as **Graf ligamentoplasty** [96, 144, 226] and **Dynesys stabilization** [237, 238] have demonstrated favorable outcomes for selected patients. Similarly, the early outcome was promising for total disc arthroplasty [62, 116, 190, 284] and posterior interspinous spacers [49, 153, 286]. However, the new technologies must pass the test of time, i.e. long-term follow-up in RCTs, before they can be broadly accepted as alternative fusion techniques. So far, no evidence has been reported to demonstrate that these new techniques are superior to spinal fusion.

The scientific literature exhibits a plethora of articles covering the outcome of surgical treatment. The vast majority of these papers cover technical aspects, safety and early clinical results without adequate control groups. Many of the studies incorporated a whole variety of indications, which limits conclusions on degenerative lumbar spondylosis without neurological compromise. However, when the scientific literature is reduced to **Level A evidence** (i.e. consistent evidence in multiple high-quality RCTs), only 31 RCTs can be identified through March 2005 [102, 103]. These facts greatly limit treatment recommendations on degenerative lumbar spondylosis. In this chapter, we therefore attempt to base treatment recommendations on the best available evidence.

The scientific evidence for spinal fusion in lumbar spondylosis is poor

### Non-instrumented Spinal Fusion

Lumbar arthrodesis can be achieved by three approaches. The most commonly used technique is **posterolateral fusion** (PLF), which comprises a bone grafting of the posterior elements. As an alternative, the bone grafting can be performed after disc excision and endplate decancellation (**interbody fusion**) by a posterior approach (posterior lumbar interbody fusion, PLIF) or the anterior approach (anterior lumbar interbody fusion, ALIF). The so-called **combined or 360 degree fusion** is the combination of both techniques.

#### *Posterolateral Fusion*

Posterolateral fusion remains the fusion gold standard

Posterolateral fusion was first described by Watkins in 1953 [270] and remains the gold standard for spinal fusion. The technique consisted of a decortication of the transverse spinous processes, pars interarticularis and facet joints with application of a large corticocancellous iliac bone block. This method has been modified by Truchly and Thompson [255], who used multiple thin iliac bone strips as graft material instead of a single corticocancellous bone block because of frequent graft dislocation [255]. In 1972, Stauffer and Coventry [245] presented the technique still used today by most surgeons, which consisted of a single midline approach (Fig. 3). However, the bilateral approach had a revival some years later when Wiltse et al. [278] suggested an anatomic muscle splitting approach which was modified by Fraser [118].

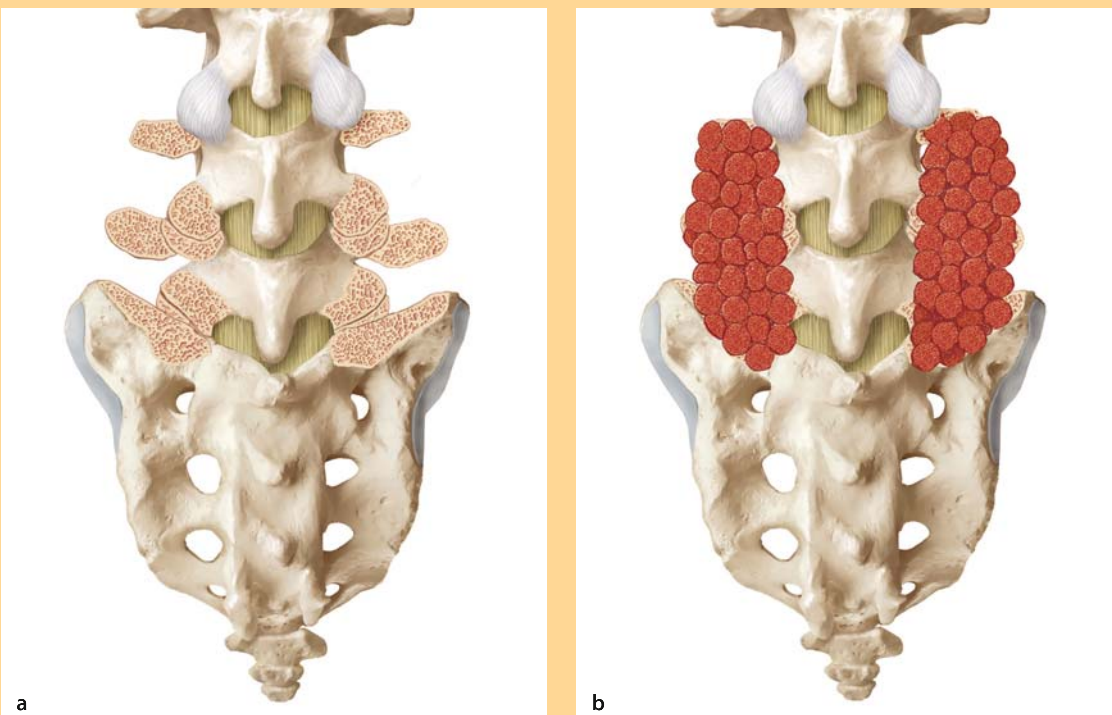


**Figure 3. Surgical technique of posterolateral fusion**

Careful preparation of the fusion bed is important and consists of: **a** decortication of the transverse process and facet joints and isthmus; **b** placement of autologous corticocancellous bone chips over the facet joints and transverse processes.

Non-instrumented posterolateral fusion remains the benchmark for comparison of fusion techniques

Boos and Webb [24] reviewed 16 earlier non-randomized studies (1966–1995) with a total of 1 264 cases and found a mean fusion rate of 87 % (range, 40–96 %) and an average rate of satisfactory outcome of 70 % (range, 52–89 %). The results reported in the article by Stauffer and Coventry [245] remain a benchmark for non-instrumented posterolateral fusion. Eighty-nine percent of those whose fusion was done as a primary procedure for degenerative disc disease achieved good clinical results and 95 % were judged to have a solid fusion. These favorable results were not surpassed by many studies which followed.

### *Posterior Lumbar Interbody Fusion*

Posterior disc excision and insertion of bone grafts was first described by Jaslow in 1946 [138] and popularized by Cloward [52, 54] and others as posterior lumbar interbody fusion (**PLIF**) (Fig. 4). The disadvantage of PLIF was the need for an extensive posterior decompression to allow for a graft insertion which destabilized the spine. Furthermore, graft insertion necessitates a substantial retraction of the nerve roots which carries the risk of nerve root injuries and significant postoperative scarring.

PLIF increases fusion rate

PLIF resulted in a somewhat higher fusion rate and better clinical outcome than posterolateral fusion. Based on an analysis of 1 372 cases reported in 8 studies [53, 56, 130, 131, 165, 171, 194, 219], mean fusion rate was 89 % (range, 82–94 %) and the average rate of satisfactory outcome was 82 % (range, 78–98 %) [24].

### *Anterior Lumbar Interbody Fusion*

Anterior spinal fusion was first described by Capener in 1932 for the treatment of spondylolisthesis [39]. However, Lane and Moore [163] were the first to perform anterior lumbar interbody fusion (ALIF) on a larger scale [163]. Iliac tricortical bone autograft as well as femoral, tibia, or fibula diaphyseal allografts were used for this technique. Particular femoral ring allografts have been recently used as cost-effective alternatives to cages and offer some advantages regarding the biology of the fusion compared to cages [167, 191]. The advantage of ALIF was that the paravertebral muscles and neural structures remained intact. A further technical advantage is that disc excision and graft bed preparation can be done better than with PLIF. On the other hand, the abdominal access is associated with specific approach related problems such as retrograde ejaculation in male patients (range, 0.1–17 %) [29, 76, 254] and vascular injuries (range, 0.8–3.4 %) [29, 210].

Stand-alone ALIF has not been successful

The results in the literature were largely variable. An analysis of 1 072 cases reported in 10 studies revealed a mean fusion rate of 76 % (range, 56–94 %) and an average satisfactory outcome rate of 76 % (range, 36–92 %) [24]. Compared to the favorable results Stauffer and Coventry achieved with a posterolateral fusion [245], the ALIF results of the same authors [244] were disappointing (fusion rate 56 %, satisfactory outcome 36 %). Stauffer and Coventry [244] concluded that ALIF should be utilized as a salvage procedure in those infrequent cases in which posterolateral fusion is inadvisable because of infection or unusual extensive scarring [244]. Graft dislocation and subsidence as well as moderate fusion rate caused the “stand-alone” ALIF to fall out of favor for some years.

## Instrumented Spinal Fusion

With the advent of pedicle screw fixation devices in the 1980s and the introduction of fusion cages in the 1990s, spinal instrumentation was widely used with the

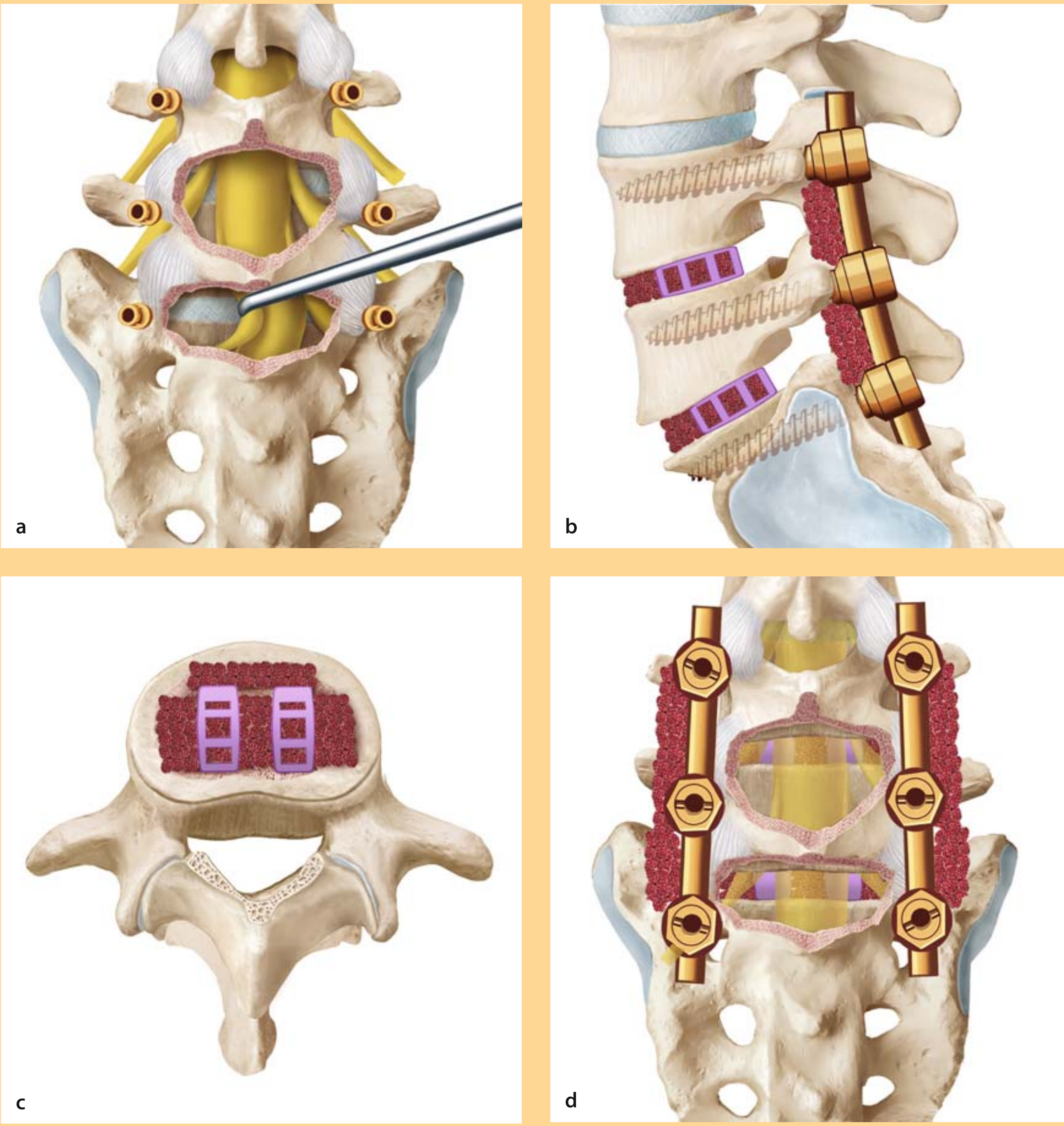



**Figure 4. Surgical technique of posterior lumbar interbody fusion**

a Pedicle screws are inserted at the target levels. A wide decompression is necessary to insert the cages safely through the spinal canal. The intervertebral disc is removed as completely as possible but without jeopardizing the anterior outer anulus (vascular injuries). The cartilage endplates are removed with curettes. Cages are inserted by retracting the nerve root and thecal sac medially. b, c Prior to insertion, the disc space is filled with cancellous bone graft particularly anteriorly. d The rod is inserted and fixed to the screws. A posterolateral fusion is added.

rationale that the improved segmental stability may enhance the fusion rate and simultaneously improve clinical outcome. The biomechanical background of spinal instrumentations is reviewed in Chapter 3.

### *Pedicle Screw Fixation*

Pedicle screw fixation is the gold standard for lumbar stabilization

The pedicle is the strongest part of the vertebra, which predestines it as an anchorage for screw fixation of the vertebral segments. Pedicle screw fixation had

Roy-Camille first used pedicle screws

its origins in France. From 1963, **Raymond Roy-Camille** first used pedicle screws with plates to stabilize the lumbar spine for various disorders [230]. Some years later, **Louis and Maresca** modified Roy-Camille's plate and technique to better adapt to the lumbosacral junction [174, 175]. Based on the pioneering work of **Fritz Magerl** [179], the concept of angle-stable pedicular fixation was introduced, which led to the development of the AO Internal Fixator [1, 67]. Around the same time, Steffee [246] developed the variable screw system (VSP), a plate pedicle screw construct. A further milestone in the development was the introduction of a new screw-rod system by **Cotrel and Dubousset** in 1984 [60]. The versatile Cotrel-Dubousset instrumentation system became widely used for the treatment of degenerative disorders. The current system offers the advantage of polyaxial screw heads which facilitate the rod screw connection. The most frequently used fusion technique today is to combine pedicle screw fixation with posterolateral fusion (Case Study 1).

Pedicle screw fixation is most commonly used in conjunction with posterolateral fusion

The fusion rates with the pedicle screw system average 91 % (range 67 – 100 %) with satisfactory clinical outcome ranging between 43 % and 95 % (mean 68 %) [24]. Many surgeons applied the pedicle screw stabilization system with the rationale that the enhanced fusion rate would also improve outcome. However, at the end of the 1990s it became obvious that pedicle screw fixation may increase the fusion rate but not necessarily clinical outcome [24, 102].

Pedicle screw fixation enhances fusion rate but not clinical outcome

### *Translaminar Screw Fixation*

Translaminar screws are an alternative to pedicle screws

An alternative method of screw fixation in the lumbar spine was first described in 1959 by **Boucher** [26]. These oblique facet screws were used to block the zygapophyseal joints. However, the stability of these screws crossing the facet joints obliquely was unsatisfactory. **Magerl** [180] developed the so-called translaminar screw fixation which crossed the facet more perpendicularly, increasing stability [126]. The initial clinical results were promising [113, 129, 136, 184]. The advantage is that the screws can be used as a minimally invasive posterior stabilization technique and can often be combined with an anterior interbody fusion [191], which can also be done minimally invasively (see below, Case Introduction) [21].

### *Cage Augmented Interbody Fusion*

Cages stabilize the anterior column and increase fusion rate

The application of interbody fusion cages for fusion enhancement is based on the rationale that a strong structural support is needed for the anterior column which does not migrate or collapse [122]. Interbody cages were designed and first used by **Bagby and Kuslich** (BAK cage) in the 1990s and consisted of threaded hollow cylinders filled with bone graft [160, 161]. Today, different designs and materials are available for anterior and posterior use (Table 6):

**Table 6.** Cage materials and design

| Designs | Materials |
|---|---|
| • threaded, cylindrical cages<br>• ring-shaped cages with and without mesh structure<br>• box-shaped cages | • titanium<br>• carbon<br>• polyetheretherketone (PEEK) |

The cages were originally designed as stand-alone anterior or posterior fusion devices. The initial studies in the literature reported promising results [161, 224, 233] and some authors reported satisfactory long term outcome [27]. However, the biomechanical (stability, no cage subsidence) and biologic (load sharing with

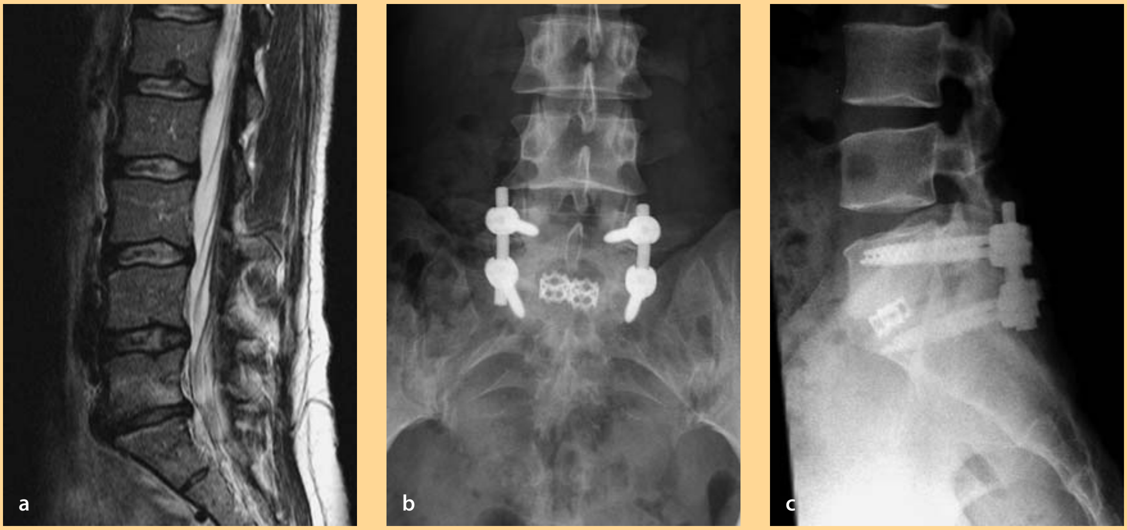



**Figure 5. Circumferential fusion**

a Young (28 years) female patient with endplate changes (Modic Type II) undergoing pedicle screw fixation L5/S1 and posterolateral fusion in combination with a cage augmented anterior lumbar interbody fusion. Postoperative b antero-posterior view and c lateral view.

the graft) requirements for spinal fusion were challenging (see Chapter 3) and resulted in a high failure rate [73, 189]. The problems associated with stand-alone cages led to the recommendation of the use of cages only in conjunction with spinal instrumentation (Fig. 5) [37, 45].

The outcome of stand-alone cages is not favorable

Although a **bilateral cage insertion** is generally recommended for biomechanical reasons, it is not always possible to insert two cages when the disc space is still high and the spinal canal rather narrow. Recently, it has been shown that **unilateral cage insertion** leads to comparable results to bilateral cage placements [82, 196]. The shortcomings of the PLIF technique (i.e. retraction of nerve roots and potential epidural fibrosis) led to a modified technique by a transforaminal route (**transforaminal lumbar interbody fusion, TLIF**). After unilateral resection of the facet joints, the disc is exposed and excised without retraction of the thecal sac and nerve roots before a cage is implanted. TLIF should only be used in conjunction with spinal instrumentations. The reported results with this technique are promising [105, 117, 123, 231, 235].

Unilateral cage insertion may suffice in selected cases

### *Circumferential Fusion*

Circumferential fusion (i.e. interbody and posterolateral fusion) was first used for the treatment of spinal trauma and deformity, then expanded to failed previous spinal fusion operations and is now used also as a primary procedure for chronic low-back pain [122]. Theoretically, this technique should increase the fusion rate by maximizing the stability within the motion segment and enhance outcome because of an elimination of potential pain sources in anterior and posterior spinal structures. Today, circumferential fusion is almost always done **in conjunction with instrumentation.** Interbody fusion can be done by a posterior (PLIF) (Fig. 4) or anterior approach (ALIF) (Figs. 5, 6) depending on the individual pathology and surgeons' preferences. There seems to be no difference between both approaches in terms of clinical outcome [178].

Outcome of PLIF and ALIF appears to be comparable

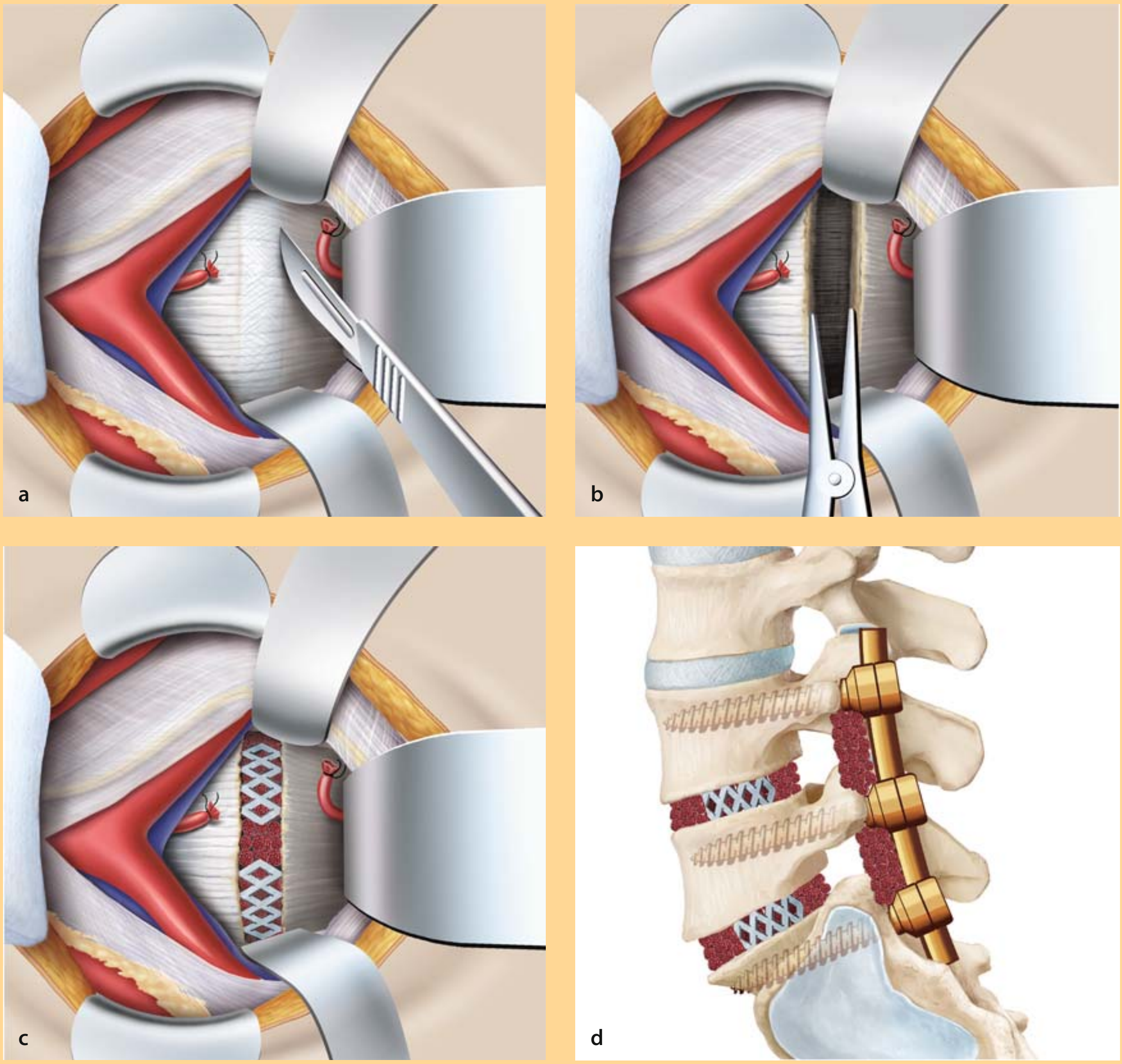



**Figure 6. Surgical technique of anterior lumbar interbody fusion**

The lumbosacral junction is exposed by a minimally invasive retroperitoneal approach. **a** The intervertebral disc is excised; **b** the endplates can be distracted with a spreader and the endplate cartilage is removed with curettes; **c** the disc space is filled with cancellous bone and supported with two cages. Ring-shaped cage design allows sufficient bone graft to be placed around the cages. **d** Pedicle screw fixation is added in conjunction with posterolateral fusion.

Combined interbody and posterolateral fusion has the highest fusion rate

Several studies have consistently demonstrated that circumferential fusion increases the rate of solid fusion [48, 91], with fusion rates ranging from 91 % to 99 % [48, 91, 242, 252]. However, it remains controversial whether circumferential fusion improves clinical outcome [91, 267]. Fritzell et al. [91] did not find a significant difference in outcome when comparing non-instrumented, instrumented posterolateral or circumferential fusion. On the contrary, Videbaek et al. [267] have demonstrated that patients undergoing circumferential fusion have a significantly better long term outcome compared to posterolateral fusion in terms of disability (Oswestry Disability Index) and physical health (SF-36). Some patients continue to have pain after posterolateral spinal fusion despite apparently solid arthrodesis. One potential etiology is pain that arises from a disc within the fused levels and has positive pain provocation on discography. These patients benefit from an ALIF [8].

### Minimally Invasive Approaches for Spinal Fusion

Access technology should decrease collateral muscle damage during fusion surgery

In the last two decades, attempts have been made to minimize approach-related morbidity [98, 154, 247]. Particularly, the posterior approach to the lumbosacral spine necessitates dissection and retraction of the paraspinal muscles. The muscle retraction was shown to cause a significant muscle injury dependent on the traction time [147–150]. The use of **translaminar screw fixation** in conjunction with an ALIF has been suggested to minimize posterior exposure of the lumbar spine [9, 137, 159, 191, 241] (Case Introduction). Newer posterior techniques use a tubular retractor system for pedicle screw insertion and percutaneous rod insertion that avoids the muscle stripping associated with open procedures [71, 83, 98].

**Laparoscopic techniques** for anterior interbody fusion were developed in the 1990s to minimize surgical injury related to the anterior approach [38, 170, 252, 281]. This technique was favored in conjunction with the use of cylindrical cages and may exhibit some immediate postoperative advantages (e.g. less blood loss, shorter postoperative ileus, earlier mobilization) [61, 78]. However, this technique did not prevail because of the tedious steep learning curve, longer operation time, expensive laparoscopic instruments and tools and need for a general surgeon familiar with laparoscopy without providing superior clinical results [50, 200, 281]. Many surgeons today prefer a **mini-open anterior approach** to the lumbar spine using a retraction frame (Case Introduction), which allows a one or two level anterior fusion to be performed through a short incision [2, 186]. It also allows for a rapid extension of the exposure in case of complications such as an injury to a large vessel.

Minimally invasive approaches have not yet demonstrated superior outcomes

Many initial reports have shown similar clinical results in terms of spinal fusion rates for both traditional open and minimally invasive posterior approaches [71, 84]. However, the anterior minimally invasive procedures are often associated with a significantly greater incidence of complications and technical difficulty than their associated open approaches [71].

### Fusion Related Problems

#### *Revision Surgery for Non-union*

Revision surgery for non-union remains costly and difficult. Diagnosis of non-union by radiological assessment is not easy and solid fusion determined from radiographs ranged from 52 % to 92 % depending on the choice of surgical procedure [47].

Functional and clinical results of lumbar fusion are often not in correlation

Similarly to a primary intervention, the single most important factor in achieving a successful clinical outcome is **patient selection** [75]. It is well anticipated that functional and clinical results of lumbar fusion are often not in correlation and the rate of non-union has no significant association with clinical results in the first place [81, 277], which challenges the clinical success of revision surgery for non-union.

The best lumbar fusion rates are achieved by a circumferential fusion

Interbody fusion is advocated to repair non-union because revision surgery by posterolateral fusion has not been overly successful [55, 75]. Circumferential fusion provides the highest fusion rate. It is therefore recommended to perform a 360-degree fusion during a revision operation [47]. However, patients with a non-union after stand-alone cage augmented fusion (PLIF or ALIF) may well benefit from a revision posterolateral fusion and pedicle screw fixation [45].

Despite successful fusion repair, clinical outcome is often disappointing

Although solid fusion after non-union can be achieved in 94–100% of patients with appropriate techniques [36, 42, 99], there is only a poor correlation of the radiographic and clinical results [42]. After repair of pseudoarthrosis, Carpenter et al. reported a solid fusion rate of 94% without significant association with clinical outcome, patient's age, obesity and gender [42]. Similar findings were made by Gertzbein et al. [99]. These authors reported a fusion rate of 100% even in the face of factors often placing patients at high risk for developing a pseudarthrosis, i.e. multiple levels of previous spinal surgery, including previous pseudarthrosis, and a habit of heavy smoking. However, the satisfactory outcome rate was only somewhat better than 50%, based on a lack of substantial pain improvement and return to work [99]. It is therefore mandatory to inform surgical candidates that the risk of an unsatisfactory outcome is high despite solid fusion.

#### *Adjacent Segment Degeneration*

Adjacent segment degeneration following lumbar spine fusion remains a well known problem, but there is insufficient knowledge regarding the risk factors that contribute to its occurrence [158]. Biomechanical and radiological investigations have demonstrated increased forces, mobility, and intradiscal pressure in adjacent segments after fusion [72]. Although it is hypothesized that these changes lead to an acceleration of degeneration, the natural history of the adjacent segment remains unaddressed [72]. When discussing the problem of **adjacent segment degeneration** it is important to:

- take the preoperative degeneration grade into account
- differentiate asymptomatic and symptomatic degeneration
- consider the natural history of the adjacent motion segment

Adjacent segment degeneration is a frequent problem

There is no significant correlation between the preoperative arthritic grade and the need for additional surgery [100]. Radiographic segmental degeneration weakly correlates with clinical symptoms [208] and the age of the individual [46, 104, 213]. There are conflicting results on the influence of the length of spinal fusion [46]. Pellise et al. [213] found that radiographic changes suggesting disc degeneration appear homogeneously at several levels cephalad to fusion and seem to be determined by individual characteristics. Ghiselli et al. [100] reported a rate of symptomatic degeneration at an adjacent segment warranting either decompression or arthrodesis to be 16.5% at 5 years and 36.1% at 10 years. It remains to be seen whether disc arthroplasty will alter the rate of adjacent segment degeneration [128].

### Motion Preserving Surgery

Motion preservation surgery is still emerging

With the advent of motion preserving surgical techniques, there is a great excitement among surgeons and patients that the drawbacks of spinal fusion can be overcome. So far, the initial results are equivalent to those obtained with spinal fusion and it is hoped that there is a decrease in the rate of adjacent segment degeneration. The success of the paradigm shift toward motion preservation is still unproven but it makes intuitive and biomechanical sense [6]. A review of the biomechanical background of motion preserving surgery is included in Chapter 3.

#### *Total Disc Arthroplasty*

Attempts to artificially replace the intervertebral discs were already made in the 1950s by **Fernstrom** [79]. However, the ball like intercorporal endoprosthesis was prone to failures (i.e. loosening and migration). The disc prosthesis with the longest history is the **SB-Charité prosthesis**, which dates back to 1982. The prosthesis was developed by Kurt Schellnack and Karin Büttner-Janz at the Charité Hospital in Berlin. The prosthesis has meanwhile undergone several redesigns. The SB-Charité III disc prosthesis (Depuy Spine) was the first to receive FDA approval in 2004. In recent decades various alternative designs have been developed such as the ProDis-L (Synthes, FDA approval 2006), Maverick (MedtronicSofamorDanek), Flexicore (Stryker), Kineflex (SpinalMotion) and ActivL (B. Braun/Aesculap) total disc replacement systems.

**Indications and contraindications** for total disc arthroplasty (TDA) are (Table 7):

**Table 7.** Total disc arthroplasty

| Indications | Contraindications |
|---|---|
| • age 18–60 years<br>• severe back pain<br>• severe disability (ODI > 30–40)<br>• failed non-operative treatment for > 6 months<br>• single or two-level disc degeneration | • osteoporosis<br>• multilevel disc degeneration<br>• facet joint osteoarthritis<br>• spinal deformity or instability<br>• prior lumbar fusion<br>• obesity<br>• consuming illness (tumor, infection, inflammatory disorders)<br>• metabolic disorders<br>• known allergies |

Modified from Zigler et al. [283] and Guyer et al. [116]
*ODI* Oswestry Disability Index

German and Foley [97] have highlighted that particular attention should be paid to the presence of facet joint osteoarthritis, as this has been associated with poor clinical outcomes after arthroplasty [187, 262]. Total disc arthroplasty (Fig. 7) has meanwhile passed the level of technical feasibility and safety [11, 51, 168, 187]. However, major concerns remain regarding revision arthroplasty, which can cause life-threatening complications (e.g. in case of a major vessel injury during reoperation).

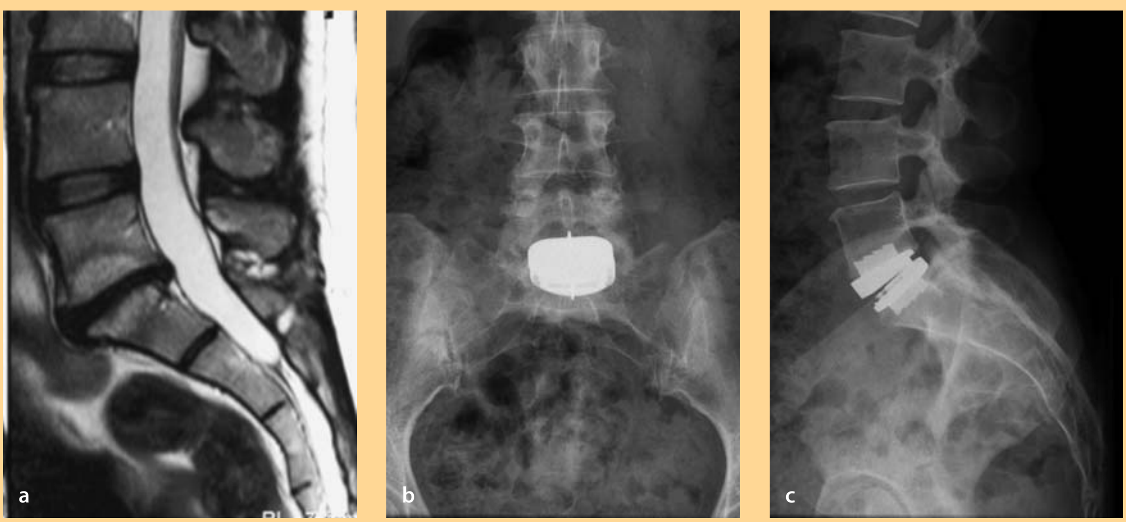



**Figure 7. Total disc arthoplasty**

Female patient (48 years) with endplate (Modic) changes at L5/S1 treated by total disc replacement with Prodisc (Synthes). **a** Sagittal T2 weighted MRI scan demonstrating Modic Type II changes at L5/S1. Postoperative **b** anteroposterior view; and **c** lateral view showing correct positioning of the TDA.

Two randomized controlled FDA IDE trials compared TDA with spinal fusion. In the first trial, the SB-Charité disc prosthesis was compared with stand-alone BAK cages with autograft from the iliac crest for one-level disc disease L4–S1 [12, 188]. The second trial compared the ProDisc-L total disc arthroplasty with circumferential spinal fusion for the treatment of discogenic pain at one vertebral level between L3 and S1 [282]. Both prospective, randomized, multicenter studies demonstrated that quantitative clinical outcome measures following TDA are at least equivalent to clinical outcomes with conventional fusion techniques.

Short-term clinical outcome of TDA is comparable to spinal fusion

Although these results are promising, only longer term follow-up will show whether TDA is superior to spinal fusion and reduce the rate of adjacent segment degeneration [97].

### *Dynamic Stabilization*

Abnormal loading patterns are a cause of pain

Mulholland [201] has hypothesized that abnormal patterns of loading rather than abnormal movement are the reason that disc degeneration causes back pain in some patients. **Abnormal load transmission** is the principal cause of pain in osteoarthritic joints. Both osteotomy and total joint replacement succeed because they alter the load transmission across the joint [201]. In this context, the spine is painful in positions and postures rather than on movement [201]. The rationale for dynamic or **"soft" stabilization** of a painful motion segment is to alter mechanical loading by unloading the disc but preserving lumbar motion in contrast to spinal fusion [205]. The **Graf ligamentoplasty** was the first dynamic stabilization system widely used in Europe [30, 96, 111]. The principle of the Graf system was to stabilize the spine in extension (locking the facet joints) using pedicle screws connected by a non-elastic band. This system increased the load over the posterior anulus, caused lateral recess and foraminal stenosis and was only modestly successful [201].

The dynamic stabilization system may alter abnormal loading and thus be effective

The **Dynesys system** is based on pedicle screws connected with a polyethylene cord and a polyurethane tube reducing movement both in flexion and extension [238, 249]. However, often it also unloads the disc to a degree that is unpredictable [201]. Non-randomized studies reported promising results [221, 249, 276]. However, Grob et al. [112] reported that only half of the patients declared that the operation had helped and had improved their overall quality of life, and less than half reported improvements in functional capacity. The reoperation rate after Dynesys was relatively high. Only long-term follow-up data and controlled prospective randomized studies will reveal whether dynamic stabilization is superior to spinal fusion for selected patients [238].

Best indications for dynamic stabilization are not well established

Recently, **interspinous implants** have been introduced as minimally invasive dynamic spine stabilization systems, e.g. X-Stop (St. Francis Medical Technologies), Diam (Medtronic), and Wallis (SpineNext). The interspinous implants act to distract the spinous processes and restrict extension. This effect will reduce posterior anulus pressures and theoretically enlarge the neural foramen [49]. These implants are therefore predominantly used for degenerative disc disorders in conjunction with spinal stenosis [157, 251, 285]. Further case-control studies and RCTs still have to identify the appropriate indications and clinical efficacy.

The clinical effectiveness of interspinous stabilization remains to be proven

## Comparison of Treatment Modalities

During the last decade, several high quality prospective randomized trials have elucidated the effect of conservative versus operative treatment on clinical outcome for lumbar degenerative disorders.

The **Swedish Lumbar Spine Study** [88–91] investigated whether lumbar fusion could reduce pain and diminish disability more effectively when compared with non-surgical treatment in patients with severe chronic low-back pain (CLBP). The surgical patients had a significantly higher rate of subjective favorable outcome and return to work rate compared to the non-surgical group.

Spinal fusion is superior to non-operative care at 2 years

However, no significant differences between fusion techniques were found among the groups in terms of subjective or objective clinical outcome [91]. The authors concluded from their studies that lumbar fusion in a well-informed and selected group of patients with severe CLBP can diminish pain and decrease disability more efficiently than commonly used non-surgical treatment and that there was no obvious disadvantage in using the least demanding surgical technique of posterolateral fusion without internal fixation [90, 91].

Surgical fusion techniques do not differ in outcome

The results of this study were analyzed in the context of cost-effectiveness. For both the society and the healthcare sectors, the 2-year costs for lumbar fusion were significantly higher compared with non-surgical treatment, but all treatment effects were significantly in favor of surgery [88]. Longer term follow-up, however, revealed that the benefits of surgery diminished over time (P. Fritzell, personal communication). Although this study was highly acclaimed for being the first of its kind, criticism arose with regard to the patient inclusion criteria (e.g. sick leave for at least 1 year) and the non-specified conservative treatment [103].

In a single blinded RCT from Norway [31, 151], the effectiveness of lumbar instrumented fusion was compared with **cognitive intervention and exercises** in patients with chronic low-back pain and disc degeneration. No significant differences were found in terms of subjective outcome or disability. Patients with chronic low-back pain who followed cognitive intervention and exercise programmes improved significantly in muscle strength compared with patients who underwent lumbar fusion [151]. The authors concluded that the main outcome measure showed equal improvement in patients with chronic low-back pain and disc degeneration randomized to cognitive intervention and exercises or lumbar fusion.

Cognitive behavioral treatment and exercises are key elements of non-operative care

The **MRC Spine Stabilization Trial** [77] assessed the clinical effectiveness of surgical stabilization (spinal fusion) compared with an intensive rehabilitation program (including cognitive behavioral treatment) for patients with chronic low-back pain. No clear evidence emerged that primary spinal fusion surgery was any more beneficial than intensive rehabilitation. The drawback of this study was that the surgical group was not well defined and a garden variety of treatment methods were applied. A cost-effectiveness analysis [227] revealed that surgical stabilization of the spine may not be a cost-effective use of scarce healthcare resources. However, sensitivity analyses show that this could change – for example, if the proportion of rehabilitation patients requiring subsequent surgery continues to increase.

Spinal fusion and intensive rehabilitation achieve similar results

The **practical implication** of these three high quality trials is that patients must be informed extensively about the current evidence in the literature prior to surgery. Presently, there is no substantial evidence that spinal fusion is superior to an intensive rehabilitation program including cognitive behavioral intervention.

Scientific evidence for the effectiveness of spinal fusion is limited

## Complications

The complication rate of surgical interventions for lumbar spondylosis is critically dependent on the extent of the intervention [253]. The reintervention rate ranges from 6% (non-instrumented fusion) to 17% (combined anterior/posterior fusion) [89]. However, the complication rate is also dependent on the surgi-

The surgeon skill factor remains widely unaddressed

cal skill of the individual surgeon, which is not well explored so far. The most frequent complications after spinal fusion for degenerative disc disease are:

- infection: 0–1.4% [77, 89, 280]
- non-union: 7–55% [89, 280]
- de novo neurological deficits: 0–2.3% [77, 253, 280]
- bone graft donor site pain: 15–39% [234]

A detailed discussion of complications related to lumbar fusion is included in Chapter 39.

## Recapitulation

**Epidemiology.** Lumbar spondylosis refers to a mixed group of pathologies related to the degeneration of the lumbar motion segment and associated pathologies or clinical syndromes of discogenic back pain, facet joint osteoarthritis (OA), and segmental instability. Morphological abnormalities in the lumbar spine are frequent in asymptomatic individuals. However, severe endplate alterations (**Modic changes**) and **advanced facet joint OA** are rare in young healthy subjects. Specific low-back pain (LBP) due to lumbar spondylosis is infrequent. The natural history of lumbar spondylosis is benign and self-limiting.

**Pathogenesis.** Disc degeneration may lead to the expression of **proinflammatory cytokines**, which are assumed to be responsible for the generation of discogenic LBP. Facet joint degeneration resembles the clinical pathology of **osteoarthritis**. The orientation of the facet joint appears to play a role in premature degeneration. A **wide range of segmental motion** can be found in asymptomatic individuals. It appears that the **kinematics of the motion** is affected by the instability and not so much the range of motion. Objective criteria for the definition of segmental instability are lacking and the diagnosis therefore remains enigmatic.

**Clinical presentation.** The clinical findings for a symptomatic lumbar spondylosis are few. Patients with **discogenic back pain** often complain of pain aggravation during sitting and forward bending. Pain can increase during the night and can radiate into the anterior thigh. A **facet joint syndrome** causes stiffness as well as pain on backward bending and rotation. In the early stages, pain often improves during motion and exhibits a "walk in" period. The pain sometimes radiates into the buttocks and posterior thigh. A **clinical instability syndrome** causes mechanical LBP, which aggravates during motion and disappears with rest.

**Diagnostic work-up.** The imaging modality of choice is **MRI**, which is sensitive but less specific in identifying the sources of back pain. Standard radiographs are helpful in identifying lumbar-sacral transitional anomalies. **Functional views** do not allow the diagnosis of segmental instability. **Computed tomography** is indicated in patients with contraindications for an MRI and for the assessment of the fusion status. **Injection studies** are indispensable for the identification of a morphological alteration as a source of back pain. Provocative discography remains the only diagnostic test for the diagnosis of discogenic back pain. It is recommended to always include an MR normal disc during discography as an internal control. The interpretation of pain relief subsequent to facet joint infiltrations is hampered by the multilevel innervation of the joints, and repeated injections are needed to improve diagnostic accuracy. Injection studies have to be interpreted with great care. The single most important factor for the choice of treatment is **patient selection**. The exclusion of risk flags is mandatory. Psychological, sociological and work-related factors have been shown to affect treatment outcome more than clinical and morphological findings.

**Non-operative treatments.** The **main objectives** of treatment are pain relief as well as improvement of quality of life (e.g. activities of daily living, recreational and social activities) and work capacity. The **mainstay of non-operative management** consists of pain management (medication), functional restoration (physical exercises), and cognitive-behavioural therapy (psychological intervention). Particularly the combination of functional treatment and cognitive behavioral intervention has been shown to be effective for degenerative lumbar spondylosis.

**Operative treatment.** **The paradigm of spinal fusion** is based on the experience that painful diarthrodial joints or joint deformities can be successfully treated by arthrodesis. The selection for surgery should be timely and based on the identification of structural abnormalities which can be well addressed with surgery. **Favorable indications** for surgery include severe structural alterations: short duration of persistent symptoms (< 6 months), one- or two-level disease, absence of risk factor flags, clinical symptoms concordant with the structural correlate, highly motivated patient, positive pain provocation and/or pain relief tests.

Understanding the **biology of spinal fusion** is necessary to select the appropriate fusion technique. Blood supply to the spinal fusion area and the properties of the bone graft (or substitutes) is important for the maturation of the fusion mass. The optimal graft material for fusion should be **osteogenetic, osteoconductive and osteoinductive**. Autologous bone possesses all three properties and remains the gold standard. **Allografts** (e.g. femoral ring) are used to support the anterior column and have some biologic advantages compared to cages but carry the risk of transmission of infection. **Calcium phosphates** only have osteoconductive properties and are of limited effectiveness. **Demineralized bone matrix** predominately has a role as a bone graft extender. **Bone morphogenetic proteins** promote spinal fusion but their cost effectiveness is so far not determined. **Posterolateral fusion** remains the fusion technique of choice for lumbar degenerative spondylosis. **Combined interbody and posterolateral fusion** yields the highest fusion rates. **Spinal instrumentation** increases the fusion rate but not equally the clinical outcome. **Cages** support the anterior column and are helpful to stabilize the anterior column and enhance fusion rates. **Minimally invasive fusion techniques** have not been shown to provide better outcome when compared to conventional techniques. Non-union and adjacent segment degenerations are frequent fusion related problems. The best fusion technique for a failed arthrodesis is an instrumented combined anterior/posterior fusion. The clinical results are often disappointing despite successful fusion repair. **Dynamic fixation systems** have so far not been shown to protect adjacent segments from premature degeneration. **Total disc arthroplasty** does not provide superior results compared to spinal fusion. Based on three high quality RCTs, there is **no scientific evidence that spinal fusion is superior to an intensive rehabilitation program** including cognitive behavioral intervention, particularly not at mid and long-term follow-up.

## Key Articles

**Stauffer RN, Coventry MB (1972) Posterolateral lumbar-spine fusion. Analysis of Mayo Clinic series. J Bone Joint Surg Am 54:1195 – 204**
Classic article on spinal fusion for back pain. The results of this early analysis have not been surpassed by many other studies which followed.

**Fritzell P, Hagg O, Wessberg P, Nordwall A (2001) 2001 Volvo Award Winner in Clinical Studies: Lumbar fusion versus nonsurgical treatment for chronic low back pain: a multicenter randomized controlled trial from the Swedish Lumbar Spine Study Group. Spine 26:2521 – 32**

**Fritzell P, Hagg O, Wessberg P, Nordwall A (2002) Chronic low back pain and fusion: a comparison of three surgical techniques: a prospective multicenter randomized study from the Swedish Lumbar Spine Study Group. Spine 27:1131 – 41**
The Swedish Lumbar Spine Study compared lumbar fusion with non-surgical treatment in patients with severe chronic low-back pain (CLBP). A total of 294 patients aged 25 – 65 years with CLBP for at least 2 years were randomized blindly into two major treatment groups, i.e. non-operative (different kinds of physical therapy) vs. operative (three different methods of spinal fusion). At the 2-year follow-up, back pain was significantly more reduced in the surgical group by 33 % compared with 7 % in the non-surgical group. Pain improved most during the first 6 months and then gradually deteriorated. The Oswestry Disability Index (ODI) was reduced by 25 % compared with 6 % among non-surgical patients. The surgical patients had a significantly higher rate (63 %) of a subjective favorable outcome ("much better" or "better") compared to the non-surgical group (29 %). The "net back to work rate" was significantly in favor of surgical treatment, or 36 % vs. 13 %. A detailed analysis of the 222 surgical patients after 2 years revealed that fusion rate was dependent on the fusion technique, i.e. non-instrumented posterolateral

fusion (72%), instrumented posterolateral fusion (87%) and instrumented combined anterior/posterior fusion (91%). All surgical techniques substantially decreased pain and disability, but no significant differences were found among the groups in terms of subjective or objective clinical outcome.

**Brox JI, Sorensen R, Friis A, Nygaard O, Indahl A, Keller A, Ingebrigtsen T, Eriksen HR, Holm I, Koller AK, Riise R, Reikeras O (2003) Randomized clinical trial of lumbar instrumented fusion and cognitive intervention and exercises in patients with chronic low back pain and disc degeneration. Spine 28:1913–21**
This single blinded RCT from Norway compared the effectiveness of lumbar instrumented fusion with cognitive intervention and exercises in patients with chronic low-back pain and disc degeneration. Sixty-four patients aged 25–60 years with low-back pain lasting longer than 1 year and evidence of disc degeneration L4–S1 were randomized to either lumbar fusion with posterior transpedicular screws and postoperative physiotherapy, or cognitive intervention and exercises. At the 1-year follow-up (97%), the ODI was significantly reduced in both groups but the group difference did not achieve statistical significance. Improvements in back pain, use of analgesics, emotional distress, life satisfaction, and return to work were not different. Fear-avoidance beliefs and fingertip-floor distance were reduced more after non-operative treatment, and lower limb pain was reduced more after surgery. The success rate was not significantly different between the two groups based on an independent observer assessment (i.e. 70% after surgery and 76% after cognitive intervention and exercises).

**Fairbank J, Frost H, Wilson-MacDonald J, Yu LM, Barker K, Collins R (2005) Randomised controlled trial to compare surgical stabilisation of the lumbar spine with an intensive rehabilitation programme for patients with chronic low back pain: the MRC spine stabilisation trial. BMJ 330:1233**
This RCT compared the clinical effectiveness of surgical stabilization (spinal fusion) with intensive rehabilitation program (including cognitive behavioral treatment) for patients with chronic low-back pain. In this UK multicenter randomized controlled trial, 349 patients aged 18–55 years with chronic low-back pain (>1 year) were randomized into a surgical group ($n=176$) and a rehabilitation group ($n=173$) and followed for 2 years (81%). The mean ODI changed favorably in both groups but with a slight but significant advantage for the surgical group. No significant differences between the treatment groups were observed in any of the other outcome measures. The authors concluded that the statistical difference between treatment groups in one of the two primary outcome measures was marginal and only just reached the predefined minimal clinical difference. No clear evidence emerged that primary spinal fusion surgery was any more beneficial than intensive rehabilitation.

**Christensen FB, Hansen ES, Eiskjaer SP, Hoy K, Helmig P, Neumann P, Niedermann B, Bunger CE (2002) Circumferential lumbar spinal fusion with Brantigan cage versus posterolateral fusion with titanium Cotrel-Dubousset instrumentation: a prospective, randomized clinical study of 146 patients. Spine 27:2674–83**

**Videbaek TS, Christensen FB, Soegaard R, Hansen ES, Hoy K, Helmig P, Niedermann B, Eiskjoer SP, Bunger CE (2006) Circumferential fusion improves outcome in comparison with instrumented posterolateral fusion: long-term results of a randomized clinical trial. Spine 31:2875–80**
This prospective randomized clinical study compared instrumented circumferential fusion (cage based ALIF and pedicle screw fixation) with instrumented posterolateral lumbar fusion. Both groups showed highly significant improvement in all four categories of life quality as well as in the back pain and leg pain index, as compared with preoperative status. There was a clear tendency toward better overall functional outcome for patients with the circumferential procedure, and this patient group also showed significantly less leg pain at the 1-year follow-up evaluation and less peak back pain at 2 years. The circumferential fusion patients showed a significantly higher posterolateral fusion rate (92%) than the posterolateral group (80%). The repeat operation rate including implant removal was significantly lower in the circumferential group (7%) than in the posterolateral group (22%). The superior result of the circumferential fusion group was preserved during a 5–9 years follow-up.

**Blumenthal S, McAfee PC, Guyer RD, Hochschuler SH, Geisler FH, Holt RT, Garcia R, Jr, Regan JJ, Ohnmeiss DD (2005) A prospective, randomized, multicenter Food and Drug**

**Administration investigational device exemptions study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: part I: evaluation of clinical outcomes. Spine 30:1565–75**

**McAfee PC, Cunningham B, Holsapple G, Adams K, Blumenthal S, Guyer RD, Dmietriev A, Maxwell JH, Regan JJ, Isaza J (2005) A prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: part II: evaluation of radiographic outcomes and correlation of surgical technique accuracy with clinical outcomes. Spine 30:1576–83**
Three hundred and four patients were enrolled in the study at 14 US centers, randomized in a 2:1 ratio (TDA vs. fusion) and followed for 24 months. Patients in both groups improved significantly following surgery. Patients in the Charité group had lower levels of disability at every time interval from 6 weeks to 24 months, compared with the control group, with statistically lower pain and disability scores at all but the 24-month follow-up. At the 24-month follow-up, a significantly greater percentage of patients in the Charité group expressed satisfaction with their treatment and would have had the same treatment again, compared with the fusion group. The hospital stay was significantly shorter in the Charité artificial disc group. The complication rate was similar between both groups. Preoperative range of motion in flexion/extension was restored and maintained in patients receiving a TDA. Clinical outcomes and flexion/extension ROM correlated with surgical technical accuracy of Charité artificial disc placement.

**Zigler J, Delamarter R, Spivak JM, Linovitz RJ, Danielson GO, 3rd, Haider TT, Cammisa F, Zuchermann J, Balderston R, Kitchel S, Foley K, Watkins R, Bradford D, Yue J, Yuan H, Herkowitz H, Geiger D, Bendo J, Peppers T, Sachs B, Girardi F, Kropf M, Goldstein J (2007) Results of the prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of the ProDisc-L total disc replacement versus circumferential fusion for the treatment of 1-level degenerative disc disease. Spine 32:1155–62**
Two hundred and eighty-six patients were included in the trial and followed for 24 months. The safety of ProDisc-L implantation was demonstrated with 0 % major complications. At 24 months, 91.8 % of investigational and 84.5 % of control patients reported improvement in the Oswestry Disability Index (ODI) from preoperative levels, and 77.2 % of investigational and 64.8 % of control patients met the improvement target of more than 15 % (ODI). At the 6 weeks and 3 months follow-up time points, the ProDisc-L patients recorded SF-36 Health Survey scores significantly higher than the control group. The visual analog scale pain assessment showed statistically significant improvement from preoperative levels regardless of treatment. Visual analog scale patient satisfaction at 24 months showed a statistically significant difference favoring investigational patients over the control group. Radiographic range of motion was maintained within a normal functional range in 93.7 % of investigational patients and averaged 7.7 degrees. From this trial it was concluded that ProDisc-L implantation is safe, efficacious and in properly chosen patients superior to circumferential fusion.

**Gibson JN, Grant IC, Waddell G (1999) The Cochrane review of surgery for lumbar disc prolapse and degenerative lumbar spondylosis. Spine 24:1820–32**

**Gibson JN, Waddell G (2005) Surgery for degenerative lumbar spondylosis: updated Cochrane Review. Spine 30:2312–20**
A must read evidence-based analysis of RCTs for degenerative lumbar spondylosis.

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