# Spinal Disorders

Fundamentals of Diagnosis and Treatment

Bearbeitet von
Norbert Boos, Max Aebi

1. Auflage 2008. Buch. lxvi, 1165 S. Hardcover
ISBN 978 3 540 40511 5
Format (B x L): 20,3 x 27,6 cm

# 31 Thoracolumbar Spinal Injuries

Michael Heinzelmann, Guido A. Wanner

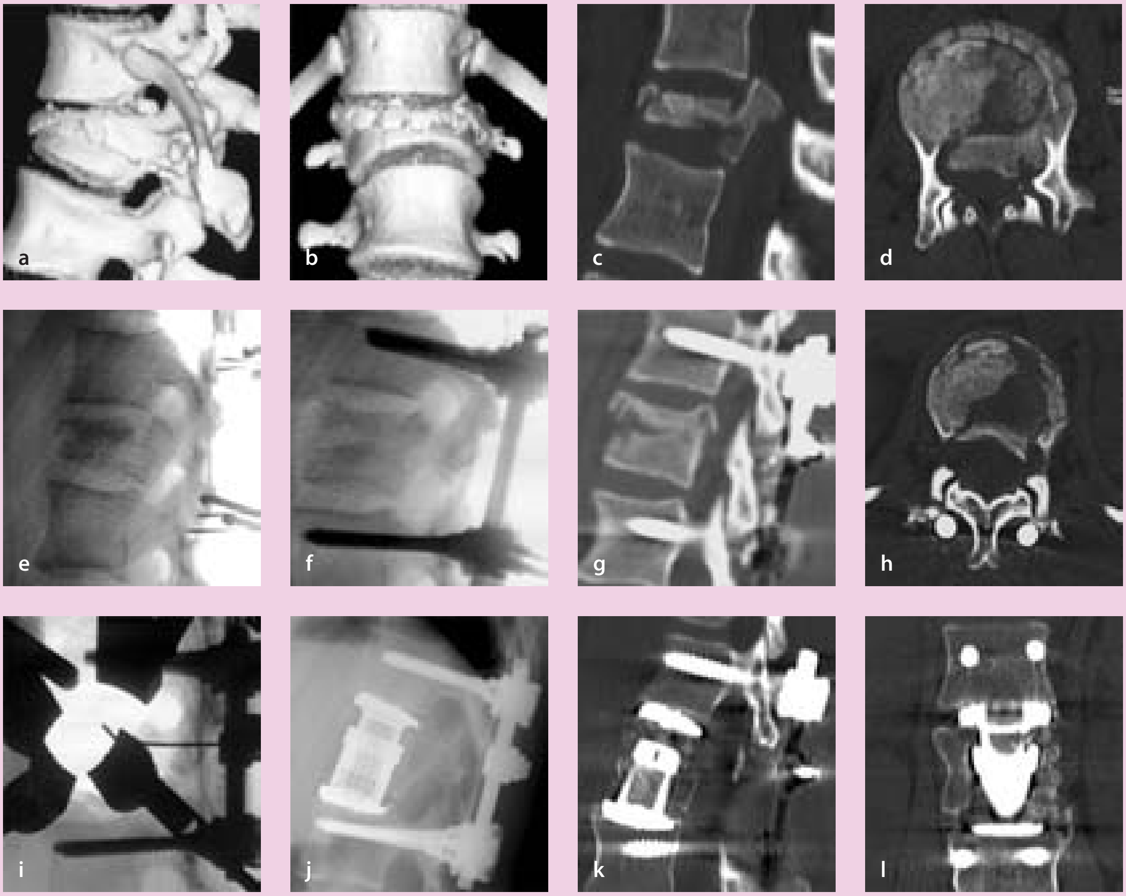
## Core Messages

- ✔ Spinal fractures are frequently located at the thoracolumbar junction for biomechanical reasons
- ✔ The AO classification has gained widespread acceptance in Europe for the grading of thoracolumbar fractures: Type A: vertebral compression fractures; Type B: anterior and posterior column injuries with distraction; Type C: anterior and posterior element injury with rotation
- ✔ The initial focus of the physical examination of a patient with a spinal injury is on the vital and neurological functions, because effective resuscitation is critical to the management of polytraumatized patients and patients with spinal cord injury
- ✔ The imaging modalities of choice are standard radiographs and CT scans. A CT scan should routinely be made to visualize bony injury. MRI is helpful to diagnose discoligamentous injuries and to identify a possible cord lesion
- ✔ Primary goals of treatment are prevention and limitation of neurological injury as well as restoration of spinal stability, regardless of whether operative or non-operative therapy is chosen
- ✔ Secondary goals consist of correction of deformities, minimizing the loss of motion, and facilitating rapid rehabilitation
- ✔ Early stabilization and fusion is generally accepted for patients with unstable fractures and neurological deficits
- ✔ The optimal treatment for patients with less instability, moderate deformity and absence of neurological compromise is not based on scientific evidence and remains a matter of debate.
- ✔ Good clinical outcome can be achieved with non-operative as well as operative treatment

## Epidemiology

Systematic epidemiologic data on traumatic thoracolumbar fractures are rare and differ depending on the area studied and on the treating center. The studies available from western countries reveal typical and comparable data on incidence, localization, and mechanisms of injury. Thoracolumbar fractures are more frequent in men (2/3) than in women (1/3) and peak between the ages of 20 and 40 years [30, 47, 65, 81, 94]. Approximately, 160 000 patients/year sustain an injury of the spinal column in the United States. The majority of these injuries comprise cervical and lumbar (L3–L5) spine fractures. However, between 15 % and 20 % of traumatic fractures occur at the thoracolumbar junction (T11–L2), whereas 9 – 16 % occur in the thoracic spine (T1–T10) [36, 46]. Hu and coworkers [56] studied the total population of a Canadian province over a period of 3 years. The incidence of spine injuries was 64/100 000 inhabitants per year, predominantly younger men and older women. A total of 2 063 patients were registered and 944 patients were treated in hospital: 182 patients (20 %) with a cervical spine injury, 286 patients (30 %) with a thoracic spine injury and 403 patients (50 %) with an injury of the lumbosacral spine. Traumatic cross-section spinal cord injury occurred in 40 out of 1 million inhabitants. About

Fractures most frequently affect the thoracolumbar junction




**Case Introduction**

This 23-year-old female sustained a motor vehicle accident as an unrestrained passenger. Clinically, she presented with an incomplete paraplegia (ASIA C) and an incomplete conus-cauda syndrome. The initial CT (**a–d**) scan demonstrates an unstable complete burst fracture of L1 (Type A3.3). The 3D reconstruction (**a, b**) gives a good overview of the degree of comminution and the deformity; the posterior fragment is best visualized in the lateral 2D reconstruction (**c**) and the axial view (**d**). In an emergency procedure, the myelon was decompressed by laminectomy and the fracture was reduced and stabilized with an internal fixator (**e–h**). Interestingly, the prone position alone (**e**) reduced the fracture to a certain degree when compared to the CT scan taken with the patient in a supine position. With the internal fixator (RecoFix), the anatomical height and physiological alignment was restored (**f**) and the posterior fragment was partially reduced (**g, h**). This indirect reduction of bony fragments, called ligamentotaxis, is possible if the posterior ligaments and the attachment to the anulus fibrosus are intact. We performed a complete clearance of the spinal canal by an anterior approach 5 days later (**i–l**). In this minimally invasive technique, the spine is approached by a small thoracotomy from the left, the ruptured disc and bony fragments are removed, and an expandable cage is inserted. One of the first steps in this technique is the positioning of a K-wire in the upper disc space of the fractured vertebra (**i**). In this figure, the four retractors of the Synframe and the endoscopic light source are seen. The final result after 9 months (**j–l**) demonstrates the cage (Synex), the physiological alignment without signs of implant failure or kyphosis, a good clearance of the spinal canal from anterior and the laminectomy from posterior (**k**), and a bony healing of the local bone transplant of the lateral side of the cage (**l**). Fortunately, the patient completely recovered from her neurological deficit (ASIA E).

50–60% of thoracolumbar fractures affect the transition T11–L2, 25–40% the thoracic spine and 10–14% the lower lumbar spine and sacrum [80, 86].

In a study by Magerl and Engelhardt [81] on 1 446 thoracolumbar fractures, most injuries concerned the first lumbar vertebra, i.e., 28% ($n=402$), followed by T12 (17%, $n=246$) and L2 (14%, $n=208$). The epidemiologic multicenter study on fractures of the thoracolumbar transition (T10–L2) by the German Trauma Society studied 682 patients and revealed 50% ($n=336$) L1 fractures, 25%

($n=170$) T12 fractures, and 21 % ($n=141$) L2 fractures [65]. Our own series at the University Hospital in Zürich demonstrated a very similar distribution for operated spine fractures (1992 – 2004, $n=1744$): 20 % cervical spine ($n=350$), 8 % thoracic spine T1–T10 ($n=142$), 62 % thoracolumbar spine T11–L2 ($n=1075$), and 10 % lumbosacral spine L3-sacrum ($n=176$). The **susceptibility of the thoracolumbar transition** is attributed mainly to the following anatomical reasons:

- The transition from a relatively rigid thoracic kyphosis to a more mobile lumbar lordosis occurs at T11 – 12.
- The lowest thoracic ribs (T11 and T12) provide less stability at the thoracolumbar junction region compared to the rostral thoracic region, because they do not connect to the sternum and are free floating.
- The facet joints of the thoracic region are oriented in the coronal (frontal) plane, limiting flexion and extension while providing substantial resistance to anteroposterior translation [36]. In the lumbosacral region, the facet joints are oriented in a more sagittal alignment, which increases the degree of potential flexion and extension at the expense of limiting lateral bending and rotation.

Spinal cord injury occurs in about 10 – 30 % of traumatic fractures

**Spinal cord injury** occurs in about 10 – 30 % of traumatic spinal fractures [37, 56]. In thoracolumbar spine fractures (T1–L5), Magerl et al. [81] and Gertzbein [47] reported 22 % and 35.8 % neurological deficiencies, respectively. The epidemiologic multicenter study on fractures of the thoracolumbar transition (T10–L2) by the German Society of Traumatology [65] revealed neurological deficiencies in 22 – 51 %, depending on the fracture type (22 % in Type A fractures, 28 % in Type B fractures, and 51 % in Type C fractures, according to the AO classification). Complete paraplegia was found in 5 % of the patients with fractures of the thoracolumbar transition.

## Pathomechanisms

At the time of injury, several forces may act together to produce structural damage to the spine. However, most frequently, one or two major forces, defining the major injury vector, account for most of the bony and ligamentous damage. The **most relevant forces** are:

- axial compression
- flexion/distraction
- hyperextension
- rotation
- shear

### Axial Compression

Axial load may result in a burst fracture

While axial loading of the body results in anterior flexion forces in the kyphotic thoracic spine, mainly compressive forces occur in the straight thoracolumbar region [64]. Axial loading of a vertebra produces endplate failure followed by vertebral body compression [98]. Depending on the energy, the axial load may result in incomplete or complete **burst fractures**, i.e., vertical fractures with centripetal displacement of the fragments [12, 33]. The posterior elements are usually intact; however, with severe compression, significant disruption of these elements may occur. The combination of an axially directed central compressive force with an eccentric compressive force anterior to the axis of rotation (center of nucleus pulposus) typically leads to **wedge compression fractures**. Herein, the vertebral body fails in (wedge) compression, while the posterior ligamentous and osseous elements may remain intact or fail in tension, depending on the energy level of the injury. In the latter case, the injury is classified as flexion-distraction injury. Violent trauma is the most common cause of compression fractures in young and middle-aged adults. The most frequent causes are motor vehicle accidents and falls from a height, followed by sports and recreational activity injuries. In the elderly population, osteoporotic compression fractures following low-energy trauma are most common.

## Flexion/Distraction

Flexion forces cause eccentric compression of the vertebral bodies and discs and cause tension to the posterior elements. If the anterior wedging exceeds 40 – 50 %, **rupture** of the **posterior ligaments** and **facet joint capsules** must be assumed [117]. In flexion/distraction injuries, the axis of flexion is moved anteriorly (towards the anterior abdominal wall), and the entire vertebral column is subjected to large tensile forces. These forces can produce:

- pure osseous lesion
- mixed osteoligamentous lesion
- pure soft tissue (ligamentous or disc) lesion

In flexion/distraction injuries, the posterior ligamentous and osseous elements fail in tension

Distraction leads to a **horizontal disrupture** of the anterior and/or posterior elements. A distraction fracture that extends through the bone was first described by **Chance** [22]. This lesion involves a horizontal fracture, which begins in the spinous process, progresses through the lamina, transverse processes, and pedicles, and extends into the vertebral body. Depending on the axis of flexion the vertebral body and disc may rupture or may be compressed anteriorly as described above. Although any accident providing significant forward flexion combined with distraction can produce this type of injury, the typical cause is a motor vehicle accident with the victim wearing a lap seat belt. These injuries are associated with a high rate of hollow visceral organ lesions, typically of the small bowel, colon or stomach, but also pancreatic injuries have been reported [3, 13].

## Hyperextension

Hyperextension may result in anterior discoligamentous disruption and posterior compression fractures of facets, laminae, or spinous processes

Extension forces occur when the upper part of the trunk is thrust posteriorly. This produces an injury pattern that is the reverse of that seen with flexion. Tension is applied anteriorly to the strong anterior longitudinal ligaments and anterior portion of the anulus fibrosus, whereas compression forces are transmitted to the posterior elements. This mechanism results in a rupture from anterior to posterior and may result in facet, lamina, and spinous process fractures [43]. Denis and Burks reported on a hyperextension injury pattern that they termed **lumberjack fracture-dislocation** [32]. The mechanism of this injury is a falling mass, often timber, striking the midportion of the patient's back. The injury involves complete disruption of the anterior ligaments and is an extremely unstable injury pattern. These injuries are the result of a reversed trauma mechanism. The intervertebral disc ruptures from anterior to posterior. The lesion may proceed into the posterior column and is then unstable against extension and shearing forces.

## Rotational Injuries

Rotational injuries combine compressive forces and flexion/distraction mechanisms and are highly unstable

Both compressive forces and flexion-distraction mechanisms may be combined with rotational forces and lead to **rotational fracture dislocations**. As rotational forces increase, ligaments and facet capsules fail and lead to subsequent disruption of both the anterior and posterior elements. A highly unstable injury pattern will develop, i.e., the posterior ligaments and joint capsule will rupture and the anterior disc and vertebral body will disrupt obliquely or will be compressed. Rotational forces may further be combined with shearing forces and lead to most unstable fractures (slice fractures, Holdsworth) [54]. These patients have often been thrown against an obstacle or hit by a heavy device. Thus, the patients often have widespread dermabrasions and contusions on the back.

### Shear

Shear forces produce severe ligamentous disruption and may result in anterior, posterior or lateral vertebral displacement [98]. The most frequent type is traumatic anterior spondylolisthesis that usually results in a complete spinal cord injury.

Shear forces produce severe ligamentous disruption and are often associated with spinal cord injury

## Classification

Vertebral spine injuries are very heterogeneous in nature. Most important for the understanding and treatment of these injuries is the evaluation of spinal **stability** or **instability**, respectively. However, the conclusive evaluation of this question is difficult because the term "**instability**" is not yet clearly defined in the context of spinal disorders.

Several classifications of spinal injuries have been introduced based primarily on fracture morphology and different stability concepts. White and Panjabi [118] defined clinical instability of the spine as shown in Table 1:

**Table 1.** Definition of spinal instability

| |
|---|
| • Loss of the ability of the spine under physiologic loads to maintain relationships between vertebrae in such a way that there is neither damage nor subsequent irritation to the spinal cord or nerve root and, in addition, there is no development of incapacitating deformity or pain from structural changes |

Physiologic loads are defined as loads during normal activity, incapacitating deformity as gross deformity unacceptable to the patient, and incapacitating pain as discomfort uncontrolled by non-narcotic analgesics.

Presently, there is no generally used classification for thoracolumbar injuries. However, the **most important classification** of spinal injuries aims to differentiate between:

- stable fractures
- unstable fractures

This concept was first introduced by Nicoll in 1949 [89] and is still the most widely accepted differentiation. However, this classification is insufficient to give detailed treatment recommendations.

Holdsworth [54] was the first to stress the mechanism of injury to classify spinal injuries and described five different injury types. Kelly and Whitesides [61, 119] reorganized the mechanistic classification and defined the two column concept, which became the basis of the AO classification (see below). Louis further modified this structural classification scheme and suggested the posterior facet joint complex of each side to become a separate column [79]. The ventral column consists of the vertebral body; the two dorsal columns involve the facet articulations of both sides. Roy-Camille was concerned about the relationship of the injury to vertebra, especially the neural ring, and the spinal cord. He described the "*segment moyen*," referring to the neural ring, and related injury of the *segment moyen* to instability [99]. This aspect led to the term of the so-called "middle column," which is not a distinct anatomic column.

## Denis Classification

The middle column became a central part of the classification of spinal injuries according to Denis [30], which is in widespread use in the United States. Accordingly, the vertebral column is divided into **three columns** [30]:

- anterior column
- middle column
- posterior column

The **anterior column** consists of the ventral longitudinal ligament (VLL), the anterior anulus fibrosus, and the anterior half of the vertebral bodies. The **middle column** consists of the posterior longitudinal ligament (PLL), the dorsal anulus fibrosus, and the dorsal half of the vertebral bodies. Finally, the **posterior column** consists of the bony neural arch, posterior spinous ligaments and ligamentum flavum, as well as the facet joints.

The Denis classification does not allow for a detailed fracture classification

Denis considered the **middle column** to be the **key structure**. A relevant injury to the middle column was therefore the essential criterion for instability. According to the Denis classification, rupture of the posterior ligamentous complex only creates instability if there is concomitant disruption of at least the PLL and dorsal anulus. However, the middle column is not clearly defined either anatomically or biomechanically, i.e., the middle column bony part resists compression forces, and the ligamentous part resists distraction forces. Although the three column concept by Denis raised several concerns, his classification is still frequently used, because it is simple and includes all the injury patterns most commonly seen. Denis distinguished minor and major injuries: minor injuries included fractures of the articular, transverse, and spinous processes as well as the pars interarticularis. Major spinal injuries were divided into compression fractures, burst fractures, flexion-distraction (seat-belt) injuries, and fracture dislocations.

## AO Classification

The AO/ASIF (Arbeitsgemeinschaft für Osteosynthesefragen/Association for the Study of Internal Fixation) classification introduced by Magerl et al. in 1994 [80] is increasingly being accepted as the gold standard for documentation and treatment of injuries of the vertebral spine.

The AO classification is based on the "**two column theory**" described by Holdsworth [54, 55] and Kelly and Whitesides [61, 119]. The AO classification considers the spine to comprise two functionally separate supportive columns. The **anterior column** consists of the vertebral body and the intervertebral discs and is loaded in compression. The **posterior column** consists of the pedicles, the laminae, the facet joints, and the posterior ligamentous complex, and is loaded in tension. According to the common AO classification system, injuries are categorized with increasing severity into types (Fig. 1):

- Type A: compression injuries
- Type B: distraction injuries
- Type C: rotational injuries

**Type A** injuries are the result of compression by axial loading (e.g., compression and burst fractures). **Type B** injuries are flexion-distraction or hyperextension injuries and involve the anterior and posterior column. Disruption may occur in the posterior or anterior structures. **Type C** fractures are the result of a compression or flexion/distraction force in combination with a rotational force in the horizontal plane (e.g., fracture dislocations with a rotatory component). Each type is classified into **three major groups (1 – 3)** of increasing severity (Fig. 2) and can further be divided into subgroups and specifications (Table 2).

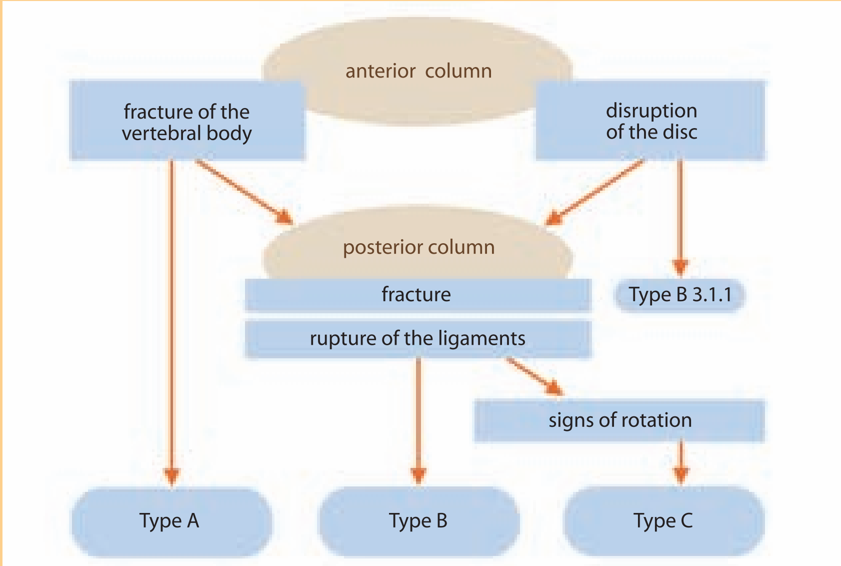



**Figure 1. Algorithm for AO fracture type classification**

According to Magerl et al. [80].

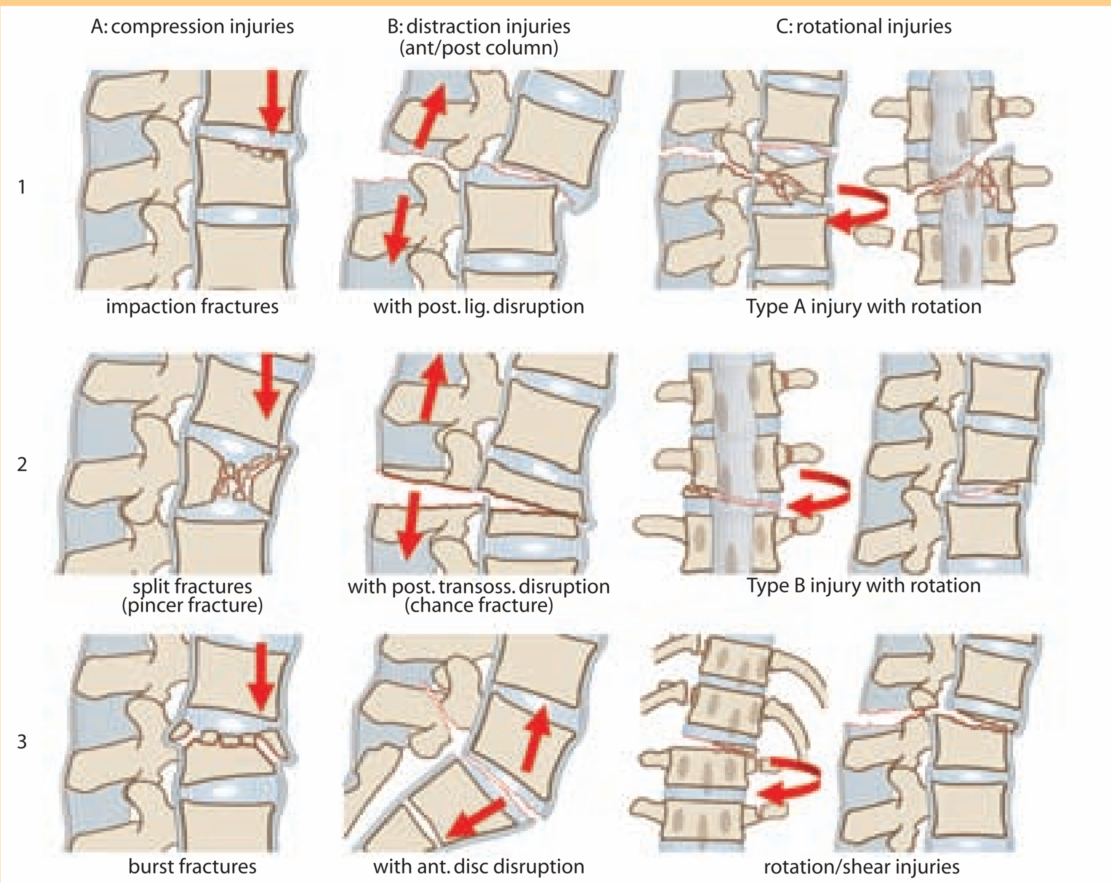



**Figure 2. AO fracture classification – fracture types and groups**

According to Magerl et al. [80].

**Table 2.** AO fracture classification

| Type A: vertebral body compression | Type B: anterior and posterior element injury with distraction | Type C: anterior and posterior element injury with rotation |
|---|---|---|
| A1. Impaction fractures<br>A1.1. Endplate impaction<br>A1.2. Wedge impaction fractures<br>A1.2.1. Superior wedge impaction fracture<br>A1.2.2. Lateral wedge impaction fracture<br>A1.2.3. Inferior wedge impaction fracture | B1. Posterior disruption predominantly ligamentous (flexion-distraction injury)<br>B1.1. With transverse disruption of the disc<br>B1.1.1. Flexion-subluxation<br>B1.1.2. Anterior dislocation<br>B1.1.3. Flexion-subluxation/anterior dislocation with fracture of the articular processes<br>B1.2. With Type A fracture of the vertebral body<br>B1.2.1. Flexion-subluxation + Type A fracture<br>B1.2.2. Anterior dislocation + Type A fracture<br>B1.2.3. Flexion-subluxation/anterior dislocation with fracture of the articular processes + Type A fracture | C1. Type A injuries with rotation (compression injuries with rotation)<br>C1.1. Rotational wedge fracture<br>C1.2. Rotational split fractures<br>C1.2.1. Rotational sagittal split fracture<br>C1.2.2. Rotational coronal split fracture<br>C1.2.3. Rotational pincer fracture<br>C1.2.4. Vertebral body separation<br>C1.3. Rotational burst fractures<br>C1.3.1. Incomplete rotational burst fractures<br>C1.3.2. Rotational burst-split fracture<br>C1.3.3. Complete rotational burst fracture |
| A2. Split fractures<br>A2.1. Sagittal split fracture<br>A2.2. Coronal split fracture<br>A2.3. Pincer fracture | B2. Posterior disruption predominantly osseous (flexion-distraction injury)<br>B2.1. Transverse bicolumn fracture<br>B2.2. With transverse disruption of the disc<br>B2.2.1. Disruption through the pedicle and disc<br>B2.2.2. Disruption through the pars interarticularis and disc (flexion-spondylolysis)<br>B2.3. With Type A fracture of the vertebral body<br>B2.3.1. Fracture through the pedicle + Type A fracture<br>B2.3.2. Fracture through the pars interarticularis (flexion-spondylolysis) + Type A fracture | C2. Type B injuries with rotation<br>C2.1. B1 injuries with rotation (flexion-distraction injuries with rotation)<br>C2.1.1. Rotational flexion subluxation<br>C2.1.2. Rotational flexion subluxation with unilateral articular process fracture<br>C2.1.3. Unilateral dislocation<br>C2.1.4. Rotational anterior dislocation without/with fracture of articular processes<br>C2.1.5. Rotational flexion subluxation without/with unilateral articular process + Type A fracture<br>C2.1.6. Unilateral dislocation + Type A fracture<br>C2.1.7. Rotational anterior dislocation without/with fracture of articular processes + Type A fracture<br>C2.2. B2 injuries with rotation (flexion distraction injuries with rotation)<br>C2.2.1. Rotational transverse bicolumn fracture<br>C2.2.2. Unilateral flexion spondylolysis with disruption of the disc<br>C2.2.3. Unilateral flexion spondylolysis + Type A fracture<br>C2.3. B3 injuries with rotation (hyperextension-shear injuries with rotation)<br>C2.3.1. Rotational hyperextension-subluxation without/with fracture of posterior vertebral elements<br>C2.3.2. Unilateral hyperextension-spondylolysis<br>C2.3.3. Posterior dislocation with rotation |
| A3. Burst fractures<br>A3.1. Incomplete burst fracture<br>A3.1.1. Superior incomplete burst fracture<br>A3.1.2. Lateral incomplete burst fracture<br>A3.1.3. Inferior incomplete burst fracture<br>A3.2. Burst-split fracture<br>A3.2.1. Superior burst-split fracture<br>A3.2.2. Lateral burst-split fracture<br>A3.2.3. Inferior burst-split fracture<br>A3.3. Complete burst fracture<br>A3.3.1. Pincer burst fracture<br>A3.3.2. Complete flexion burst fracture<br>A3.3.3. Complete axial burst fracture | B3. Anterior disruption through the disc (hyperextension-shear injury)<br>B3.1. Hyperextension-subluxations<br>B3.1.1. Without injury of the posterior column<br>B3.1.2. With injury of the posterior column<br>B3.2. Hyperextension-spondylolysis<br>B3.3. Posterior dislocation | C3. Rotational-shear injuries<br>C3.1. Slice fracture<br>C3.2. Oblique fracture |

Types, groups, subgroups and specifications allow for a morphology based classification of thoracolumbar fractures according to Magerl et al. [80]

**Table 3.** Frequency of fracture types and groups

| | Case | Percentage of total | Percentage of type |
|---|---|---|---|
| **Type A** | **956** | **66.16** | |
| A1 | 502 | 34.74 | 52.51 |
| A2 | 50 | 3.46 | 5.23 |
| A3 | 404 | 27.96 | 42.26 |
| **Type B** | **209** | **14.46** | |
| B1 | 126 | 8.72 | 60.29 |
| B2 | 80 | 5.54 | 38.28 |
| B3 | 3 | 0.21 | 1.44 |
| **Type C** | **280** | **19.38** | |
| C1 | 156 | 10.80 | 55.71 |
| C2 | 108 | 7.47 | 38.57 |
| C3 | 16 | 1.11 | 5.71 |

Based on an analysis of 1 445 cases (Magerl et al. [80])

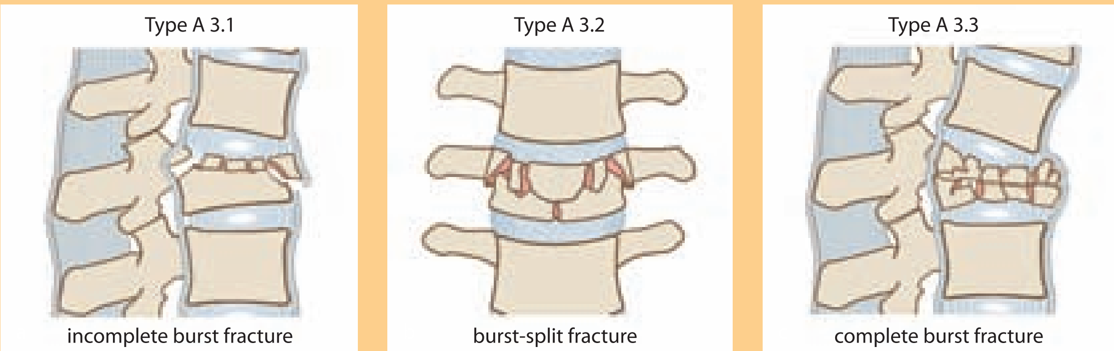



**Figure 3. Burst fracture subgroups**

According to Magerl et al. [80].

Impaction and burst fracture are the most frequent fracture types

Second to **simple impaction fractures** (A1), the most frequent injury types are burst fractures, which can be divided into **three major subgroups** (Table 3, Fig. 3). The likelihood of neurological deficit increases in the higher subgroups (Table 4).

The important morphological criteria of instability according to the AO classification are injuries to the ligaments and discs. A graded classification is useful because there is a range from "definitely stable" to "definitely unstable" fractures.

Fractures are considered **stable** if no injury to ligaments or discs is evident, e.g., pure impaction fractures (Type A1). Structural changes of the spine under physiologic loads are unlikely. **Slightly unstable fractures** reveal partial damage of ligaments and intervertebral discs, but heal under functional treatment without gross deformity and without additional neurological deficit. This is the case in a frequent type (A3), the so-called incomplete superior burst fracture (A3.1.1). **Highly unstable** implicates a severe damage of the ligaments and intervertebral discs, as it occurs in the fracture Types A3, B, and C.

**Table 4.** Frequency of neurological deficits

| Types and groups | Number of injuries | Neurological deficit (%) |
|---|---|---|
| **Type A** | **890** | **14** |
| A1 | 501 | 2 |
| A2 | 45 | 4 |
| A3 | 344 | 32 |
| **Type B** | **145** | **32** |
| B1 | 61 | 30 |
| B2 | 82 | 33 |
| B3 | 2 | 50 |
| **Type C** | **177** | **55** |
| C1 | 99 | 53 |
| C2 | 62 | 60 |
| C3 | 16 | 50 |
| **Total** | **1 212** | **22** |

Based on an analysis of 1 212 cases (Magerl et al. [80])

## Clinical Presentation

The clinical assessment of patients with a putative trauma to the spine has **three major objectives**, i.e., to identify:

- the spinal injury
- neurological deficits
- concomitant non-spinal injuries

### Spinal Injuries

About 30% of polytraumatized patients have a spinal injury

It is obvious that the management and the priorities differ between a life-threatening polytrauma that includes a spinal injury and a monotrauma of the spine. In the case of a polytrauma, about one-fourth to one-third of patients have a spinal injury [120]. In our institution, we found spinal injuries in 22% of polytraumatized patients. In a series of 147 consecutive patients with multiple trauma, Dai et al. [24] found a delayed diagnosis of thoracolumbar fractures in 19%, confirming an earlier study by Anderson et al. [5], in which 23% of patients with major thoracolumbar fractures were diagnosed after the patient had left the emergency department. A delay in the diagnosis of thoracolumbar fractures is frequently associated with an unstable patient condition that necessitates higher-priority procedures than thoracolumbar spine radiographs in the emergency department. However, with the routine use of multi-slice computed tomography (CT) in polytraumatized patients, the diagnostic work-up is usually adequate [57, 106] and delayed diagnosis of spine fractures should become rare. Multiple burst fractures occur in approximately 10–34% [10, 11, 53].

Polytraumatized patients should be screened for spinal fracture by CT

### Neurological Deficit

Sacral sparing indicates an incomplete lesion with a better prognosis

An accurate and well-documented neurological examination is of great importance. With an inaccurate or incomplete examination and a subsequent variation of the patient's neurological deficit, it will be unclear if the situation has changed or if the initial assessment was simply inappropriate. In the case of a progressive neurological deficit, this may hinder urgent further management, i.e., the need for a surgical intervention with spinal decompression. Neurological assessment is usually done according to the guidelines of the **American Spinal Injury Association** (see Chapter 11). Importantly, the examination has to include the "search for a sacral sparing" which will determine the completeness of the deficit and the prognosis.

## Concomitant Non-spinal Injuries

About one-third of all spine injuries have concomitant injuries [65, 100, 120]. In a review of 508 consecutive hospital admissions of patients with spinal injuries, Saboe et al. [100] identified the presence of associated injuries in 240 (47%) individuals. Most frequently found **concomitant injuries** were:

- head injuries (26%)
- chest injuries (24%)
- long bone injuries (23%)

About one-third of all spinal injuries have concomitant injuries

One associated injury was found in 22%, two injuries in 15%, and 10% of the patients had three or more associated injuries. Most spine fractures involved the lower cervical spine (29%) or the thoracolumbar junction (21%). Eighty-two percent of thoracic fractures and 72% of lumbar fractures had associated injuries compared to 28% of lower cervical spine fractures [100]. There is an association between flexion injuries of the lumbar spine (**Chance type**) and **abdominal injuries in seat belt injuries**. Anderson et al. [2] reviewed 20 cases of Chance-type thoracolumbar flexion-distraction fractures and found that 13 patients (65%) had associated life-threatening intra-abdominal trauma. Twelve of these patients had bowel wall injury. Conversely, specific injury mechanisms and fracture patterns should lead to a targeted search for concomitant spinal injuries. It is well established that calcaneus or tibia plateau fractures following a fall from a great height are associated with spinal burst fractures. Also, sternal injuries may be associated with spinal fractures. Injury to the sternum, when due to indirect violence, is almost always associated with a severe spinal column injury [48].

Flexion injuries are frequently associated with abdominal injuries

## History

The history of a patient who sustained a thoracolumbar spinal injury is usually obvious. The **cardinal symptoms** are:

- pain
- loss of function (inability to move)
- sensorimotor deficit
- bowel and bladder dysfunction

The history should include a **detailed assessment of the injury**, i.e.:

History should include the trauma type and injury mechanism

- type of trauma (high vs. low energy)
- mechanism of injury (compression, flexion/distraction, hyperextension, rotation, shear injury)

Fractures of the thoracolumbar spine usually result from high-energy trauma such as traffic accidents and falls from a great height. Recreational activities frequently associated with spinal injuries are skiing, snowboarding, paragliding or horseriding. A spinal fracture should be suspected in any patient who has had a high-energy trauma. Consequently, patients should be treated as if they have a spinal injury unless proven otherwise [97]. On the contrary, vertebral compression fractures can also occur in less severe accidents or more or less spontaneously in elderly patients with osteoporotic bones (see Chapter 32) [63].

In patients with **neurological deficits**, the history must be detailed regarding:

- time of onset
- course (unchanged, progressive, or improving)

The time course of the neurological deficit matters

As outlined in Chapter 30, polytraumatized and unconscious (head-injured) patients are difficult to assess. Polytraumatized patients carry a high risk (up to

30%) of having suffered a spinal fracture and must be scrutinized for such an injury. Assessing the history is not possible in unconscious patients and the diagnosis must therefore be based on thorough imaging studies.

## Physical Findings

Similarly to the assessment of the patient with a cervical spine injury (see Chapter 30), the initial focus of the physical examination is on the **assessment** of:

- vital functions
- neurological deficits

Assess vital functions and neurological deficits

The goal is to immediately secure vital functions, which can be compromised in polytraumatized patients and patients with a spinal cord injury. Often hypotension and hypovolemia is encountered both in polytraumatized and spinal cord injured patients. Importantly, secondary deterioration of spinal cord function that results from hypotension and inadequate tissue oxygenization has to be avoided by timely and appropriate treatment.

Neurological deficits due to thoracolumbar fractures vary considerably

A thorough **neurological examination** is indispensable (see Chapter 11). The spinal cord usually terminates at the level of L1 in adults, although it may extend to L2 in some patients. Therefore, fractures at the thoracolumbar junction may result in a variety of neurological injury types and symptoms, i.e., damage to:

- distal spinal cord with complete/incomplete paraplegia
- conus medullaris with malfunction of the vegetative system
- cauda equina
- thoracolumbar nerve roots

Consider a spinal shock in patients with neurological deficits

In the case of a neurological deficit, the differentiation between a complete and incomplete paraplegia is of great importance for the prognosis, because approximately 60% of patients with an incomplete lesion have the potential to make a functionally relevant improvement. In thoracolumbar fractures, the clinical picture of a complete neurogenic shock will not develop, because only the caudal parts of the sympathetic system are possibly damaged. However, a **spinal shock** may be present (see Chapter 30). It is mandatory to exclude a spinal shock because spinal shock can disguise remaining neural function and has an impact on the treatment decision and timing.

Thoracolumbar factures may damage the parasympathic centers located in the conus medullaris. This injury will lead to bladder dysfunction, bowel dysfunction as well as sexual dysfunction. In the case of damage to the cauda equina or in a combination with damage to the conus medullaris, a more diffuse distribution of lower extremity paresthesia, weakness and loss of reflexes is found. Radiculopathy can be identified by a segmental pattern of sensory alterations that do not have to be combined with motor dysfunction. As outlined in the previous chapter, the neurological function must be precisely documented. The **ASIA protocol** [84] has become an assessment standard for this objective (see Chapter 11).

The **inspection and palpation** of the spine should include the search for:

- skin bruises, lacerations, ecchymoses
- open wounds
- swellings
- hematoma
- spinal (mal)alignment
- gaps

# Diagnostic Work-up

## Imaging Studies

The radiographic examination is an extension of the physical examination that confirms clinical suspicions and documents the presence and the extent of many injuries. Similarly to the "clearance of the cervical spine" [97], the clinical assessment is of great importance to evaluate the necessity of imaging studies. In the alert patient who has no distracting injuries, and is not affected by sedative drugs, alcohol, or neurological deficit, the requirement for imaging is guided by clinical symptoms. The absence of back pain and tenderness has been shown to exclude a thoracolumbar injury [101].

Modern imaging studies such as computed tomography (**CT**) and magnetic resonance imaging (**MRI**) have substantially improved the diagnosis of osseous and discoligamentous injuries after spinal trauma. Thus, changes such as improvement in scan availability, image quality, acquisition time, and image reformatting have changed commonly used algorithms [6]. However, plain films are still helpful, because they allow a quick overview of the bony deformity. Also, standard radiographs are important for analyzing long-term results and deformities at follow-up.

Static imaging studies may disguise the real extent of displacement at the time of impact

It is important to remember that any static imaging study is a "snapshot in time" that is taken **after** the major impact has hit the spine. Thus, even CT scans or MRI do not reveal the actual degree of spinal displacement that may have happened during the injury. Also, routine plain X-rays, CT and MRI studies are taken with the patient in a prone position, i.e., in a position that lacks physiological load, and may therefore lead to a misjudgement of the severity and instability of the spine injury.

### Standard Radiographs

Supine radiographs underestimate the kyphotic deformity

In most institutions, anterior-posterior and lateral radiographs of the entire spine are standard imaging studies after a spinal trauma. If there is a clinical suspicion of a spinal injury, plain radiographs (anterior-posterior and lateral view) should be obtained. Radiographs taken with the patient in the prone position underestimate the extent of kyphotic deformity. Films taken with the patient in the standing position can demonstrate a possible loss of integrity of the posterior tension band under axial loading and should be done in equivocal cases.

Emergency radiographs often do not suffice because of their poor quality

Krueger and coworkers [74] studied 28 patients with fractures of the lumbar transverse process and found that three patients (11%) had a lumbar spine fracture that was identified by CT but was overlooked on plain radiographs. They concluded that patients with acute trauma and fractures of the transverse process should be examined with CT, because CT scanning decreases the risk of missing potentially serious injuries. In a prospective series, Hauser et al. [52] compared plain films and initial CT of the chest, abdomen, and pelvis with thin cut CT scans. The authors found that all unstable fractures were diagnosed with plain radiographs. However, the initial CT detected acute fractures that were missed with the conventional X-rays and correctly classified old fractures that plain films read as "possibly" acute. The total misclassification rate for plain films was 12.6% compared to 1.4% for the initial CT. In an emergency situation radiographs are often of poor quality and CT is prompted if a fracture cannot be ruled out with certainty.

CT has replaced radiographs for the assessment of seriously injured patients

Measurements should be made at the level of injury and be compared with the vertebrae at the more cranial and caudal levels. Any posterior cortical disruption seen in the lateral view or any interpedicular widening seen in the anteroposterior view suggests a burst fracture that should be further analyzed by CT scan.

When analyzing plain films, the following signs and points have to be considered and searched for [13] in **the anteroposterior view**:

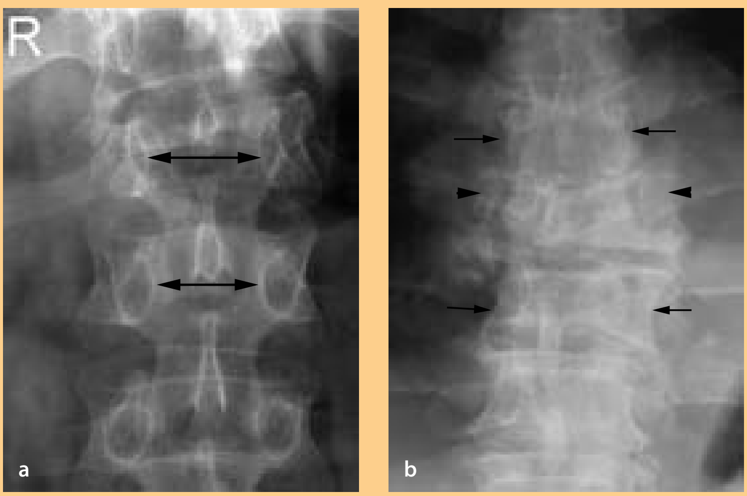
- loss of lateral vertebral body height (i.e., scoliotic deformity) (Fig. 4a)
- changes in horizontal and vertical interpedicular distance (Fig. 4a)
- asymmetry of the posterior structures (Fig. 4b)
- luxation of costotransverse articulations (Fig. 4b)
- perpendicular or oblique fractures of the dorsal elements
- irregular distance between the spinous processes (equivocal sign)

In the **lateral view**, the following features should be investigated:

- sagittal profile (Fig. 4c)
- degree of vertebral body compression (Fig. 4c)
- interruption or bulging of the posterior line of the vertebral body (Fig. 4d)
- dislocation of a dorsoapical fragment (Fig. 4d)
- height of the intervertebral space

### Computed Tomography

There is an increasing trend in trauma management, especially polytrauma management, to exclude visceral injuries with a multislice spiral CT scan of the chest, abdomen and pelvis [77]. In a systematic review of the literature in polytrauma patients, Woltmann and Bühren [120] advocate that imaging diagnostics, preferably as multislice spiral CT, should be performed after stabilization of the patient's general condition and before admission to the intensive care unit. Because CT has a better sensitivity and specificity compared to standard radiographs, Hauser et al. [52] point out that an initial CT scan should replace plain



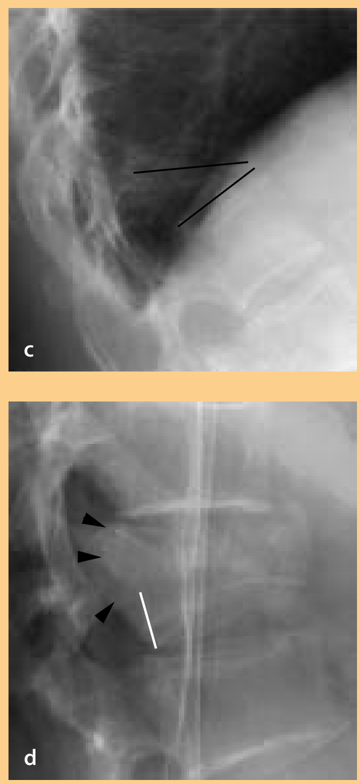




**Figure 4. Radiographic fracture assessment**

The standard anteroposterior radiographs demonstrate: **a** widening of the interpedicular distance as evidence for a burst fracture and unilateral loss of vertebral body height (scoliosis); **b** asymmetry of the spinal alignment (*arrows*) with luxation of the costotransverse articulations (*arrowheads*). Standard lateral radiographs demonstrate: **c** the altered sagittal profile with segmental kyphosis; **d** disruption of the posterior vertebral body wall and dislocation of a dorsoapical fragment

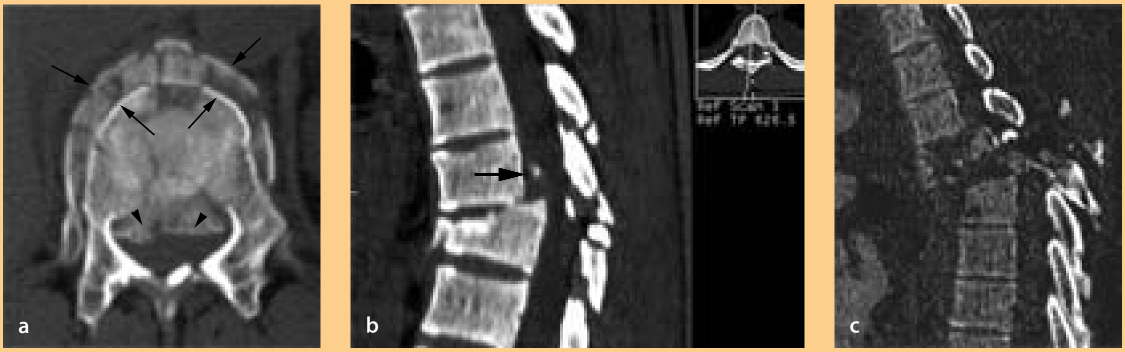




**Figure 5. CT fracture assessment**

The axial CT scan reveals: **a** significant spinal canal compromise by a retropulsed bony fragment. Note the double contour of the vertebral body indicating a "burst" component. **b** Sagittal 2D image reformation demonstrating fracture subluxation. Note the bony fragment behind the vertebral body which may cause neural compression when the fracture is reduced. **c** Severe luxation fracture of the spine. **d** The 3D CT reformation nicely demonstrates the rotation component indicating a Type C lesion

radiographs in high-risk trauma patients who require screening. In their prospective series of 222 patients with 63 thoracic and lumbar injuries, the results of conventional X-ray compared to initial CT scan were as follows: sensitivity 58 % vs. 97 %, specificity 93 % vs. 99 %, positive predictive value 64 % vs. 97 %, negative predictive value 92 % vs. 99 %, respectively.

CT is the imaging study of choice to demonstrate bony injuries

The axial view allows an accurate assessment of the comminution of the fracture and dislocation of fragments into the spinal canal (Fig. 5a). Sagittal and coronal 2D or 3D reconstructions are helpful for determining the fracture pattern (Fig. 5b–d). The canal at the injured segment should be measured in the anteroposterior and transverse planes and compared with the cephalad and caudal segments.

### Magnetic Resonance Imaging

MRI is helpful in ruling out discoligamentous lesions

In the presence of neurological deficits, MRI is recommended to identify a possible cord lesion or a cord compression that may be due to disc or fracture fragments or to an epidural hematoma (Fig. 6a). In the absence of neurological deficits, MRI of the thoracolumbar area is usually not necessary in the acute phase. However, MRI can be helpful in determining the integrity of the posterior ligamentous structures and thereby differentiate between a Type A and an unstable Type B lesion. For this purpose a fluid sensitive sequence (e.g., STIR) is frequently used to determine edema (Fig. 6b).

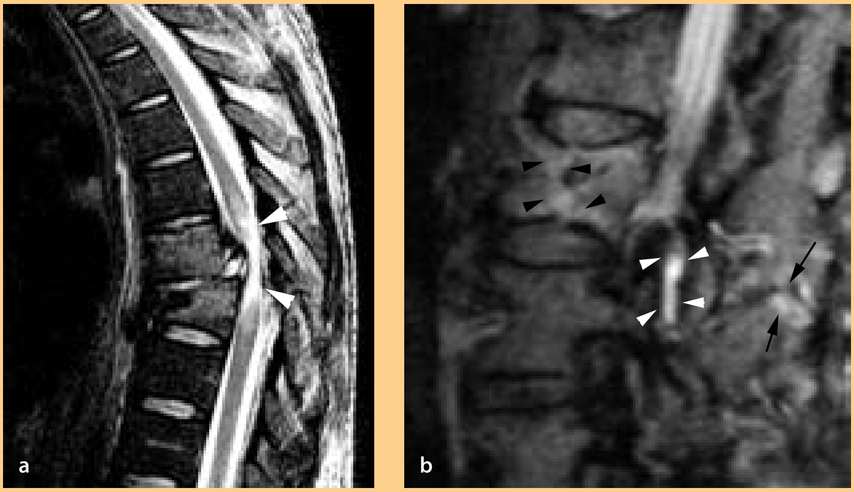



**Figure 6. MRI fracture assessment**

**a** The T2 weighted MR scan reveals a fracture subluxation with disc material retropulsed behind the vertebral body. Note the severe signal intensity alterations of the spinal cord as the morphological correlate for a complete spinal cord injury (*arrowheads*). **b** The parasagittal STIR image demonstrates a pincer fracture (*black arrowheads*). Note the joint effusion (*white arrowheads*) and the bright signal intensity alterations in the posterior elements indicating that this pincer fracture is combined with a posterior injury (Type B lesion)

### Radionuclide Studies

Radionuclide studies are **very infrequently used to diagnose acute vertebral fractures.** However, skeletal scintigraphy may be useful for fracture screening in polytraumatized patients, especially in a medicolegal context. Spitz et al. [109] found that after 10 – 12 days, with the aim of skeletal scintigraphy, an additional fracture was found in half of all patients, and was subsequently verified radiologically. Because skeletal scintigraphy can be employed with equal efficacy to reliably exclude bone injuries, the authors advocate that skeletal scintigraphy is of particular significance in the determination of the extent of bone injury in polytraumatized patients. However, bone scans have been surpassed by MRI using fluid-sensitive sequences which demonstrate the subtle lesions (e.g., bone bruise).

## Non-operative Treatment

Progress in pre-hospital care has considerably improved outcomes for patients with spinal injuries. This is in part due to the knowledge and awareness of the rescue team, the adherence to the Advanced Trauma Life Support (ATLS) protocols, and the transportation on a backboard or a vacuum board (see Chapter 30).

The general objectives of the treatment of thoracolumbar injuries are the same as for cervical injuries (Table 5):

**Table 5.** General objectives of treatment

| | |
|---|---|
| • restoration of spinal alignment | • preservation or improvement of neurological function |
| • restoration of spinal stability | • avoidance of collateral damage |

The treatment should provide a biologically and biomechanically sound environment that allows accurate bone and soft-tissue healing and eventually creates a stable and pain-free spinal column. These goals should be accomplished with a minimal risk of morbidity. Hence, the **main advantage** of non-operative treatment of thoracolumbar fracture is avoidance of surgery-related complications such as:

The main advantage of non-operative treatment is the avoidance of surgery-related complications

- infection
- iatrogenic neurological injury
- failure of instrumentation
- anesthesia-related complications

The relationship between post-traumatic kyphotic deformity and chronic back pain is not well established in the literature. Most clinicians believe that kyphotic deformity of the thoracolumbar area is synonymous with a poor clinical outcome. Although few studies provide some evidence that moderate kyphosis is associated with either pain or disability [47], several studies suggest that there is no direct relationship between kyphosis and back pain or functional impairment [20, 73, 87, 89, 116].

## Steroid Treatment of Spinal Cord Injury

High-dose steroid treatment is highly controversial

The controversy over steroid treatment of thoracolumbar spinal cord injury is discussed in the previous chapter (see Chapter 30). The overall consensus is that high-dose steroid treatment is regarded as an option for spinal monotrauma in young patients but not as a guideline for standard of care.

## Non-operative Treatment Modalities

As more and more data are collected, information emerges that supports both surgical and non-operative treatment. Non-operative treatment is still a viable and effective treatment for the vast majority of thoracolumbar fractures (Table 6) and should be part of the armamentarium available to all clinicians that treat these patients [92].

**Table 6.** Favorable indications for non-operative treatment

| | |
|---|---|
| • pure osseous lesions | • absence of malalignment |
| • absence of neurological deficits | • absence of gross bony destruction |
| • only mild to moderate pain on mobilization | • absence of osteopenia/osteoporosis |

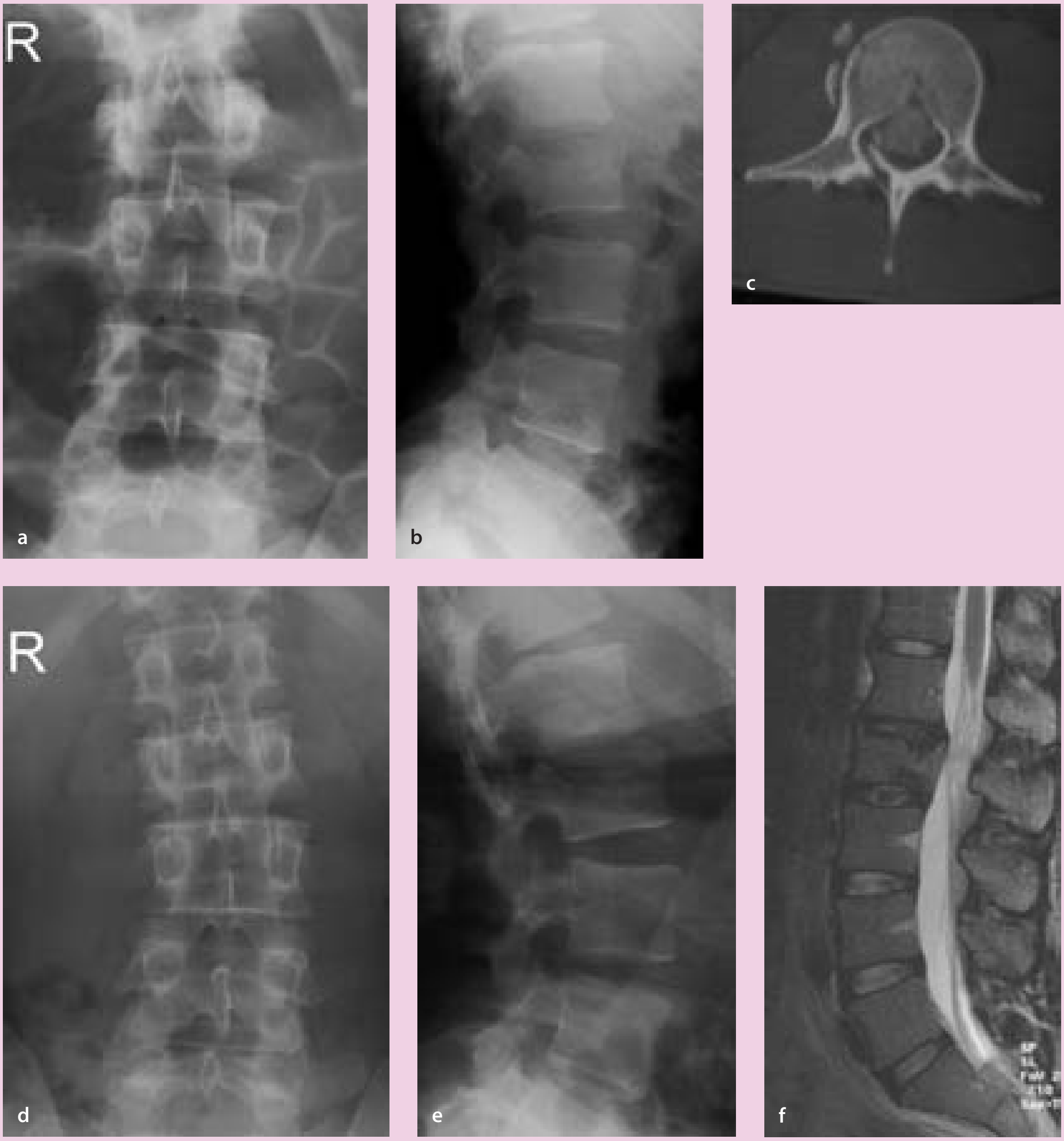
There are **three different methods** of non-operative treatment:

- repositioning and cast stabilization
- functional treatment and bracing without repositioning
- functional treatment without bracing

However, functional treatment without bracing is not applicable to all fracture types, while basically all fractures can be treated with repositioning and formal casting (Böhler technique).

### Repositioning and Cast Stabilization

Böhler [18] was one of the first to advocate a conservative treatment with repositioning and retention in a cast. The correct technique of repositioning and immobilization in a plaster of Paris cast is quite sophisticated and needs to be performed perfectly to obtain good results [13, 58]. The fracture is reduced using a fracture table with the abdomen hanging freely. The hyperextension results in a fracture reduction by ligamentotaxis (Case Study 1). As a general rule, Böhler




## Case Study 1

In 1988, a 33-year-old male sustained a motor vehicle accident and was admitted to hospital. On examination, the patient had severe pain at the thoracolumbar junction and in his right foot (talus neck fracture). The neurological examination was normal with some slight sensory deficit of L2 predominantly on the right side. Standard radiographs (a, b) revealed a burst fracture at the level of L2 with scoliotic deformity. The axial CT scan showed a burst fracture with severe retropulsion of a dorsoapical fragment and almost complete spinal canal stenosis (c). Despite this severe canal compromise, the patient was treated non-operatively for unknown reasons. The conservative treatment consisted of bed rest for 3–4 weeks in conjunction with reduction on a fracture table and cast fixation. The patient was mobilized thereafter with a thoracolumbar cast. At 4 months the patient was treated with a functional brace for an additional 2 months. The patient was reevaluated 10 years later in a medicolegal context related to his injury. Standard radiographs (d, e) demonstrated significant disc height decrease (L1/2) but without segmental kyphosis. The scoliotic deformity remained unchanged. An MRI scan revealed a complete resorption of the dorsoapical fragment with spontaneous canal clearance, and only mild to moderate disc degeneration at the level of L1/2 and L2/3 (f). At the time of follow-up examination, the patient was fully functional and only had very occasional back pain. This case nicely demonstrates that even severe burst fractures can be treated conservatively with excellent results although today we would suggest surgical treatment in this case to shorten the hospital stay and rehabilitation period. (Courtesy University Hospital Balgrist).

used the kyphosis angle in degrees to calculate the numbers of weeks of immobilization (minimum 12 weeks, maximum 5 months). Patients were allowed to ambulate almost immediately and were discharged home after a couple of days. Regular clinical and radiological exams were performed, initially every 2 weeks, then every 4 weeks, and the cast had to be changed if it became loose. Importantly, an intense and skillful physical therapy was, and still is, paramount to achieving good or satisfactory results.

Böhler's fracture treatment today is still a viable treatment option

The **disadvantage of the Böhler technique** is that it is very uncomfortable and painful for the patient and often requires sedation and strong analgesics. The Böhler technique is also prone to plaster cast related pressure sores. In patients with an indication for conservative treatment, we prefer to apply the cast in the standing position in hyperextension. This is possible in the vast majority of patients after a few days post-trauma and after orthostatic training on a vertically tilted board (Fig. 7).

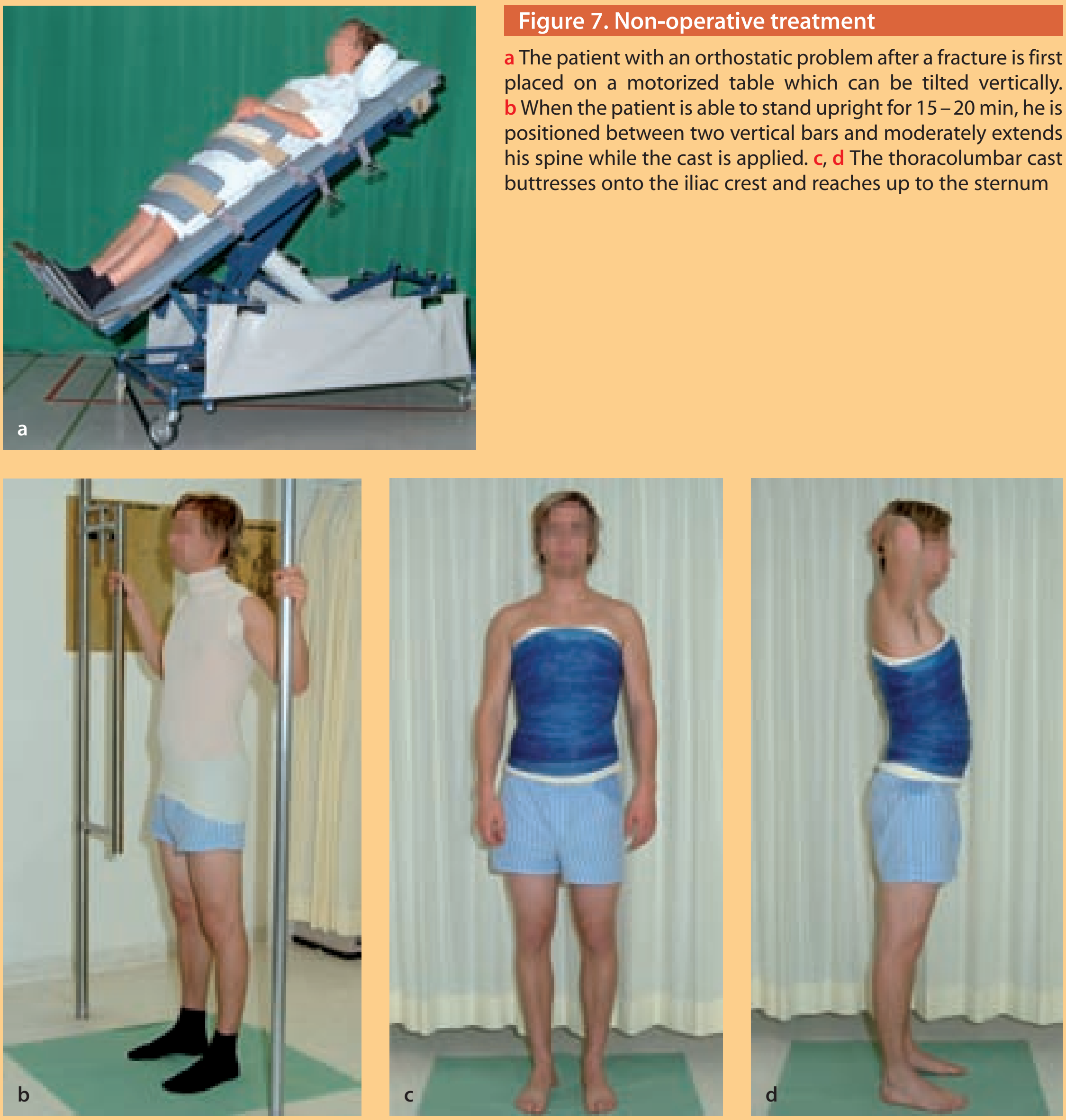



**Figure 7. Non-operative treatment**

**a** The patient with an orthostatic problem after a fracture is first placed on a motorized table which can be tilted vertically. **b** When the patient is able to stand upright for 15–20 min, he is positioned between two vertical bars and moderately extends his spine while the cast is applied. **c**, **d** The thoracolumbar cast buttresses onto the iliac crest and reaches up to the sternum

### Functional Bracing

Reduced kyphotic fractures are prone to return to the initial deformity, placing a questionmark over reduction

Magnus [82] advocated early functional treatment without repositioning. According to this concept, a thoracolumbar fracture is bound to return to the initial deformity and repositioning is therefore not necessary. The functional treatment concept was initiated with a phase of prone position on a stable bed and, if necessary, with lordotic support. The time of immobilization in bed depended on the fracture type. The next phases of treatment consisted of physical therapy to enhance muscle strength, mobilization in a waterbath, mobilization with a three point orthesis to prevent flexion and to assure an upright position of the patient, and a discharge home after approximately 3 weeks. Outpatient treatment was continued for another 3–4 months and physical therapy to enhance spine mobility was initiated after radiologic consolidation of the fracture, i.e., after 3–4 months.

### Functional Treatment

Functional treatment is indicated only in unequivocal stable fractures

In contrast to Böhler's repositioning and stabilization [18] or Magnus' functional bracing [82], functional treatment does not include any bracing device. Especially patients with stable fractures will benefit from this treatment (**Table 7**). Some braces are rather cumbersome and will hinder the patient in many activities of daily life. In fact, braces can be considered an "aide-mémoire" and remind the patient not to perform painful movements. With the functional treatment, patients are advised to mobilize freely according to their capabilities and according to the resulting pain. Importantly, qualified physical therapy and adequate pain medication are necessary to obtain optimal results.

**Table 7.** Outcome of conservative and operative treatment

| Authors | Cases | Study design | Fracture type (numbers) | Type of treatment | Neurological deficit | Follow-up (months) | Outcome | Conclusions |
|---|---|---|---|---|---|---|---|---|
| Weinstein et al. (1988) [116] | 42 | retrospective | burst fractures (T10–L5) | *non-operative:* treatment ranged from immediate ambulation in a body cast or brace to 3 months bed rest | 22% | 240 | neurological deterioration: none<br>able to return to work: 88%<br>kyphotic angle 26.4° in flexion and 16.8° in extension<br>average back pain score 3.5 (0–10) | non-operative treatment of thoracolumbar burst fractures without neurological deficit can lead to acceptable long-term results |
| Mumfordt et al. (1993) [87] | 41 | retrospective | single level thoracolumbar burst fractures T11–L5:<br>type I: 5%<br>type II: 78%<br>type III: 5%<br>type V: 12%<br>(Denis classification) | *non-operative:* bedrest mean: 31.3 (range, 7–68 days)<br>bracing mean 11.9 (range, 2–24 weeks) | none | 24 | functional results:<br>excellent 49%<br>good 17%<br>fair 22%<br>poor 12%<br>one patient developed neurological deterioration that required surgery | for patients with burst fractures without neurological deficit: non-operative management yields acceptable results<br>bony deformity progresses marginally relative to the rate of canal area remodeling<br>radiographic severity of injury or residual deformity does not correlate with long-term symptoms |
| Chow et al. (1996) [23] | 24 | retrospective | unstable burst fractures (T11–L2) | *non-operative:* casting or bracing and early ambulation | None | 34 | no correlation between post-traumatic kyphosis and outcome<br>little/no pain 79%<br>return to work 75%<br>no restrictions at work 75% | hyperextension casting or bracing is a safe and effective method for treatment of thoracolumbar burst fractures |

**Table 7.** (*Cont.*)

| Authors | Cases | Study design | Fracture type (numbers) | Type of treatment | Neuro-logical deficit | Follow-up (months) | Outcome | Conclusions |
|---|---|---|---|---|---|---|---|---|
| Kaneda et al. (1997) [60] | 150 | retro-spec-tive | Frankel grades A (24%) B (58%) C (6%) D (7%) E (4%) | *operative:* single stage anterior spinal decompres-sion, strut graf-ting, and ante-rior instrumen-tation | 100% | 96 (60–156) | neurological function improved at least one grade in 95% of patients. 72% of patients with bladder dysfunction recovered completely. 96% returned to work, 86% to their previous job without restrictions | anterior decompression and stabilization in patients with burst frac-tures and neurological deficit yielded good functional results |
| Knop et al. (2001) [67] | 372 | pro-spec-tive, multi-center | thoracolum-bar fractures (T12–L2) type: A (69%) B (17%) C (14%) | *operative:* Posterior (59%) combined anterior-pos-terior (35%) anterior (6%) stabilization | 20% | 27 (4–61) | for detailed description see text | all treatment methods resulted in compara-ble clinical and func-tional outcome one-third of all patients had severe and persist-ing functional disabili-ties |
| Khoo et al. (2002) [62] | 371 | retro-spec-tive | N/A | 35% stand-alone ante-rior thora-coscopic sta-bilization 65% additional posterior pedi-cle screw instrumenta-tion | 15% | 24 (4–72) | low rate of severe com-plications (1.3%); one case each of aortic injury, splenic contu-sion, neurological deterioration, CSF fluid leak, and severe wound infection 42% less narcotics for postoperative pain treatment compared to a group of 30 patients treated with open thoracotomy | anterior thoracoscopic-assisted reconstruction of thoracolumbar frac-tures can be safely accomplished, reducing pain and morbidity associated with open approaches |
| Defino and Scar-paro (2005) [29] | 18 | retro-spec-tive | type B and C fractures (AO classifi-cation), T10–L4 | *operative:* posterior monosegmen-tal fixation and arthrodesis | 38.9% | 78 (24–144) | low residual pain rates and high level patient satisfaction with final result. 95.5% returned to work and presented with a low disability index (Oswestry Disabil-ity Index = 10.33%) | posterior monoseg-mental fixation is an adequate and satisfac-tory procedure in spe-cific types of thoraco-lumbar spine fractures |
| Wood et al. (2005) [122] | 38 | pro-spec-tive, ran-domi-zed | isolated burst frac-tures (T10–L2) | *operative:* 18 posterior fusion 20 anterior sta-bilization | none | 43 (24–108) | 17 minor complications in patients treated posteriorly, including implant removal, 3 minor complications with anterior stabiliza-tion similar functional out-comes | anterior fusion and instrumentation may exhibit fewer complica-tions and fewer addi-tional surgeries |

## Operative Treatment

### General Principles

There is a general trend towards operative treatment of unstable fractures [31, 47], mostly because **surgical stabilizing** allows for:

- early mobilization of the patient
- diminished pain
- facilitated nursing care (polytraumatized patients)
- earlier return to work
- avoidance of late neurological complications

Despite theoretical advantages, the superiority of surgical fracture treatment is not supported by scientific evidence

However, evidence suggests that there is no difference as regards neurological recovery (**Frankel score**) and no substantial difference in functional long-term outcome between the operative and non-operative treatment [114]. This is clearly valid for compression fractures that are relatively stable, i.e., A1 and A2 fractures, according to the AO classification. Quite frequently, however, studies presented in the literature analyze a mixed cohort of fracture types without further differentiation, which leaves their results somewhat inconclusive.

In burst fractures, there is often some degree of canal compromise with a potential risk of neurological injury. Hence, progressive neurological deterioration in the presence of substantial canal compromise is an indication for surgical decompression and stabilization. Importantly, neurological status, spinal stability, degree of deformity of the injured segment, degree of canal compromise, and associated injuries are the most relevant factors that need to be considered when deciding on operative or non-operative treatment for patients with a thoracolumbar spine fracture. Most surgeons agree on **absolute indications** for surgery while relative indications are debatable (**Table 8**):

Progressive neurological deficit is an absolute indication for surgery

**Table 8.** Indications for surgical treatment

| Absolute | Relative |
|---|---|
| • incomplete paraparesis | • pure osseous lesions |
| • progressive neurological deficit | • desire for early return to regular activities |
| • spinal cord compression w/o neurological deficit | • avoidance of secondary kyphosis |
| • fracture dislocation | • concomitant injuries (thoracic, cerebral) |
| • severe segmental kyphosis (>30°) | • facilitating nursing in paraplegic patients |
| • predominant ligamentous injuries | |

In the absence of class I or II level scientific evidence for the vast majority of fracture types, treatment guidelines remain controversial but a pragmatic approach as used in our center may be useful.

### Spinal Cord Decompression

Decompression of incomplete spinal cord lesions with persistent compression is generally recommended

The severity of a spinal cord injury is related to the force and duration of compression, the displacement and the kinetic energy. Many animal models, including primates, have demonstrated that neurological recovery is enhanced by early decompression [40]. However, this compelling evidence has not been able to be translated into patients with acute spinal cord injury. This may in part be due to: (1) heterogeneous injury patterns and to (2) the absence of thoroughly designed and well-performed randomized controlled trials. However, a number of studies have documented recovery of neurological function after delayed decompression of the spinal cord (months to years) after the injury [4, 14, 15, 76, 112]. The improvement in neurological function with delayed decompression in patients with cervical or thoracolumbar spinal cord injury who have plateaued in their recovery is noteworthy and suggests that compression of the cord is an important contributing cause of neurological dysfunction. Although many clinical studies do not support the concept that surgery improves neurological deficits, most investigators recommend early surgical decompression in cases of an incomplete spinal cord injury and persistent compression of neurogenic structures.

### Timing of Surgery

The timing of surgery remains controversial. While one randomized controlled trial showed no benefit of early (<72 h) decompression [113], several recent prospective series suggest that early decompression (< 12 h) can be performed safely and may improve neurological outcomes [40].

La Rosa et al. [75] published a meta-analysis on the issue of early decompression in acute spinal cord injury. They reviewed 1 687 patients in studies published up to 2000. Patients were divided into three treatment groups: early decompression (< 24 h), delayed decompression (> 24 h), and conservative treatment. Statistically, early decompression resulted in better outcomes compared to both delayed decompression and conservative management. Because the analysis of homogeneity demonstrated that only data regarding patients with incomplete spinal cord injury who underwent early decompression were reliable, the authors concluded that early decompression can only be considered a practice option. Currently, there are no standards regarding the role and timing of decompression in acute spinal cord injury. Also, the presence and duration of a therapeutic window, during which surgical decompression could attenuate the secondary mechanisms of spinal cord injury, remains unclear. In a recent article, Fehlings et al. [40] provide evidence-based recommendations regarding spinal cord decompression in patients with acute spinal cord injury. Animal studies consistently show that neurological recovery is enhanced by early decompression. One randomized controlled trial showed no benefit to early (< 72 h) decompression. Several recent prospective series suggest that early decompression (< 12 h) can be performed safely and may improve neurological outcomes. Currently, there are no standards regarding the role and timing of decompression in acute spinal cord injury. On the other hand, no significant adverse effects of early decompression have been documented. In the absence of clear guidelines from the literature, early decompression of compressed neurological structures appears to be best practice.

Early rather than late decompression is recommended

Early decompression of progressive neurological deficits is indicated

## Surgical Techniques

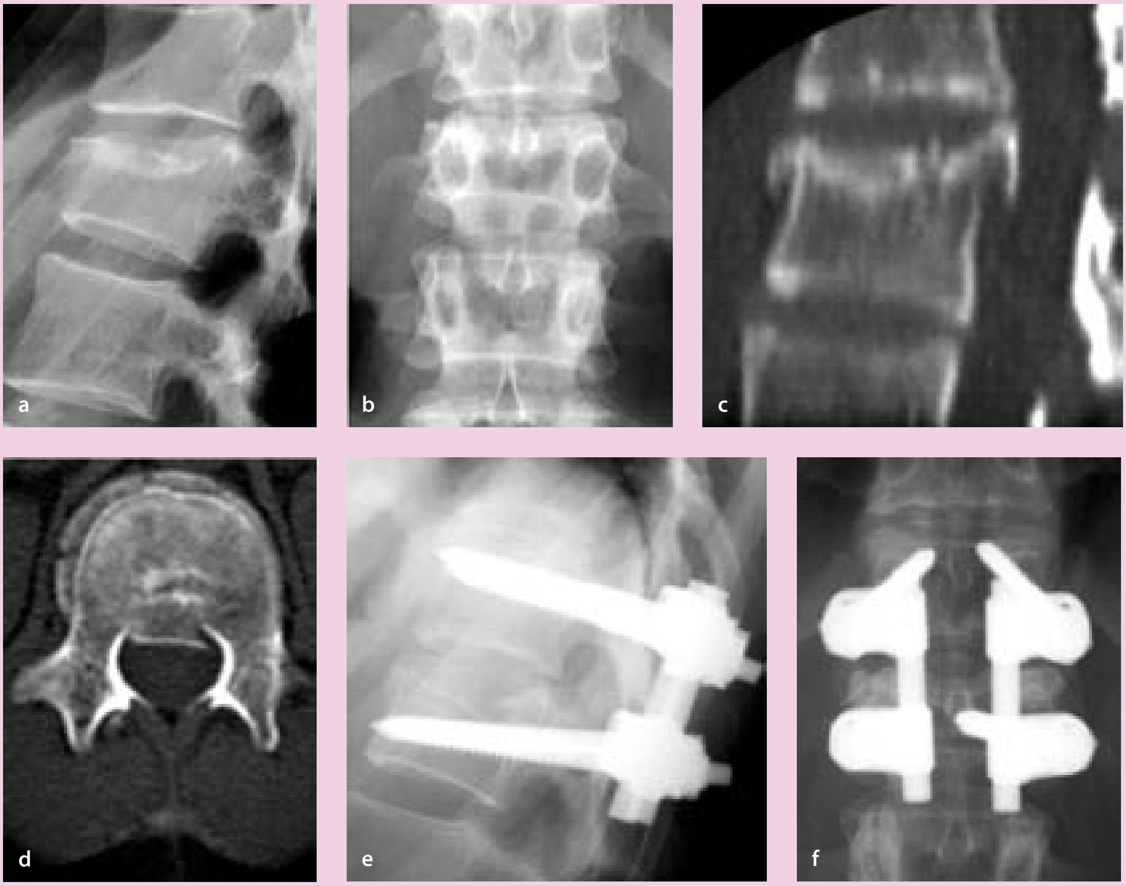
If surgical treatment is chosen, further debate arises over the appropriate type of approach. Similarly to the treatment decision of conservative vs. operative, scientific evidence is lacking for the superiority of one surgical technique over the other. Particularly for the frequent superior burst fracture (Fig. 3), a large variety of surgical techniques are available. Finally, it depends on the surgical expertise of the surgeon and their preference which technique is chosen. It is difficult to base treatment recommendations on treatment outcome in the literature (Table 7).

### Posterior Approach

#### *Posterior Monosegmental Reduction and Stabilization*

The group of Gotzen et al. [49, 59] was the first to publish their results after monosegmental reduction and stabilization (Case Study 2). In their initial report [49], 14 patients with unstable compression fractures Grade II were treated by posterior one-level internal fixation (9 patients had stabilization with plates and cerclage wire, 5 with internal fixator). The results were compared to a series of 11 patients with equivalent fractures treated non-operatively. The authors conclude that posterior single level stabilization and fusion is a recommendable surgical procedure. In their second publication, Junge et al. [59] describe the technique, which always included a posterior allogenic bone grafting and to some extent also transpedicular bone grafting. The 2-year follow-up of 39 patients demonstrated that 17 patients (43 %) were completely free of pain and 17 patients were only sensitive to weather changes or had minor pain during great physical stress.

Posterior monosegmental reduction and stabilization is feasible in selected Type A and B fractures




## Case Study 2

This 39-year-old female fell from her bike and complained about severe back pain at the thoracolumbar junction. On admission, the patient was neurologically intact. Standard anteroposterior and lateral radiographs demonstrated an incomplete burst fracture of L1 (a, b). The sagittal CT reformation confirmed the diagnosis of a superior burst fracture (c). The axial CT scan showed a minor dislocation of the dorsoapical vertebral fragment without neural compromise and intact pedicles (d). Based on this fracture type non-operative as well as operative treatment was discussed. The patient opted for surgery and preferred the posterior over the anterior approach. The spine was instrumented monosegmentally with the lower screw aiming towards the intact anterior vertebral cortex. A posterolateral fusion was added with autologous bone graft from the iliac crest. Follow-up radiographs (e, f) demonstrated an anatomic reduction of the fracture. The patient was fully mobile on the first postoperative day and remained symptomfree during a 5 years follow-up. (Courtesy University Hospital Balgrist).

However, five patients (13%) had pain even during slight physical stress or at rest. Importantly, no implant fatigue failure was noted although five minor complications occurred.

One-level posterior instrumentation is indicated only in incomplete burst fractures with intact pedicles

Wawro et al. [115] also published a small series of 14 patients that were stabilized over a single segment. In addition, they characterized the fracture type in which single-segment stabilization is possible and described differences in the operation technique compared with multisegmental internal fixation. For example, the pedicle screws occasionally needed to be inserted extremely close to the endplates if the remaining part of the vertebral body had been destroyed and could therefore not provide stability. Contraindications to a monosegmental posterior stabilization are broken pedicles and complete burst fractures of the body. In accordance with our concept, only incomplete burst fractures with intact pedicles and inferior endplate (i.e., Type A1 and A3.1) should be considered for posterior monosegmental reduction and stabilization. Probably the pathophysiologically most sound indication for a monosegmental dorsal stabilization is a Type B fracture with only ligamentous posterior injury combined with a Type A1 or A3.1 fracture of the vertebral body with intact endplates and intact pedicles, because the dorsal stabilization restores the tension band function of the ruptured ligaments.

In a similar small series of 18 patients undergoing posterior monosegmental stabilization, Defino et al. [29] report a clinical and radiological follow-up after 2–12 years (mean 6.6±3 years) to demonstrate that posterior monosegmental fixation is an adequate and satisfactory procedure in specific types of thoracolumbar spine fractures. Clinical evaluation revealed low residual pain rates and a high level of patient satisfaction with the final result. Functional evaluation showed that 95.5% of the patients returned to work on a full-time basis and presented with a low disability index (Oswestry Disability Index =10.33%). Radiographic evaluation demonstrated increased kyphosis in the fixed vertebral segment during the late postoperative period, accompanied by a reduced height of the intervertebral disc. There was no implant failure, and no signs of pseudoarthrosis were observed in any patient.

### *Posterior Bisegmental Reduction and Stabilization*

Posterior two-level reduction and fracture stabilization remains the gold standard for the vast majority of thoracolumbar fractures

The bisegmental, two-level posterior approach (short segmental stabilization) is the "working horse" of the posterior techniques that allows a secure fixation of the pedicle screws in the intact vertebra one level above and below the fracture (Fig. 8). With this construct, a good reduction and stable fixation is reliably achieved.

Fredrickson et al. [45] studied the mechanisms of ligamentotaxis to reduce the intracanal fragment of a burst fracture. Examination of anatomic data provided by microtome section indicated that the fibers that actually reduce the intracanal fragment originate in the anulus of the superior vertebra in the midportion of the endplate and insert into the lateral margins of the intracanal fragment. Investigations using MRI confirmed that these obliquely directed fibers account for the indirect reduction of the fragment. Further studies demonstrate that the posterior longitudinal ligament provided only a minor contribution in the reduction of the fracture in comparison to the attachments of the posterior portion of the anulus fibrosus.

Harrington et al. [51] studied the biomechanics of indirect reduction of bone retropulsed into the spinal canal in vertebral fracture and made several clinically relevant observations. It was not possible to produce an anteriorly directed force in the posterior longitudinal ligament at less than 35% canal occlusion, partly because the posterior longitudinal ligament stands away from the midbody of the vertebra. Regardless of the relative sagittal plane angulation of the vertebrae, distraction was the governing factor in generating force in the posterior longitudinal ligament. Because positioning the vertebrae in lordosis before applying distraction significantly slackens the posterior longitudinal ligament, it is suggested that distraction be applied before angular positioning of the vertebrae is performed. However, this procedure risks overdistraction with deleterious results for the spinal cord.

A comminuted anterior column demands anterior load sharing support

Depending on the comminution of the fractured vertebral body, additional anterior load sharing support is needed. McLain et al. [85] reported early failure of short-segment pedicle instrumentation for thoracolumbar fractures. Out of 19 patients with unstable thoracolumbar fractures, 10 patients had early failure of fixation: progressive kyphosis, osseous collapse, vertebral translation, screw

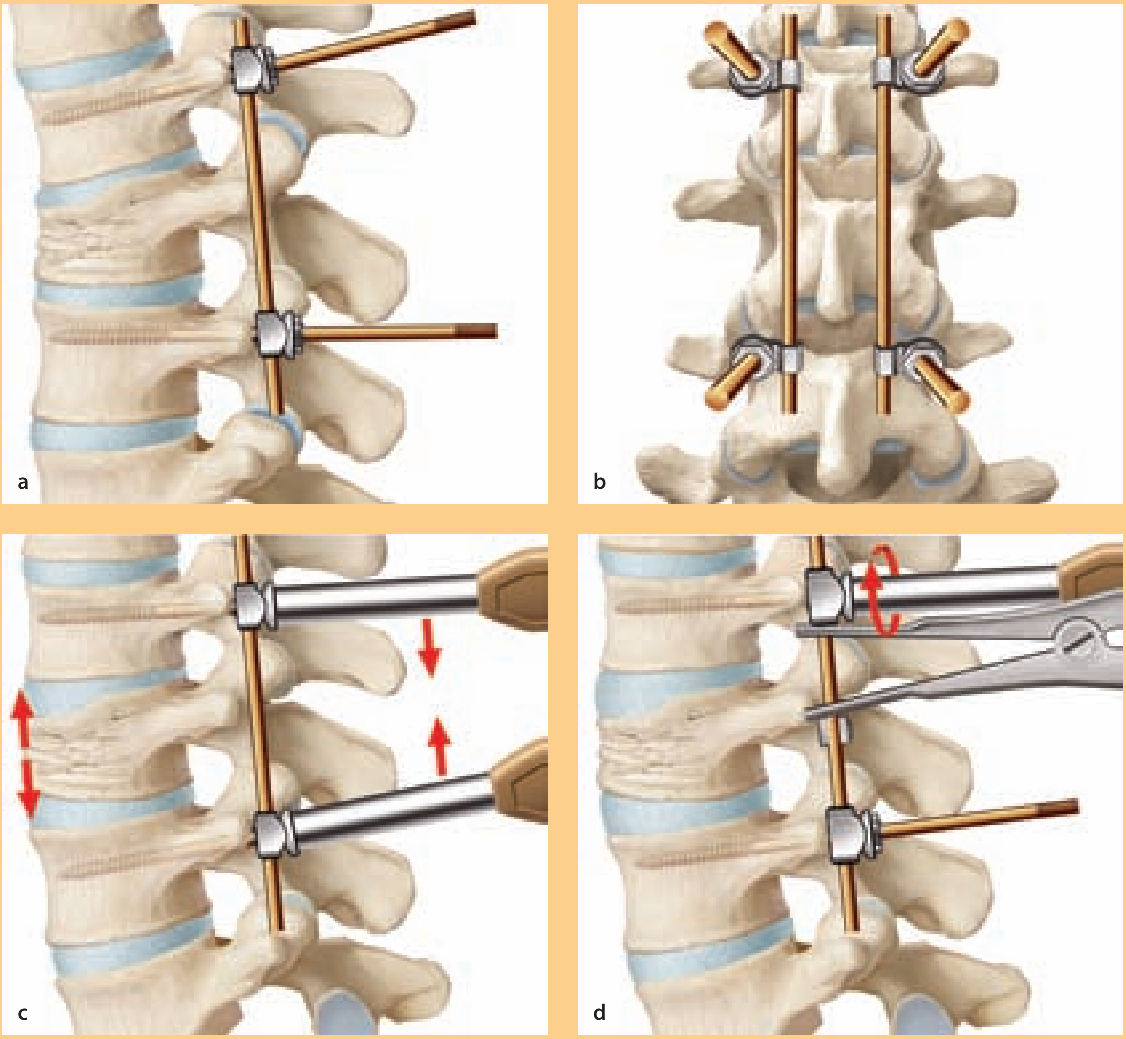



**Figure 8. Surgical technique of two-level fracture reduction and stabilization**

The technique demonstrates the use of the Fracture Module of Universal Spine System (Synthes) but the general principles similarly apply to other fracture systems. **a** Schanz screws are inserted in the pedicles of the vertebral bodies superior and inferior to the fracture. **b** Screw clamps connected with the rods are mounted and fixed (*arrow*). **c** The fracture can be reduced by lordosing both screwdrivers. However, it is often better to first tighten the two lower screws and reduce the fracture simultaneously by lordosing the cranial screw bilaterally with the help of the screwdriver. **d** If this reduction maneuver does not suffice to restore vertebral height, a temporary C-clamp can be mounted and the fracture distracted after loosening the upper screws. Care must be taken not to overdistract the fracture because of the inherent neurological risks. Finally, the Schanz screws are cut with a special screwcutter (not shown). Dependent on canal clearance and anterior vertebral column restoration, an additional anterior approach can be added (preferably in a second stage)

breakage or loosening. These results indicate the need for an adequate anterior column support and an optimal anterior-posterior column load sharing environment.

Transpedicular cancellous bone grafting is insufficient to stabilize the anterior column

If no anterior stabilization is planned, a posterolateral fusion [78, 88] is mandatory. In addition, transpedicular bone grafting in the disrupted disc space has been a treatment option [26, 78, 90]. However, transpedicular bone grafting could not prevent kyphosis after dorsal removal on implants [1, 68, 108]. Knop et al. [68] studied 56 patients after implant removal and concluded that, because of the disappointing results, they cannot recommend the additional transpedicular cancellous bone grafting as an interbody fusion technique after posterior stabilization in cases of complete or incomplete burst injury to the vertebral body. Similarly, Alanay et al. [1] concluded that short-segment transpedicular instrumentation of thoracolumbar burst fractures is associated with a high rate of failure that cannot be decreased by additional transpedicular intracorporeal grafting.

#### *Posterior Reduction and Multisegmental Stabilization*

Fracture dislocations usually require multilevel spinal stabilization

Multilevel stabilization is indicated for the very unstable thoracolumbar luxation fractures (Type C lesions) which usually cannot be accurately reduced and stabilized with a short two-level construct. Usually, fixation of two to three segments above and below the injury is recommended for a stable fixation. Unstable fractures of the thoracic spine that need to be stabilized are often combined with a significant thorax trauma or a polytrauma. In these patients, an early posterior stabilization with additional bone grafting allows for (1) a stable fixation of the spine with restoration of the dorsal tension band function, (2) the possibility of early and orthosis-free mobilization in the intensive care unit or later in a center of rehabilitation, and finally (3) bony fusion.

### Anterior Approach

Rationale for the anterior approach is that the spine should be treated where the injury has occurred

From the biomechanical point of view, it is obvious that the damaged spine has to be treated according to the injury mechanism and the site of injury. In a flexion injury (e.g., Chance fracture) with fracture of the pedicles and the vertebral body, stabilization can be performed by a dorsal approach and restores the tension band function until bony healing has occurred. Similarly, the biomechanics of the anterior column has to be considered in the case of a burst fracture. About 80 % of the axial load of an intact spine is supported by the anterior column. When the anterior column is substantially injured, the anterior support is dramatically reduced to about 10 %, leaving 90 % of the load to be resisted by the implant and the posterior elements. These general biomechanical considerations support the use of an anterior load sharing support (e.g., by a tricortical bone graft or a cage).

The **primary indications** for the anterior approach are:

- insufficient spinal decompression
- insufficient anterior column restoration

Spinal canal compromise in patients presenting with neurological deficits which cannot adequately be resolved by a dorsal approach alone requires anterior decompression. An additional indication is a vertebral body fracture with substantial comminution and dislocation which cannot be adequately restored by a posterior approach alone [50].

Type A fractures can be treated by an anterior approach alone

However, Type A fractures can be treated by an anterior approach alone. Kaneda et al. [60] reported a study on 150 consecutive patients who had a burst fracture of the thoracolumbar spine and associated neurological deficits. The patients were managed with a single-stage anterior spinal decompression, strut-grafting, and anterior spinal instrumentation. At a mean of 8 years (range 5 – 12 years) after the operation, radiographs showed successful fusion of the injured spinal segment in 140 patients (93 %). Ten patients had a pseudarthrosis, and all were managed successfully with posterior spinal instrumentation and a posterolateral arthrodesis. Despite breakage of the Kaneda device in nine patients, removal of the implant was not necessary in any patient. None of the patients had iatrogenic neurological deficits. Subsequent to anterior decompression, the neurological function of 142 (95%) of the 150 patients improved by at least one Frankel grade. Fifty-six (72%) of the 78 patients who had preoperative paralysis or dysfunction of the bladder recovered completely. One hundred and twenty-five (96%) of the 130 patients who were employed before the injury returned to work after the operation, and 112 (86%) of them returned to their previous job without restrictions. The authors concluded that anterior decompression, strut-grafting, and fixation with the Kaneda device in patients who had a burst fracture of the thoracolumbar spine and associated neurological deficits yielded good radiographic and functional results.

Wood et al. [122] conducted a prospective randomized study to evaluate differences in radiographic, clinical, or functional outcomes when individuals with stable burst fractures of the thoracolumbar junction (T10–L2) without neurological deficit are treated with either a posterior fusion with instrumentation or anterior reconstruction, fusion, and instrumentation. Of 43 enrolled patients, 38 completed a minimum 2-year follow-up (average: 43 months; range: 24–108 months). Eighteen patients received a posterior spine fusion and 20 an anterior approach. There were 17 "complications" including instrumentation removal for pain in 18 patients treated posteriorly, but only 3 minor complications in 3 patients treated anteriorly. Patient-related functional outcomes were similar for the two groups. The authors concluded that although patient outcomes are similar, anterior fusion and instrumentation for thoracolumbar burst fractures may present fewer complications or additional surgeries. Hence, using minimally invasive techniques (see below) the collateral damage can significantly be reduced, which increases the indications for the anterior approach in stable thoracolumbar fractures.

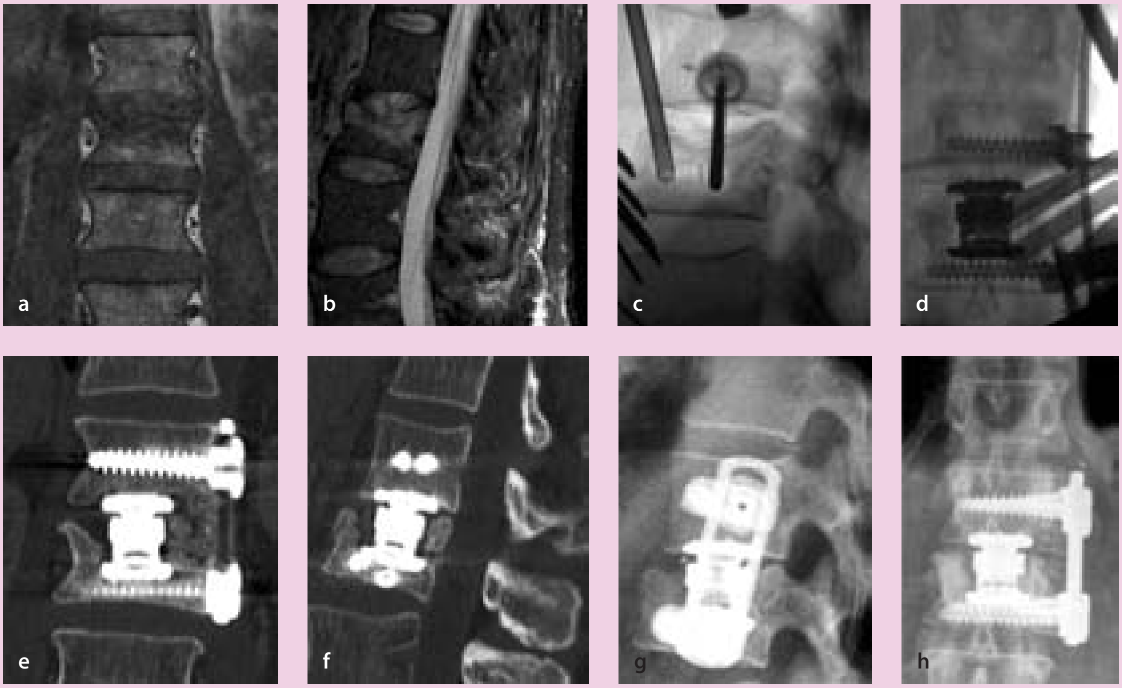
Sasso et al. [103] retrospectively analyzed 40 patients with unstable thoracolumbar injuries that were operated on between 1992 and 1998. The study was conducted to evaluate the efficacy of stand-alone anterior decompression and reconstruction of unstable three-column thoracolumbar injuries, utilizing current-generation anterior spinal instrumentation. According to the AO classification, there were 24 (60%) Type B1.2, 10 (25%) Type B2.3, 5 (12.5%) Type C1.3, and 1 (2.5%) Type C2.1 injuries. One early construct failure due to technical error is reported. Thirty-seven of the remaining patients (95%) went on to apparently stable arthrodesis. The authors conclude that current types of anterior spinal instrumentation and reconstruction techniques can allow some types of unstable three-column thoracolumbar injuries to be treated in an anterior stand-alone fashion. This allows direct anterior decompression of neural elements, improvement in segmental angulation, and acceptable fusion rates without the need for supplemental posterior instrumentation.

Selected Type B and C fractures can be treated with an anterior approach alone when using rigid angle-stable anterior fixation

### *Minimally Invasive Approach*

Conventional surgical approaches for the treatment of thoracic and thoracolumbar fractures require extensive exposure and often lead to significant postoperative pain and morbidity. In order to reduce the collateral damage created by the large surgical access, lesser and minimally invasive methods have been developed (Case Study 3). The use of a retractor system such as SynFrame allows the anterior spine to be accessed in an open but minimally invasive way. In an analysis of the first 65 patients, Kossmann et al. [72] reported no intra- or postoperative complications related to this minimally invasive procedure. In addition, no intercostal neuralgia, no post-thoracotomy pain syndromes, no superficial or deep wound infections and no deep venous thromboses occurred.

Access technology has contributed to minimizing collateral damage by the anterior approach




## Case Study 3

This 48-year-old female fell from a horse and presented with an incomplete burst fracture of L2 (Type A3.1) without neurological deficits (ASIA E). The MRI scan (**a**, **b**) was performed to evaluate the integrity of the dorsal elements. The coronal view (**a**) shows the T1 sequence and demonstrates a cranial fracture of L2 and a rupture of the disc L1/L2. The STIR sequence (**b**), which is very sensitive to edema, confirms the fracture of the vertebral body but does not show any evidence of a posterior injury. This allows the distinction between a Type A injury and an unstable Type B injury and helped us to choose the operative approach. We performed a monosegmental anterior stabilization with an expandable cage (Stryker) and an angular stable implant (MACS), which was especially designed for the thoracoscopic technique (**c**, **d**). After a small diaphragmatic split, one of the first steps is the positioning of a K-wire just above the endplate of L2 (**c**); in this figure, the retractor (*left*), the suctioning device (*middle*) and the aiming device for the K-wire (*right*) can be distinguished. The polyaxial screws are inserted under fluoroscopic control, the ruptured disc and the cranial part of the fractured vertebral body are removed, and the cage is inserted (**d**). The postoperative control radiographs (**e**–**g**) demonstrate a correct positioning of the screws in the anteroposterior view (**e**) and lateral view (**f**); in addition, the local bone transplant on the right side of the cage is seen in **e**. The conventional X-rays (**g**, **h**) demonstrate a physiologic alignment and a correct positioning of the implants.

Minimally invasive anterior access technologies offer perioperative advantages

Thoracoscopic spinal surgery is another technique that reduces the morbidity of extensive surgical approaches while it still achieves the primary goals of spinal decompression, reconstruction, and stabilization. Since the development of specially designed instruments and implants, the "pure" thoracoscopic operation technique has become possible and feasible. Through the transdiaphragmatic approach it was also possible to open up the thoracolumbar junction, including the retroperitoneal segments of the spine, to the endoscopic technique. In an early series, Bühren et al. [19] analyzed 38 patients. The authors conclude that, compared to the open method, minimally invasive surgery had the benefit of reducing postoperative pain, shortening hospitalization, leading to early recovery of function and reducing the morbidity of the operative approach. These findings have been confirmed in later reports [8, 9, 62]. The rate of severe complications was low (1.3 %), with one case each of aortic injury, splenic contusion, neurological deterioration, cerebrospinal fluid leak, and severe wound infection [62]. Overall, the complication rate was not increased when compared to the open technique; however, there were clear advantages in terms of the reduced access morbidity.

Importantly, the endoscopic technique is also effective for anterior spinal canal decompression. Beisse et al. [8] published a series of 30 patients with thoracolumbar canal compromise that underwent endoscopic anterior spinal canal decompression and report that 25 % of patients with complete paraplegia and 65 % of those with incomplete neurological deficit improved neurologically.

The following factors have gradually opened up the entire spectrum of anterior spine surgery to endoscopic techniques [9]:

- a standardized operating technique
- instruments and implants specially developed for the endoscopic procedure, i.e.:
- angle-stable plate and screw implants and
- endoscopically implantable vertebral body replacements

### Combined Anterior-Posterior Approach

Studies on posterior stabilization of thoracolumbar fractures demonstrated that fractures with comminution of the anterior column often lead to early failure [85]. Therefore, **in addition** to the posterior two-level repositioning and stabilization, several techniques were introduced to stabilize the anterior column: iliac anterior crest [41], possibly in an inlay technique [71] or with vertebral body replacements in different materials, shapes, sizes, and configurations (i.e., non-expandable vs. expandable cages). In our institution, we prefer to adhere to a two-staged procedure that includes (Case Introduction):

- **Stage 1:** posterior fracture reduction and usually a two-level stabilization (w/o decompression depending on neural compromise)
- **Stage 2:** delayed anterior surgery depending on the patients' condition

Many peers recommend a combined posterior/anterior approach for unstable fractures

It is evident that, although posterior reduction and stabilization provides effective restoration of the sagittal alignment, the reduction capability of the intracanal bone fragments is distinctly limited [50, 107, 123]. The anterior reconstruction method permits effective decompression of the spinal canal and offers superior mechanical stability compared with the indirect decompression and stabilization of posterior instrumentation.

### Treatment Guidelines

Most treatment recommendations are not based on scientific evidence

Critically evaluate anecdotal treatment recommendations before adaptation

The conflicting results and the diversity of studies presented in this chapter indicate that there is no gold standard for the vast majority of fractures and treatment decisions are almost always lacking scientific evidence. Treatment options are often based on the experience and the tradition of the institute and the treating physicians. Importantly, the patient and the treating team must be aware of the attainable results, the time course of the treatment, the pitfalls, and the complication of the respective method, be it conservative or operative. Under these limitations, we have summarized some general guidelines (Fig. 9). However, we want to emphasize that these general recommendations may not apply to the individual case and confounding variables have to be considered, e.g., general condition, injury pattern, polytrauma, age, associated diseases, etc.

**Type A1 fractures** are usually treated conservatively. However, if kyphosis becomes relevant (more than 20°–25°) an operative correction of the kyphosis has to be considered. In this case, we advocate an early correction, i.e., when the fracture is not consolidated and still can be reduced to avoid more complex and difficult correction surgery in a later stage. Also **Type A2 fractures** can be treated

| | Type A | Type B | Type C |
|---|---|---|---|
| **Group 1** | functional treatment / functional bracing / thoracolumbar cast, if: kyphosis <20-25° | posterior approach[2,4,5] w/o anterior approach[4] | posterior approach[4,6] w/o anterior approach[4] |
| **Group 2** | functional bracing / thoracolumbar cast (A 2.1 or A2.2 lesions) | thoracolumbar cast, if: • normal neurology • kyphosis <20-25°) • purely osseous lesion (Chance fracture) | posterior approach[4,6] w/o anterior approach[4] |
| | anterior approach[1] (A2.3 lesions) or posterior approach[2] (A2.3 lesions) | posterior approach[2,3] w/o anterior approach[4] | |
| **Group 3** | thoracolumbar cast, if: • normal neurology • kyphosis <20-25°) • less comminuted anterior column | posterior approach[2,3] | posterior approach[4,6] w/o anterior approach[4] |
| | anterior approach[1,3] or posterior approach[2,3,4] | | |

**Figure 9. General treatment guidelines**

1 Corpectomy, interbody fusion with strut graft/cage, anterior instrumentation
2 Two-level instrumentation, reduction, posterolateral fusion (optional with one-level fusion and posterior implant removal after 10–12 months to liberate the uninjured segment)
3 One-level stabilization and fusion possible in cases of monosegmental lesions (incomplete burst fractures, anterior disc disruption)
4 Additional anterior approach (corpectomy w/o decompression, interbody fusion with strut graft/cage) is indicated in cases of persistent neural compression (incomplete canal clearance) or comminuted anterior column or to enhance fusion in discoligamentous injuries
5 One-level stabilization and fusion possible in cases of discoligamentous injuries or concomitant incomplete burst fractures
6 Multilevel stabilization often required (two or three levels above/below the injury)

conservatively with the exception of A2.3 type fractures, the so-called **"pincer" type.** In this fracture type, both discs are usually ruptured and pushed into the fractured vertebral body. This injury pattern often leads to non-union and results in painful instability. From a pathophysiological and biomechanical view, an anterior approach makes most sense in these A2.3 fractures, because the pathology is treated where the pathology is located. Probably the most controversy exists in **A3 type fractures** particularly the incomplete burst fracture (A3.1). In this fracture type, the accepted treatments range from bracing to combined anterior/posterior approach all with acceptable results (Case Studies 2, 3). The treatment options depend on the comminution of the vertebral body, the degree of kyphosis, and the presence or absence of neurology. If one decides to stabilize A3 fractures, the goal of neural decompression, sagittal alignment, and anterior support will dictate the operative approach. In an emergency situation, a primarily posterior approach will allow to reduce and stabilize the fracture with an internal fixator with or without laminectomy to decompress neural structure (Case Introduction). At a later stage, the surgeon can decide if an additional anterior approach is needed, based on the persistence of neurological compression and the comminution of the anterior column. A CT scan after the postoperative

Pincer fractures are prone to non-union and are better treated surgically

Type A3.1 fractures are the most controversial ones regarding treatment recommendations approach is often helpful for decision making. Alternatively, an anterior approach only with corpectomy, interbody fusion with strut graft/cage, and anterior instrumentation will provide an appropriate stabilization (see Case Study 3).

The paradigm of a primarily posterior approach with or without an additional anterior operation is also true for Type B and Type C fractures. One exception is the **purely osseous "Chance" fracture**, because fractured bones heal better and faster than ligamentous injuries. In this case, a thoracolumbar cast fixation that prevents flexion/distraction movements of the injured segment is applied for 6–8 weeks. Alternatively, one might also prefer to treat Chance fractures with an operative stabilization and restore the ruptured tension band with a posterior bisegmental stabilization without posterolateral fusion. Removal of the hardware is then usually performed after 4 months. In **B-type fractures**, posterior stabilization is usually performed with a two-level instrumentation, reduction, and posterolateral fusion or optionally with a one-level fusion and posterior implant removal after 10–12 months to liberate the uninjured segment. Alternatively, two-level stabilization and fusion is possible in Type B cases with discoligamentous injuries or concomitant complete burst fractures. The decision whether an additional anterior support is necessary or not depends on the persistence of neural compression (**incomplete canal clearance**) or the comminution of the anterior column or the need to enhance arthrodeses by adding an interbody fusion. In **Type C injuries**, multilevel stabilization is often required (two or three levels above/below the injury) for reduction and stabilization. Additional anterior surgery again depends on canal clearance and anterior column reconstruction.

The indication for an additional anterior approach depends on neurological compromise and anterior column comminution

Type C injuries are very unstable and commonly require multisegmental fixation

## Outcome of Operative Versus Non-operative Treatment

Despite many theoretical advantages of operative spinal fracture treatment, there is a lack of scientific evidence which supports the benefits of surgery (Table 9). Many studies were not able to prove a substantial difference in functional outcome between the operative and non-operative treatment, regardless of the neurological injury [16, 17, 20, 73, 87, 92, 105, 116, 121]. Chow et al. [23] retrospectively reviewed 24 neurologically healthy patients (mean follow-up of 34 months) with unstable thoracolumbar burst fractures (T11–L2) managed with either casting or bracing and early ambulation. Clinical follow-up examination was performed by the use of a questionnaire in which the patients were asked to rate their pain, ability to work, ability to perform in recreational activities, and their overall satisfaction with treatment. Kyphotic deformity could be corrected with hyperextension casting but tended to recur during the course of mobilization and healing, as hypothesized by Magnus [82] and confirmed by other studies [96, 111]. No correlation was found between kyphosis and clinical outcome. At final follow-up evaluation, 79% had little or no pain; 75% had returned to work; 75% stated that they had few or no restrictions in their ability to work; and 67% stated that they had few or no restrictions in their ability to participate in recreational activities. Only one patient (4%) reported being dissatisfied with the initial non-operative treatment of his spine fracture. The authors conclude that non-operative management of thoracolumbar burst fractures with hyperextension casting or bracing is a safe and effective method of treatment in selected patients.

Favorable outcome has been reported with conservative as well as operative treatment when applying the correct technique

In the series of Daniaux et al. [27], 85% of patients with a thoracolumbar fracture were treated conservatively. In 40%, a functional treatment was possible; these were patients with stable impaction and split fractures as well as burst fractures that were considered to be stable and that had a kyphotic deformity of less than 10° for T12–L2 and 15° for T11, respectively. In 45%, a repositioning and

**Table 9.** Operative vs. non-operative treatment

| Authors | Cases | Study design | Fracture type (numbers) | Type of treatment | Neuro-logical deficit | Follow-up (months) | Outcome | Conclusion |
|---|---|---|---|---|---|---|---|---|
| Burke and Murray (1976) [17] | 115 (140) | retro-spective | flexion/rotation (80)<br>compression fractures (27)<br>pure ligamentous injuries (3)<br>hyperextension (2)<br>other (3) | 89 *non-operative* (postural reduction)<br>26 *operative* (posterior stabilization ± laminectomy) | 62% | N/A | *conservative:*<br>secondary spinal fusion $n=3$<br>severe chronic pain: 2 neurological improvement 35%<br>*operative:*<br>severe chronic pain $n=8$<br>Neurological improvement 38% | the indication for early surgery might be still further restricted. |
| Rechtine et al. (1999) [93] | 235 | chart review for complications | unstable thoracolumbar fractures | 117 *operative*<br>118 *non-operative* 6 weeks bed rest) | | N/A | comparable rates of decubitus, deep venous thrombosis, pulmonary emboli, and mortality between both groups<br>8% deep wound infections after operative treatment<br>shorter hospital stay after operative treatment | both treatment modalities are viable alternatives |
| Shen et al. (2001) [105] | 80 | pro-spective | single-level burst fractures T11–L2, no fracture dislocations or pedicle fractures | *47 non-operative:*<br>using a hyperextension brace<br>*33 operative:*<br>posterior fixation | none | 288 | less pain in the surgical group after 3 and months. Complications after surgery: 1 superficial infection and 2 broken screws<br>hospital charges were 4 times higher in the operative group | posterior fixation provides partial kyphosis correction and earlier pain relief. Functional outcome at 2 years is similar |
| Wood et al. (2003) [121] | 47 | pro-spective, randomized | single thoracolumbar burst fractures (T10–L2) | *24 operative:*<br>posterior or anterior instrumented fusion<br>*23 non-operative*:<br>body cast or orthosis | none | 44 | no difference between groups was found in terms of pain, and return to work. Non-operatively treated patients reported less disability | no long-term advantage for operative treatment of burst fractures compared with non-operative treatment |

retention in a cast according to Böhler's principles was performed. A repositioning was possible in 90%; however, only 50% could be maintained over the treatment period, 20% returned to the initial kyphotic level and 5% had a worse result.

Reinhold et al. [95] reviewed 43 patients 16.3 years after thoracolumbar fracture and non-operative therapy. On average, patients showed a radiologic increase in the kyphosis angle of 5.2° compared to the time of injury. No difference was noted between early functional therapy and treatment with closed reduction and immobilization by cast. Results of validated psychometric questionnaires such as SF-36 and VAS showed the characteristic pattern of a population with chronic back pain. The authors conclude that a radiologic increase in the traumatic kyphotic deformity in patients with a non-operative treatment protocol has to be expected and that measurable negative physical and social long-term consequences can be anticipated after sustaining a Type A fracture of thoracolumbar vertebral bodies. However, no correlation between radiologic and functional results was observed.

In an earlier report, Weinstein et al. [116] also addressed the long-term results of 42 patients with non-operative treatment for fractures of the thoracolumbar spine. Average time from injury to follow-up was 20.2 years. At follow-up, the average back pain score was 3.5, with 0 being no pain at all and 10 being very severe pain. No patient required narcotic medication for pain control. Eighty-eight percent of patients were able to work at their usual level of activity. Follow-up radiographs revealed an average kyphosis angle of 26.4° in flexion and 16.8° in extension. The degree of kyphosis did not correlate with pain or function at follow-up.

Burke et al. [17] reported in his retrospective study that 3 of 89 patients with conservative therapy required a secondary spinal fusion for suspected instability after a period of conservative treatment. Frankel [44] found that 2 of 394 conservatively treated patients required surgery because of instability.

Braakman et al. [16] prospectively studied 70 consecutive patients with injuries of the thoracic and lumbar spine with a neurological deficit. The authors could not establish a difference in neurological recovery between those patients who were managed conservatively and those in whom a surgical decompression and stabilization procedure was performed. Surgical stabilizing procedures, however, resulted in immediate stabilization of the spine, diminished pain, facilitated nursing care and allowed more rapid mobilization and earlier active rehabilitation.

Shen at al. [104] studied 38 patients after functional treatment with a follow-up of 4.1 years. Four patients had moderate pain, 2 had moderate to severe pain, and 29 (76%) were able to work at the same level. The authors conclude that activity restriction and bracing may be important for pain control but probably do not change the long-term result. The same authors [105] also conducted a prospective trial with 80 patients to compare the results of non-operative treatment ($n=47$) versus short-segment posterior fixation using pedicle screws; follow-up was 2 years. They found that posterior fixation provides partial kyphosis correction and earlier pain relief, but the functional outcome at 2 years is similar.

Wood et al. [121] published a prospective, randomized study comparing operative (posterior or anterior arthrodesis and instrumentation) and non-operative treatment (application of a body cast or orthosis) of stable thoracolumbar burst fractures in 47 patients without neurological deficit. After treatment, patients indicated the degree of pain with use of the visual analog scale and they completed the Roland and Morris Disability Questionnaire, the Oswestry Back-Pain Questionnaire, and the Short Form-36 (SF-36) Health Survey. No significant difference was found between the two groups with respect to return to work. The preinjury scores were similar for both groups; however, at the time of the final follow-up (on average after 44 months), those who were treated non-operatively reported less disability. The authors conclude that operative treatment of patients with a stable thoracolumbar burst fracture and normal findings on the neurological examination provided no major long-term advantage compared with non-operative treatment.

The superiority of surgical fracture treatment is not well supported in the literature

Rechtine et al. [93] reviewed the medical charts of 235 patients with thoracolumbar fractures to evaluate a difference in the occurrence of complications after conservative (118 patients) or operative treatment (117 patients). There was no significant difference in the occurrence of decubitus, deep venous thromboses, pulmonary emboli, or mortality between the two groups. Deep wound infections occurred in 8% of the operative cases. However, the length of stay was 24 days longer in the non-operative group. The authors conclude that the selection of treatment method remains a matter of controversy.

## Complications

A surgery-related complication is a relevant shortcoming of any operative procedure with potentially devastating consequences, especially in spine surgery (see Chapter 39). The reported complication rate in the literature is largely variable and critically dependent on the pathology and type of surgery [7, 8, 19, 25, 34, 35, 38, 39, 42, 62, 68, 70, 83, 102, 110, 115].

The reported complication rate in the literature varies largely

One of the largest series which considered complications in the surgical treatment of spinal fractures is the multicenter study of the Spine Study Group of the German Trauma Association (DGU). Knop et al. [69] reviewed sources of error and specific complications [67, 65, 66]. A total of 682 patients were operated on for acute traumatic injuries of the thoracolumbar spine. In 101 cases (15%) at least one complication occurred intra- or postoperatively. In 41 patients (6%) a revision was performed, and in 60 patients (9%) complications without operative revision were observed. Typical errors and possible complications during operations were related to different steps of the operation:

- positioning and closed reduction of fractures
- approach
- decompression of the spinal canal
- instrumentation and stabilization
- intervertebral fusion

In addition, there are general surgical complications, which are not specific to spinal operations.

Postoperative neurological complications are rare

- Complications specific to the procedure that were **revised** included ($n=40$): deep infection 15 (2.2%), hematoma/wound healing disorder 12 (1.8%), instability or segmental malalignment 5 (0.7%), misplacement of screw/implant 4 (0.6%), persisting liquor fistula 2 (0.3%), sewn-in drain 1 (0.1%), arterial embolism of femoral artery 1 (0.1%).
- Complications specific to the procedure that were ($n=29$) **not revised** included: intraoperative bleeding 10 (1.5%), iatrogenic pedicle fracture 5 (0.7%), misplacement of screw/implant 3 (0.4%), instability or consecutive malalignment 2 (0.3%), infection/healing disorder iliac crest 2 (0.3%), not specified 2 (0.3%), iatrogenic rip fracture, approach related 1 (0.1%), iatrogenic lesion of pleura/peritoneum 1 (0.1%), narrowing of spinal canal with bone graft 1 (0.1%), fracture of iliac crest after graft harvesting 1 (0.1%), persisting liquor fistula 1 (0.1%).
- Neurological complications ($n=13$), revised and non-revised included: peripheral lesion of nerve roots (0.7%), remittent neurologic deficit 4 (0.6%), neurologic deterioration (Frankel/ASIA E to D) 2 (0.3%), neurologic deterioration (Frankel/ASIA D to A) 1 (0.1%), paresthesia without neurological deficit 1 (0.1%).

## Recapitulation

**Epidemiology.** About 60% of thoracic and lumbar spine fractures are located at the transition **T11–L2**, 30% in the thoracic spine and 10% in the lower lumbar spine. **Spinal cord injury** occurs in about 10–30% of traumatic spinal fractures.

**Pathogenesis.** The most relevant forces that produce structural damage to the spine are axial compression, flexion/distraction, hyperextension, rotation, and shear. **Axial load** may result in a burst fracture; the posterior elements are usually intact. In **flexion/distraction injuries**, the posterior ligamentous and osseous elements fail in tension; a wedge compression fracture of the vertebral body is often associated. **Hyperextension** may result in rupture of the anterior ligament and the disc as well as in compression injuries of the posterior elements, i.e., fracture of the facets, the laminae, or the spinous processes. **Rotational injuries** combine compressive forces and flexion/distraction mechanisms and are highly unstable injuries. Shear forces produce severe ligamentous disruption and usually result in complete spinal cord injury.

**Clinical presentation.** In the case of a polytrauma, about 30% of the patients have a spinal injury. The neurological examination has to include the "**search for a sacral sparing**" which determines the completeness of the deficit and the prognosis. About one-third of all spinal injuries have **concomitant injuries**; the most frequent are: head injuries, chest injuries and long bone injuries. The history should include the type of trauma (high vs. low energy injuries) and the time course of a possible neurological deficit. The initial focus of the physical examination is on the assessment of **vital functions and neurological deficits**. Because the spinal cord usually terminates at the level of L1, injuries to the thoracolumbar junction may result in various neurological symptoms: e.g., complete/incomplete paraplegia (distal spinal cord), malfunction of the vegetative system (conus medullaris), or cauda equina syndrome.

**Diagnostic work-up.** Static imaging studies are "snapshots in time" and do not reveal the real degree of spinal canal compromise that may have happened during the injury. A posterior cortical disruption seen in the lateral view or an interpedicular widening seen in the anteroposterior view suggests a burst fracture that should be further analyzed by CT scan. **CT is the imaging study of choice** to demonstrate bony destruction. **MRI** is recommended to identify a possible cord lesion or a cord compression in patients with **neurological deficits**. MRI can be helpful in determining the integrity of the posterior ligamentous structures and thereby in **differentiating between a Type A and a Type B lesion**.

**Non-operative treatment.** Management of thoracolumbar and sacral spinal fractures remains a controversial area in modern spinal surgery. The literature demonstrates a wide range of conflicting results and recommendations. Unfortunately, the vast majority of clinical studies can be criticized because of their retrospective design, heterogeneous patient populations and treatment strategies, limited follow-up, and poorly defined outcome measures.

The main advantage of non-operative treatment of thoracolumbar fracture is the avoidance of surgery-related complications. According to Böhler, the time of immobilization in a cast is usually 3–5 months depending on the fracture type. Importantly, skillful physical therapy is paramount to achieve good results. Because thoracolumbar fractures are bound to return to the initial deformity, functional bracing without repositioning is an alternative to Böhler's concept of repositioning and stabilization with a cast if the initial deformity is acceptable. Many studies were not able to prove a substantial difference in functional outcome between the operative and non-operative treatment, regardless of the neurological injury.

**Operative treatment.** There is a general trend towards operative treatment of unstable fractures mostly because surgical stabilizing procedures result in early mobilization, diminished pain, facilitated nursing care, earlier return to work, and avoidance of late neurological complications. In experimental animal models, persistent compression of the spinal cord is potentially reversible from a secondary injury by early decompression. Most investigators **recommend a surgical decompression** in the setting of major neurological deficit, progressive neurological loss, and substantial compromise of the spinal canal. Currently, there are **no gold standards regarding the role and timing of decompression** in acute spinal cord injury. Posterior bisegmental reduction and stabilization is the "working horse" of the posterior approach technique that allows for fracture reduction and stable fixation. Depending on the persistence of spinal canal compromise or comminution of the fractured vertebral body, an additional anterior approach is needed. Transpedicular cancellous bone grafting for interbody fusion after posterior stabilization is not recommended in complete or incomplete burst fractures. Only incomplete Type A burst fractures with intact pedicles and a lower endplate should be considered for **posterior monosegmental reduction and stabilization**. Compared to the open method, minimally invasive surgery reduces postoperative pain, shortens hospitalization, leads to early recovery of function and reduces morbidity of the operative approach. A **combined posterior and anterior approach** is used to reduce and stabilize severely comminuted vertebral body fractures and to decompress the spinal canal. In **Type C lesions often multisegmental instrumentation** is needed to reliably stabilize the spine.

**Complications.** The reported complication rate in the literature varies largely and ranges from 3.6 % to 10 %. Postoperative neurological complications range from 0.1 % to 0.7 %. Only honest and accurate assessment of complications will lead to scientific and clinical progress.

## Key Articles

**Böhler L (1951) Die Technik der Knochenbruchbehandlung. Maudrich, Vienna**
Lorenz Böhler was one of the first to advocate a conservative treatment with fracture reduction and retention in a cast.

**Roaf R (1960) A study of the mechanics of spinal injuries. J Bone Joint Surg Br 42B:810 – 23**
In this article Roaf studies the biomechanics of spinal injuries and describes the results of studies of spinal units when subjected to forces of different magnitude and direction, i.e., compression, flexion, extension, lateral flexion, rotation, and horizontal shear.

**Denis F (1983) The three column spine and its significance in the classification of acute thoraco-lumbar spinal injuries. Spine 8:817 – 31**
This article is a presentation of the concept of the three-column spine. The concept evolved from a retrospective review of 412 thoracolumbar spine injuries and observations on spinal instability. The posterior column consists of what Holdsworth described as the posterior ligamentous complex. The middle column includes the posterior longitudinal ligament, posterior anulus fibrosus, and posterior wall of the vertebral body. The anterior column consists of the anterior vertebral body, anterior anulus fibrosus, and anterior longitudinal ligament.

**Dick W (1987) The "fixateur interne" as a versatile implant for spine surgery. Spine 12:882 – 900**
This article introduced a new angle-stable fixation device which first allowed a short segmental reduction and fixation of fractures.

**Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S (1994) A comprehensive classification of thoracic and lumbar injuries. Eur Spine J 3:184 – 201**
This article describes a classification of thoracic and lumbar injuries. As a result of more than a decade of consideration of the subject matter and a review of 1 445 consecutive thoracolumbar injuries, a comprehensive classification of thoracic and lumbar injuries is proposed. The classification is primarily based on pathomorphological criteria. Three mechanisms classify the injury pattern according to the AO classification: axial compression (Type A), flexion distraction (Type B) and rotational/shear injuries (Type C).

**Kaneda K, Taneichi H, Abumi K, Hashimoto T, Satoh S, Fujiya M (1997) Anterior decompression and stabilization with the Kaneda device for thoracolumbar burst fractures associated with neurological deficits. J Bone Joint Surg Am 79:69 – 83**
One hundred and fifty consecutive patients who had a burst fracture of the thoracolumbar spine and associated neurological deficits were managed with a single-stage anterior spinal decompression, strut-grafting, and Kaneda spinal instrumentation. The authors conclude that anterior decompression, strut-grafting, and fixation with the Kaneda

device in patients who had a burst fracture of the thoracolumbar spine and associated neurological deficits yielded good radiographic and functional results. This article established the single stage anterior approach for this fracture type.

**Knop C, Blauth M, Bühren V, Hax PM, Kinzl L, Mutschler W, Pommer A, Ulrich C, Wagner S, Weckbach A, Wentzensen A, Wörsdörfer O (1999) Surgical treatment of injuries of the thoracolumbar transition. 1: Epidemiology. Unfallchirurg 102:924–35**

**Knop C, Blauth M, Bühren V, Hax PM, Kinzl L, Mutschler W, Pommer A, Ulrich C, Wagner S, Weckbach A, Wentzensen A, Wörsdörfer O (2000) Surgical treatment of injuries of the thoracolumbar transition. 2: Operation and roentgenologic findings. Unfallchirurg 103:1032–47**

**Knop C, Blauth M, Bühren V, Arand M, Egbers HJ, Hax PM, Nothwang J, Oestern HJ, Pizanis A, Roth R, Weckbach A, Wentzensen A (2001) Surgical treatment of injuries of the thoracolumbar transition – 3: Follow-up examination. Results of a prospective multi-center study by the "Spinal" Study Group of the German Society of Trauma Surgery. Unfallchirurg 104:583–600**
These three reports summarize the experience based on 682 patients included in a prospective multicenter study by the "Spinal" Study Group of the German Society of Trauma Surgery. All treatment methods under study were appropriate for achieving comparable clinical and functional outcome. The internal fixator was found superior in restoration of the spinal alignment. Best radiological outcomes were achieved by combined stabilization. Merely by direct reconstruction of the anterior column the postoperative re-kyphosing is prevented and a gain in segmental angle is achieved. However, this benefit was not reflected in the clinical outcome.

**Fehlings MG, Perrin RG (2005) The role and timing of early decompression for cervical spinal cord injury: Update with a review of recent clinical evidence. Injury S-B13–S-B26**
Evidence-based recommendations regarding spinal cord decompression in patients with acute spinal cord injury.

**Beisse R (2006) Endoscopic surgery on the thoracolumbar junction of the spine. Eur Spine J 15:687–704**
This article summarizes the technique and results based on a large patient group from a German trauma center: A now standardized operating technique, instruments and implants specially developed for the endoscopic procedure, from angle stable plate and screw implants to endoscopically implantable vertebral body replacements, have gradually opened up the entire spectrum of anterior spine surgery to endoscopic techniques.

## References


1. Alanay A, Acaroglu E, Yazici M, Oznur A, Surat A (2001) Short-segment pedicle instrumentation of thoracolumbar burst fractures: does transpedicular intracorporeal grafting prevent early failure? Spine 26:213–7
2. Anderson PA, Henley MB, Rivara FP, Maier RV (1991) Flexion distraction and chance injuries to the thoracolumbar spine. J Orthop Trauma 5:153–60
3. Anderson PA, Rivara FP, Maier RV, Drake C (1991) The epidemiology of seatbelt-associated injuries. J Trauma 31:60–7
4. Anderson PA, Bohlman HH (1992) Anterior decompression and arthrodesis of the cervical spine: long-term motor improvement. Part II – Improvement in complete traumatic quadriplegia. J Bone Joint Surg Am 74:683–92
5. Anderson S, Biros MH, Reardon RF (1996) Delayed diagnosis of thoracolumbar fractures in multiple-trauma patients. Acad Emerg Med 3:832–9
6. Bagley LJ (2006) Imaging of spinal trauma. Radiol Clin North Am 44:1–12, vii
7. Been HD, Bouma GJ (1999) Comparison of two types of surgery for thoraco-lumbar burst fractures: combined anterior and posterior stabilisation vs. posterior instrumentation only. Acta Neurochir (Wien) 141:349–57
8. Beisse R, Muckley T, Schmidt MH, Hauschild M, Buhren V (2005) Surgical technique and results of endoscopic anterior spinal canal decompression. J Neurosurg Spine 2:128–36
9. Beisse R (2006) Endoscopic surgery on the thoracolumbar junction of the spine. Eur Spine J 15:687–704

10. Bensch FV, Kiuru MJ, Koivikko MP, Koskinen SK (2004) Spine fractures in falling accidents: analysis of multidetector CT findings. Eur Radiol 14:618–24
11. Bensch FV, Koivikko MP, Kiuru MJ, Koskinen SK (2006) The incidence and distribution of burst fractures. Emerg Radiol 12:124–9
12. Benson DR (1988) Unstable thoracolumbar fractures, with emphasis on the burst fracture. Clin Orthop Relat Res 14–29
13. Blauth M, Knop C, Bastian L (1998) Wirbelsäule. In: Tscherne H, Blauth M (eds) Tscherne Unfallchirurgie, vol 3. Springer, Berlin Heidelberg New York, pp 241–381
14. Bohlman HH, Anderson PA (1992) Anterior decompression and arthrodesis of the cervical spine: long-term motor improvement. Part I – Improvement in incomplete traumatic quadriparesis. J Bone Joint Surg Am 74:671–82
15. Bohlman HH, Kirkpatrick JS, Delamarter RB, Leventhal M (1994) Anterior decompression for late pain and paralysis after fractures of the thoracolumbar spine. Clin Orthop 24–9
16. Braakman R, Fontijne WP, Zeegers R, Steenbeek JR, Tanghe HL (1991) Neurological deficit in injuries of the thoracic and lumbar spine. A consecutive series of 70 patients. Acta Neurochir (Wien) 111:11–7
17. Burke DC, Murray DD (1976) The management of thoracic and thoraco-lumbar injuries of the spine with neurological involvement. J Bone Joint Surg Br 58:72–8
18. Böhler L (1951) Die Technik der Knochenbruchbehandlung. Maudrich Verlag, Vienna
19. Bühren V, Beisse R, Potulski M (1997) [Minimally invasive ventral spondylodesis in injuries to the thoracic and lumbar spine]. Chirurg 68:1076–84
20. Cantor JB, Lebwohl NH, Garvey T, Eismont FJ (1993) Nonoperative management of stable thoracolumbar burst fractures with early ambulation and bracing. Spine 18:971–6
21. Carl AL, Tromanhauser SG, Roger DJ (1992) Pedicle screw instrumentation for thoracolumbar burst fractures and fracture-dislocations. Spine 17:S317–24
22. Chance G (1948) Note on a type of flexion fracture of the spine. Br J Radiol 21:452–3
23. Chow GH, Nelson BJ, Gebhard JS, Brugman JL, Brown CW, Donaldson DH (1996) Functional outcome of thoracolumbar burst fractures managed with hyperextension casting or bracing and early mobilization. Spine 21:2170–5
24. Dai L-Y, Yao W-F, Cui Y-M, Zhou Q (2004) Thoracolumbar fractures in patients with multiple injuries: diagnosis and treatment – a review of 147 cases. J Trauma 56:348–55
25. Daniaux H (1986) Transpedicular repositioning and spongioplasty in fractures of the vertebral bodies of the lower thoracic and lumbar spine. Unfallchirurg 89:197–213
26. Daniaux H, Seykora P, Genelin A, Lang T, Kathrein A (1991) Application of posterior plating and modifications in thoracolumbar spine injuries. Indication, techniques, and results. Spine 16:S125–33
27. Daniaux H, Wagner M, Kathrein A, Lang T (1999) [Fractures of the thoraco-lumbar junction. Conservative management]. Orthopade 28:682–91
28. Defino HL, Rodriguez-Fuentes AE (1998) Treatment of fractures of the thoracolumbar spine by combined anteroposterior fixation using the Harms method. Eur Spine J 7:187–94
29. Defino HL, Scarparo P (2005) Fractures of thoracolumbar spine: monosegmental fixation. Injury 36 Suppl 2:B90–7
30. Denis F (1983) The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine 8:817–31
31. Denis F, Armstrong GW, Searls K, Matta L (1984) Acute thoracolumbar burst fractures in the absence of neurologic deficit. A comparison between operative and nonoperative treatment. Clin Orthop Relat Res 142–9
32. Denis F, Burkus JK (1992) Shear fracture-dislocations of the thoracic and lumbar spine associated with forceful hyperextension (lumberjack paraplegia). Spine 17:156–61
33. DeWald RL (1984) Burst fractures of the thoracic and lumbar spine. Clin Orthop Relat Res 150–61
34. Dick W (1987) The "fixateur interne" as a versatile implant for spine surgery. Spine 12: 882–900
35. Dickson JH, Harrington PR, Erwin WD (1978) Results of reduction and stabilization of the severely fractured thoracic and lumbar spine. J Bone Joint Surg Am 60:799–805
36. el-Khoury GY, Whitten CG (1993) Trauma to the upper thoracic spine: anatomy, biomechanics, and unique imaging features. AJR Am J Roentgenol 160:95–102
37. Evans L (1988) Risk of fatality from physical trauma versus sex and age. J Trauma 28:368–78
38. Eysel P, Meinig G, Sanner F (1991) Comparative study of various dorsal stabilization procedures in recent fractures of the thoracic spine. Unfallchirurgie 17:264–73
39. Faciszewski T, Winter RB, Lonstein JE, Denis F, Johnson L (1995) The surgical and medical perioperative complications of anterior spinal fusion surgery in the thoracic and lumbar spine in adults. A review of 1223 procedures. Spine 20:1592–9
40. Fehlings MG, Perrin RG (2005) The role and timing of early decompression for cervical spinal cord injury: Update with a review of recent clinical evidence. Injury S-B13–S-B26
41. Feil J, Wörsdörfer O (1992) [Ventral stabilization in the area of the thoracic and lumbar spine]. Chirurg 63:856–65

42. Feil J, Wörsdörfer O (1992) Complications in surgical management of spinal injuries. Langenbecks Arch Chir Suppl Kongressbd 304–10
43. Floman Y, Fast A, Pollack D, Yosipovitch Z, Robin GC (1986) The simultaneous application of an interspinous compressive wire and Harrington distraction rods in the treatment of fracture-dislocation of the thoracic and lumbar spine. Clin Orthop Relat Res 207–15
44. Frankel HL, Hancock DO, Hyslop G, Melzak J, Michaelis LS, Ungar GH, Vernon JD, Walsh JJ (1969) The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. I. Paraplegia 7:179–92
45. Fredrickson BE, Edwards WT, Rauschning W, Bayley JC, Yuan HA (1992) Vertebral burst fractures: an experimental, morphologic, and radiographic study. Spine 17:1012–21
46. Gertzbein SD (1992) Fractures of the thoracic and lumbar spine. Williams & Wilkins, Baltimore
47. Gertzbein SD (1992) Scoliosis Research Society. Multicenter spine fracture study. Spine 17:528–40
48. Gopalakrishnan KC, el Masri WS (1986) Fractures of the sternum associated with spinal injury. J Bone Joint Surg Br 68:178–81
49. Gotzen L, Puplat D, Junge A (1992) Indications, technique and results of monosegmental dorsal spondylodesis in wedge compression fractures (grade II) of the thoracolumbar spine. Unfallchirurg 95:445–54
50. Haas N, Blauth M, Tscherne H (1991) Anterior plating in thoracolumbar spine injuries. Indication, technique, and results. Spine 16:S100–11
51. Harrington RM, Budorick T, Hoyt J, Anderson PA, Tencer AF (1993) Biomechanics of indirect reduction of bone retropulsed into the spinal canal in vertebral fracture. Spine 18:692–9
52. Hauser CJ, Visvikis G, Hinrichs C, Eber CD, Cho K, Lavery RF, Livingston DH (2003) Prospective validation of computed tomographic screening of the thoracolumbar spine in trauma. J Trauma 55:228–34; discussion 34–5
53. Henderson RL, Reid DC, Saboe LA (1991) Multiple noncontiguous spine fractures. Spine 16:128–31
54. Holdsworth F (1963) Fractures, dislocations, and fracture-dislocations of the spine. J Bone Joint Surg Am 45:6–20
55. Holdsworth F (1970) Fractures, dislocations, and fracture-dislocations of the spine. J Bone Joint Surg Am 52:1534–51
56. Hu R, Mustard CA, Burns C (1996) Epidemiology of incident spinal fracture in a complete population. Spine 21:492–9
57. Inaba K, Munera F, McKenney M, Schulman C, de Moya M, Rivas L, Pearce A, Cohn S (2006) Visceral torso computed tomography for clearance of the thoracolumbar spine in trauma: a review of the literature. J Trauma 60:915–20
58. Jahna H, Wittich H (1985) Konservative Methoden in der Frakturbehandlung. Urban & Fischer, Vienna, pp 121–38
59. Junge A, Gotzen L, von Garrel T, Ziring E, Giannadakis K (1997) [Monosegmental internal fixator instrumentation and fusion in treatment of fractures of the thoracolumbar spine. Indications, technique and results]. Unfallchirurg 100:880–7
60. Kaneda K, Taneichi H, Abumi K, Hashimoto T, Satoh S, Fujiya M (1997) Anterior decompression and stabilization with the Kaneda device for thoracolumbar burst fractures associated with neurological deficits. J Bone Joint Surg Am 79:69–83
61. Kelly RP, Whitesides TE (1968) Treatment of lumbodorsal fracture-dislocations. Ann Surg 167:705–17
62. Khoo LT, Beisse R, Potulski M (2002) Thoracoscopic-assisted treatment of thoracic and lumbar fractures: a series of 371 consecutive cases. Neurosurgery 51:104–17
63. Kim DH, Silber JS, Albert TJ (2003) Osteoporotic vertebral compression fractures. Instr Course Lect 52:541–50
64. King AG (1987) Burst compression fractures of the thoracolumbar spine. Pathologic anatomy and surgical management. Orthopedics 10:1711–9
65. Knop C, Blauth M, Bühren V, Hax PM, Kinzl L, Mutschler W, Pommer A, Ulrich C, Wagner S, Weckbach A, Wentzensen A, Wörsdörfer O (1999) Surgical treatment of injuries of the thoracolumbar transition. 1: Epidemiology. Unfallchirurg 102:924–35
66. Knop C, Blauth M, Bühren V, Hax PM, Kinzl L, Mutschler W, Pommer A, Ulrich C, Wagner S, Weckbach A, Wentzensen A, Wörsdörfer O (2000) Surgical treatment of injuries of the thoracolumbar transition. 2: Operation and roentgenologic findings. Unfallchirurg 103:1032–47
67. Knop C, Blauth M, Bühren V, Arand M, Egbers HJ, Hax PM, Nothwang J, Oestern HJ, Pizanis A, Roth R, Weckbach A, Wentzensen A (2001) Surgical treatment of injuries of the thoracolumbar transition – 3: Follow-up examination. Results of a prospective multi-center study by the "Spinal" Study Group of the German Society of Trauma Surgery. Unfallchirurg 104:583–600
68. Knop C, Fabian HF, Bastian L, Blauth M (2001) Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting. Spine 26:88–99

69. Knop C, Bastian L, Lange U, Oeser M, Zdichavsky M, Blauth M (2002) Complications in surgical treatment of thoracolumbar injuries. Eur Spine J 11:214–26
70. Knop C, Fabian HF, Bastian L, Rosenthal H, Lange U, Zdichavsky M, Blauth M (2002) Fate of the transpedicular intervertebral bone graft after posterior stabilisation of thoracolumbar fractures. Eur Spine J 11:251–7
71. Kossmann T, Ertel W, Platz A, Trentz O (1999) [Combined surgery for fractures of the thoraco-lumbar junction using the inlay-span method]. Orthopade 28:432–40
72. Kossmann T, Jacobi D, Trentz O (2001) The use of a retractor system (SynFrame) for open, minimal invasive reconstruction of the anterior column of the thoracic and lumbar spine. Eur Spine J 10:396–402
73. Kraemer WJ, Schemitsch EH, Lever J, McBroom RJ, McKee MD, Waddell JP (1996) Functional outcome of thoracolumbar burst fractures without neurological deficit. J Orthop Trauma 10:541–4
74. Krueger MA, Green DA, Hoyt D, Garfin SR (1996) Overlooked spine injuries associated with lumbar transverse process fractures. Clin Orthop 191–5
75. La Rosa G, Conti A, Cardali S, Cacciola F, Tomasello F (2004) Does early decompression improve neurological outcome of spinal cord injured patients? Appraisal of the literature using a meta-analytical approach. Spinal Cord 42:503–12
76. Larson SJ, Holst RA, Hemmy DC, Sances A (1976) Lateral extracavitary approach to traumatic lesions of the thoracic and lumbar spine. J Neurosurg 45:628–37
77. Leidner B, Adiels M, Aspelin P, Gullstrand P, Wallen S (1998) Standardized CT examination of the multitraumatized patient. Eur Radiol 8:1630–8
78. Lindsey RW, Dick W (1991) The fixateur interne in the reduction and stabilization of thoracolumbar spine fractures in patients with neurologic deficit. Spine 16:S140–5
79. Louis R (1977) Unstable fractures of the spine. III. Instability. A. Theories concerning instability. Rev Chir Orthop Reparatrice Appar Mot 63:423–5
80. Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S (1994) A comprehensive classification of thoracic and lumbar injuries. Eur Spine J 3:184–201
81. Magerl F, Engelhardt P (1994) Brust- und Lendenwirbelsäule – Verlaufsformen. In: Witt AN, Rettig H, Schlegel KF (eds) Orthopädie in Praxis und Klinik, Spezielle Orthopädie (Wirbelsäule – Thorax – Becken). Thieme, Stuttgart New York, pp 3.82–3.132
82. Magnus G (1930) Die Begutachtung und Behandlung des Wirbelbruchs. Arch Orthop Unfallchir 29:277
83. Mayer H, Schaaf D, Kudernatsch M (1992) Use of internal fixator in injuries of the thoracic and lumbar spine. Chirurg 63:944–9
84. Maynard FM, Jr, Bracken MB, Creasey G, Ditunno JF, Jr, Donovan WH, Ducker TB, Garber SL, Marino RJ, Stover SL, Tator CH, Waters RL, Wilberger JE, Young W (1997) International Standards for Neurological and Functional Classification of Spinal Cord Injury. American Spinal Injury Association. Spinal Cord 35:266–74
85. McLain RF, Sparling E, Benson DR (1993) Early failure of short-segment pedicle instrumentation for thoracolumbar fractures. A preliminary report. J Bone Joint Surg Am 75:162–7
86. Meyer PR, Heim S (1989) Fractures of the thoracic spine T1–T10. In: Meyer PR (ed) Surgery of spine trauma. Churchill Livingstone, Edinburgh, pp 525–72
87. Mumford J, Weinstein JN, Spratt KF, Goel VK (1993) Thoracolumbar burst fractures. The clinical efficacy and outcome of nonoperative management. Spine 18:955–70
88. Müller U, Berlemann U, Sledge J, Schwarzenbach O (1999) Treatment of thoracolumbar burst fractures without neurologic deficit by indirect reduction and posterior instrumentation: bisegmental stabilization with monosegmental fusion. Eur Spine J 8:284–9
89. Nicoll EA (1949) Fractures of the dorso-lumbar spine. J Bone Joint Surg Br 31:376–94
90. Olerud S, Karlstrom G, Sjostrom L (1988) Transpedicular fixation of thoracolumbar vertebral fractures. Clin Orthop Relat Res 227:44–51
91. Place HM, Donaldson DH, Brown CW, Stringer EA (1994) Stabilization of thoracic spine fractures resulting in complete paraplegia. A long-term retrospective analysis. Spine 19:1726–30
92. Rechtine GR (1999) Nonsurgical treatment of thoracic and lumbar fractures. Instr Course Lect 48:413–6
93. Rechtine GR, 2nd, Cahill D, Chrin AM (1999) Treatment of thoracolumbar trauma: comparison of complications of operative versus nonoperative treatment. J Spinal Disord 12:406–9
94. Reid DC, Hu R, Davis LA, Saboe LA (1988) The nonoperative treatment of burst fractures of the thoracolumbar junction. J Trauma 28:1188–94
95. Reinhold M, Knop C, Lange U, Bastian L, Blauth M (2003) Non-operative treatment of thoracolumbar spinal fractures. Long-term clinical results over 16 years. Unfallchirurg 106: 566–76
96. Resch H, Rabl M, Klampfer H, Ritter E, Povacz P (2000) Surgical vs. conservative treatment of fractures of the thoracolumbar transition. Unfallchirurg 103:281–8
97. Richards PJ (2005) Cervical spine clearance: a review. Injury 36:248–69
98. Roaf R (1960) A study of the mechanics of spinal injuries. J Bone Joint Surg Br 42B:810–23

99. Roy-Camille R, Saillant G (1984) Spinal injuries without neurologic complications. Int Orthop 8:155–62
100. Saboe LA, Reid DC, Davis LA, Warren SA, Grace MG (1991) Spine trauma and associated injuries. J Trauma 31:43–8
101. Samuels LE, Kerstein MD (1993) 'Routine' radiologic evaluation of the thoracolumbar spine in blunt trauma patients: a reappraisal. J Trauma 34:85–9
102. Sasso RC, Cotler HB (1993) Posterior instrumentation and fusion for unstable fractures and fracture-dislocations of the thoracic and lumbar spine. A comparative study of three fixation devices in 70 patients. Spine 18:450–60
103. Sasso RC, Best NM, Reilly TM, McGuire RA (2005) Anterior-only stabilization of three-column thoracolumbar injuries. J Spinal Disord Tech 18 Suppl:S7–14
104. Shen WJ, Shen YS (1999) Nonsurgical treatment of three-column thoracolumbar junction burst fractures without neurologic deficit. Spine 24:412–5
105. Shen WJ, Liu TJ, Shen YS (2001) Nonoperative treatment versus posterior fixation for thoracolumbar junction burst fractures without neurologic deficit. Spine 26:1038–45
106. Sheridan R, Peralta R, Rhea J, Ptak T, Novelline R (2003) Reformatted visceral protocol helical computed tomographic scanning allows conventional radiographs of the thoracic and lumbar spine to be eliminated in the evaluation of blunt trauma patients. J Trauma 55:665–9
107. Shono Y, McAfee PC, Cunningham BW (1994) Experimental study of thoracolumbar burst fractures. A radiographic and biomechanical analysis of anterior and posterior instrumentation systems. Spine 19:1711–22
108. Speth MJ, Oner FC, Kadic MA, de Klerk LW, Verbout AJ (1995) Recurrent kyphosis after posterior stabilization of thoracolumbar fractures. 24 cases treated with a Dick internal fixator followed for 1.5–4 years. Acta Orthop Scand 66:406–10
109. Spitz J, Becker C, Tittel K, Weigand H (1992) [Clinical relevance of whole body skeletal scintigraphy in multiple injury and polytrauma patients]. Unfallchirurgie 18:133–47
110. Spivak JM, Neuwirth MG, Giordano CP, Bloom N (1994) The perioperative course of combined anterior and posterior spinal fusion. Spine 19:520–5
111. Steindl A, Schuh G (1992) Late results after lumbar vertebrae fracture with Lorenz Böhler conservative treatment. Unfallchirurg 95:439–44
112. Transfeldt EE, White D, Bradford DS, Roche B (1990) Delayed anterior decompression in patients with spinal cord and cauda equina injuries of the thoracolumbar spine. Spine 15:953–7
113. Vaccaro AR, Daugherty RJ, Sheehan TP, Dante SJ, Cotler JM, Balderston RA, Herbison GJ, Northrup BE (1997) Neurologic outcome of early versus late surgery for cervical spinal cord injury. Spine 22:2609–13
114. Vaccaro AR, Kim DH, Brodke DS, Harris M, Chapman JR, Schildhauer T, Routt ML, Sasso RC (2004) Diagnosis and management of thoracolumbar spine fractures. Instr Course Lect 53:359–73
115. Wawro W, Konrad L, Aebi M (1994) Single segment internal fixator device in treatment of thoracolumbar vertebral fractures. Unfallchirurg 97:114–20
116. Weinstein JN, Collalto P, Lehmann TR (1988) Thoracolumbar "burst" fractures treated conservatively: a long-term follow-up. Spine 13:33–8
117. Weitzman G (1971) Treatment of stable thoracolumbar spine compression fractures by early ambulation. Clin Orthop 76:116–22
118. White AA, 3rd, Panjabi MM (1978) The basic kinematics of the human spine. A review of past and current knowledge. Spine 3:12–20
119. Whitesides TE (1977) Traumatic kyphosis of the thoracolumbar spine. Clin Orthop 78–92
120. Woltmann A, Bühren V (2004) Emergency room management of the multiply injured patient with spine injuries. A systematic review of the literature. Unfallchirurg 107:911–9
121. Wood K, Butterman G, Mehbod A, Garvey T, Jhanjee R, Sechriest V (2003) Operative compared with nonoperative treatment of a thoracolumbar burst fracture without neurological deficit. A prospective, randomized study. J Bone Joint Surg Am 85-A:773–81
122. Wood KB, Bohn D, Mehbod A (2005) Anterior versus posterior treatment of stable thoracolumbar burst fractures without neurologic deficit: a prospective, randomized study. J Spinal Disord Tech 18 Suppl:S15–23
123. Young B, Brooks WH, Tibbs PA (1981) Anterior decompression and fusion for thoracolumbar fractures with neurological deficits. Acta Neurochir (Wien) 57:287–98