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2 Thoracolumbar Fractures

Zhe Zhao, Lihai Zhang, Yong Sun, and Jianheng Liu

2.1 Basic Theory and Concepts

2.1.1 Overview

- Thoracolumbar fractures are caused mostly by high-energy violence, of which 25% are associated with neurologic injury (Koval and Zuckerman 2006):
  – Approximately 65% of thoracolumbar fractures are caused by a motor vehicle accident or a fall from a high place.
  – The remaining 35% are caused by athletic participation or assault.
- Approximately 68% of thoracolumbar fractures are accompanied by other injuries, and 25% are accompanied by serious injuries (Lin and Lane 2004).
- With the aging of the population, the incidence of osteoporosis-related wedge compression fractures in elderly patients has been increasing in recent years (Lin and Lane 2004; Blam and Cotler 2002).
- Treatment goals: Correct deformities and prevent their progression; restore the stability of the spine; perform nerve decompression if needed; minimize the number of vertebrae involved in fusion while ensuring an adequate stability if fusion is unavoidable.

2.1.2 Applied Anatomy

1. The thoracolumbar spine is conceptually divided into three functional regions: the thoracic region, thoracolumbar region (junction), and lumbar region (Fig. 2.1).

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a. The thoracic region refers to the segment between T1 and T10 where the incidence rate of fractures is relatively low (Stagnara et al. 1982).
   - The thoracic region is stable due to the participation of the rib cage:
     – The structures, including the sternocostal joint in the anterior aspect, the costovertebral joint in the lateral aspect, and the spinous processes in an imbricated arrangement along with the surrounding ligaments and intervertebral discs in the posterior aspect, further stabilize this region.
     – Fractures within this region, which are rare but indicate highly violent force, are often severe and involve a large number of vertebrae and accessory components.
   - Fractures in this region are often associated with neurologic injury:
     – The thoracic spinal canal is relatively narrow, and the ratio of the cross-sectional areas of the spinal cord and spinal canal is only 40% (25% in the cervical spine), suggesting limited room for buffering after excluding structures such as the dural sac; particularly, the spinal canal has the smallest sagittal and transverse diameters at the level from T4 to T9.
   - Once a compression fracture occurs, the thoracic region is difficult to distract via the posterior approach:
     – Due to the protection of the rib cage and the close relationship between the transverse processes of the thoracic vertebrae and other anatomical structures such as the costal arch, the effect of posterior distraction is limited.
b. The thoracolumbar region (junction) refers to the region from T11 to L2. Approximately 50% of thoracolumbar fractures occur in this region (Gertzbein 1992).

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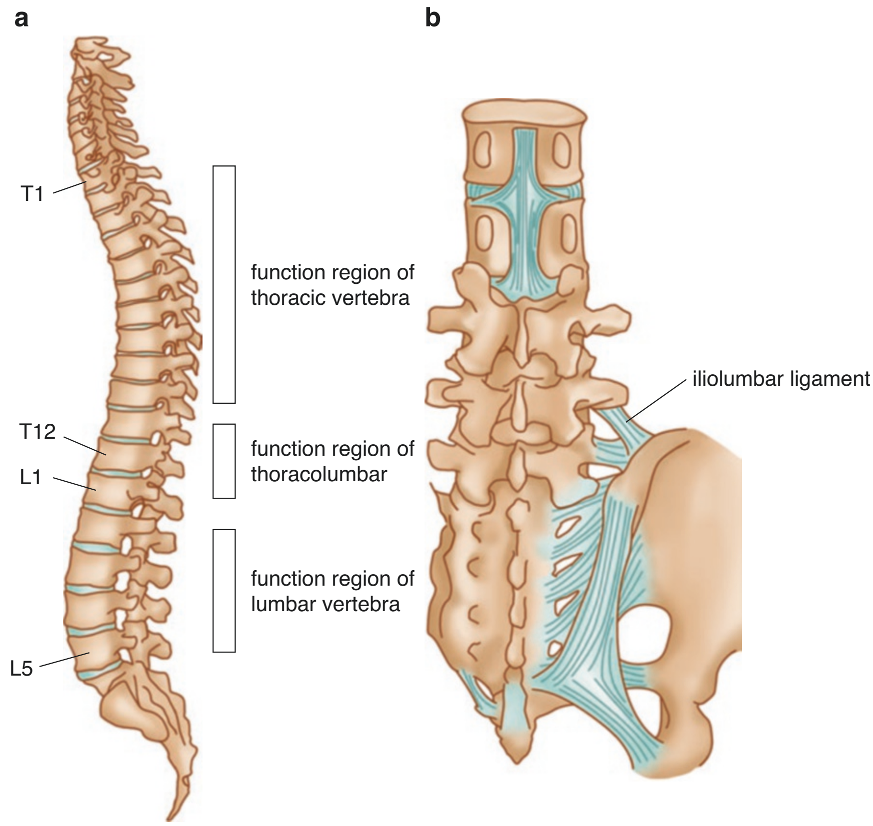

Fig. 2.1 Three functional regions of the thoracolumbar spine. (**a**) The thoracic region is kyphotic, the lumbar region is lordotic, and the thoracolumbar region is the transitional zone between the two natural curves. (**b**) The lower lumbar spine is connected to the pelvis by the iliolumbar ligament, which increases the stability of the spine

- The thoracolumbar region is the junction area for stress transmission and movement of the spine:
  - As the junction of the relatively stiff thoracic spine and the more mobile lumbar spine, this region bears the maximal stress.
  - This region is a biomechanical turning point of the spine because it is the junction of two nature curves, the kyphotic thoracic spine and the lordotic lumbar spine.
- Fractures in this region are often associated with injuries of the spine or cauda equina:
  - The medullary conus has been reported to end at the level of the lower edge of L1 in 55% of Chinese patients, where a horizontal fracture is often associated with a medullary conus injury (Guo 2001).
  - Depending on the level of the spine involved, the injury might cause damage to upper motor neurons, lower motor neurons, or both, which can be identified based on the segmental spinal cord functions and corresponding neurologic examination.

c. The lumbar region includes the region from L3 to L5 and has a relatively low incidence of fractures (White and Panjabi 1978; Vialle et al. 2005).
- Fractures within the lumbar region are primarily treated non-surgically:
  - Fractures of accessory structures often occur, including transverse process and spinous process fractures.
- The incidence of nerve injuries is low, and most of them include incomplete nerve injury.
  - The lumbar spinal canal within this region is wide.
  - The cauda equina, which passes the lumbar spinal canal in this region, is highly resistant to compression.

2. Blood supply to the spinal cord (Fig. 2.2):
   a. The spinal cord receives blood mainly from three vessels: the anterior median spinal artery and two dorsolateral spinal arteries.
   b. At each vertebral level, one pair of segmental arteries supplies blood to the internal and external components of the spine, and the radicular arteries in the thoracolumbar region (junction) mostly originate from the aorta. The branches sent from the segmental arteries near the intervertebral foramen form a vascular network in the spinal epidural loose connective tissue. Therefore, each segment of the spinal cord has an abundant blood supply, even after the corresponding segmental artery is ligated. In addition, many of the radicular arteries and the anterior median spinal artery converge, further increasing the blood supply to the spinal cord.

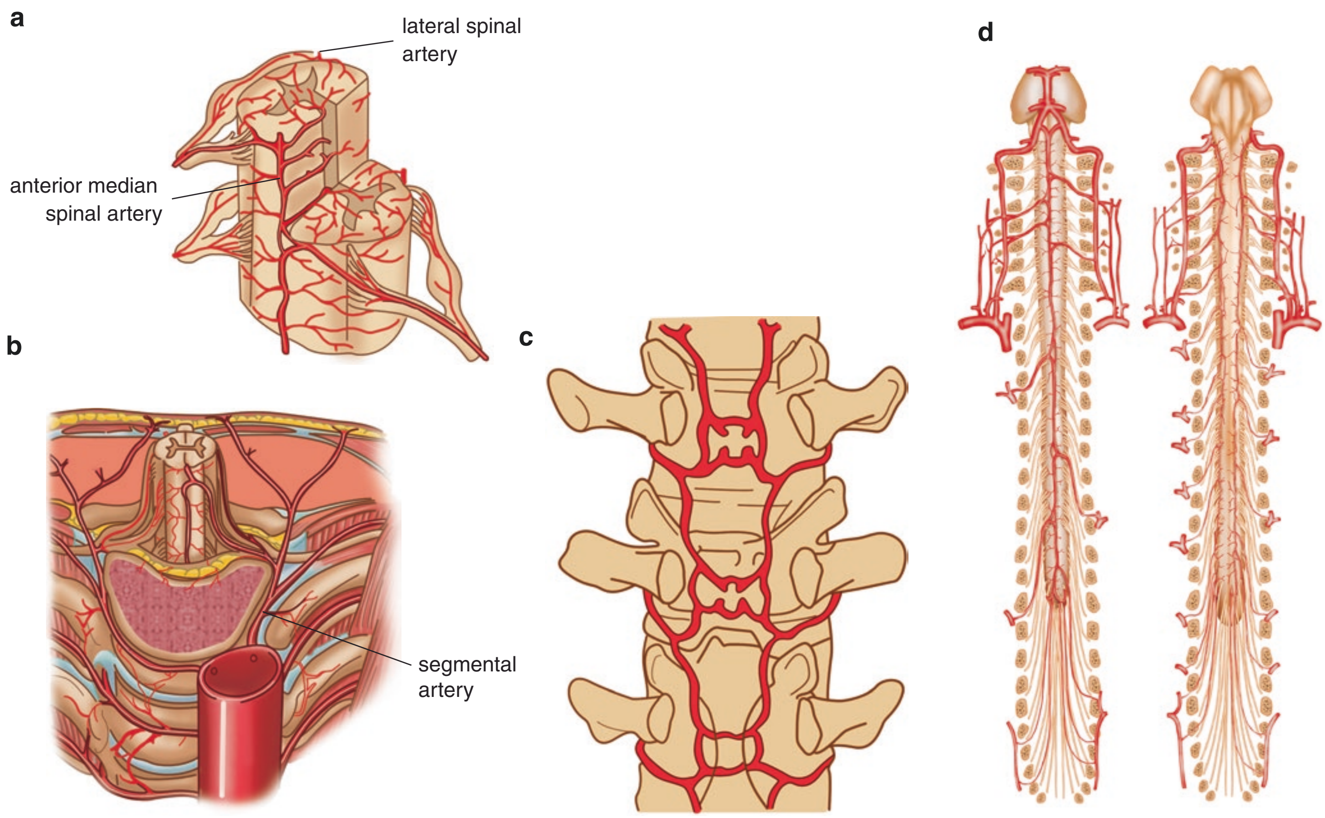

Fig. 2.2 Blood supply to the spinal cord. (**a**) The arterial network of the spinal cord is derived primarily from the anterior median spinal artery and the left and right dorsolateral spinal arteries. (**b**) In the thoracic region, each vertebral segment has one pair of segmental arteries supplying blood to the vertebral body. (**c**) The segmental arteries form the vascular network in the spinal canal. (**d**) Overview of the blood supply of the spinal cord: The location of the Adamkiewicz artery is critical

c. The Adamkiewicz artery (Alleyne et al. 1998) is the largest blood-supplying vessel to the lumbar spine. It is located on the left side at the level of T9–11 and should be protected with special precautions during surgery.
d. The region between T2 and T10 is the junction of the areas receiving blood from different origins, which proximally receives blood from the antegrade vessels in the upper thoracic spine and distally from the retrograde flow from the Adamkiewicz artery. In addition, the spinal canal at the level is narrowest between T4 and T9. Therefore, this region has the poorest blood supply and is relatively vulnerable because any trauma or surgical operation that disrupts the blood-supplying system in this region might cause neurologic deficits.
e. Thoracic spinal cord injury without fracture-dislocation, which is clinically common, is related to avascular necrosis of the thoracic spinal cord following Adamkiewicz artery damage that disrupts the blood supply. The patients are usually presented with immediate paralysis after injury, but pediatric patients might experience paralysis from 2 h to 4 days after trauma, which is called delayed paralysis.
f. The basivertebral system of veins: The veins around the vertebrae converge to the central vein, which runs out from the nutrient foramen in the middle of the posterior vertebrae and converges to the venous plexus in the spinal canal (Fig. 2.3). Damage to the central vein during surgery may cause massive bleeding.

3. The three-column structure of the spine (Fig. 2.4): This concept was first proposed by Francis Denis (Denis 1983).
   a. The anterior column consists of the anterior longitudinal ligament, anterior half of the vertebral bodies, and anterior fibrous rings.
   b. The middle column consists of the posterior half of the vertebral bodies, posterior fibrous rings, and posterior longitudinal ligament.
   c. The posterior column consists of the posterior osteoligamentous complex (the vertebral lamina, spinous process, supraspinous ligament, interspinous ligament, joint capsule, and ligamentum flavum).
   d. The anterior, middle, and posterior columns bear 40%, 30%, and 30% of the total load, respectively; therefore, a fracture involving two columns is considered unstable.

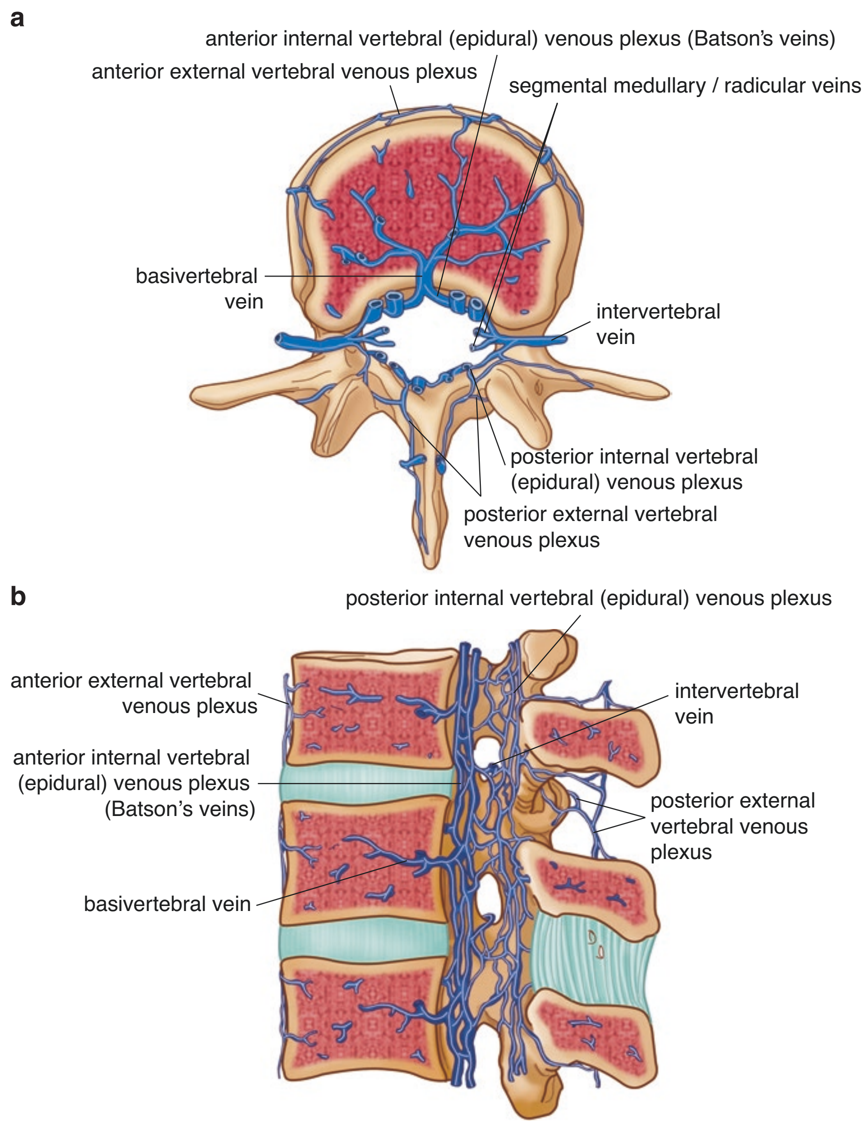

Fig. 2.3 (**a**, **b**) Cross-section (**a**) and sagittal views (**b**) of the vertebral veins showing that the veins around the vertebral body converge to the central vein, which exits the nutrient foramen in the middle of the posterior vertebrae and converges to the venous plexus in the spinal canal

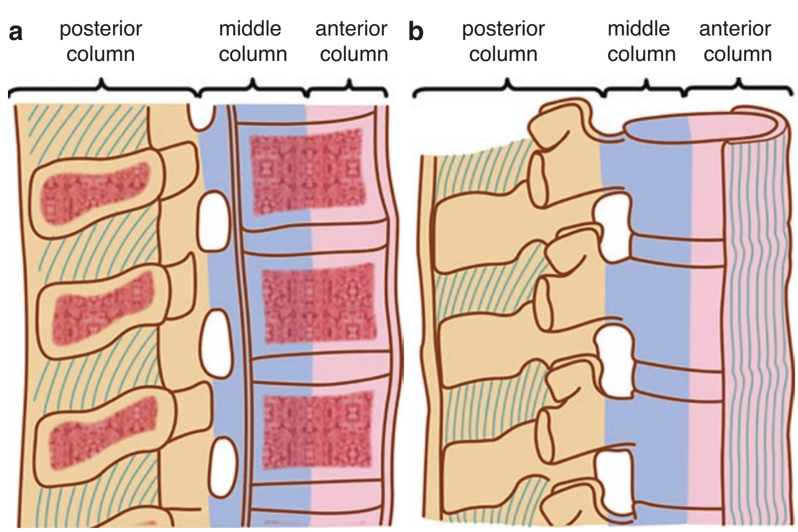

Fig. 2.4 (**a**, **b**) The anterior column consists of the anterior longitudinal ligament, the anterior half of the vertebral bodies, and the anterior fibrous rings. The middle column is composed of the posterior half of the vertebral bodies, the posterior fibrous rings, and the posterior longitudinal ligament. The posterior column is composed of the posterior osteoligamentous complex

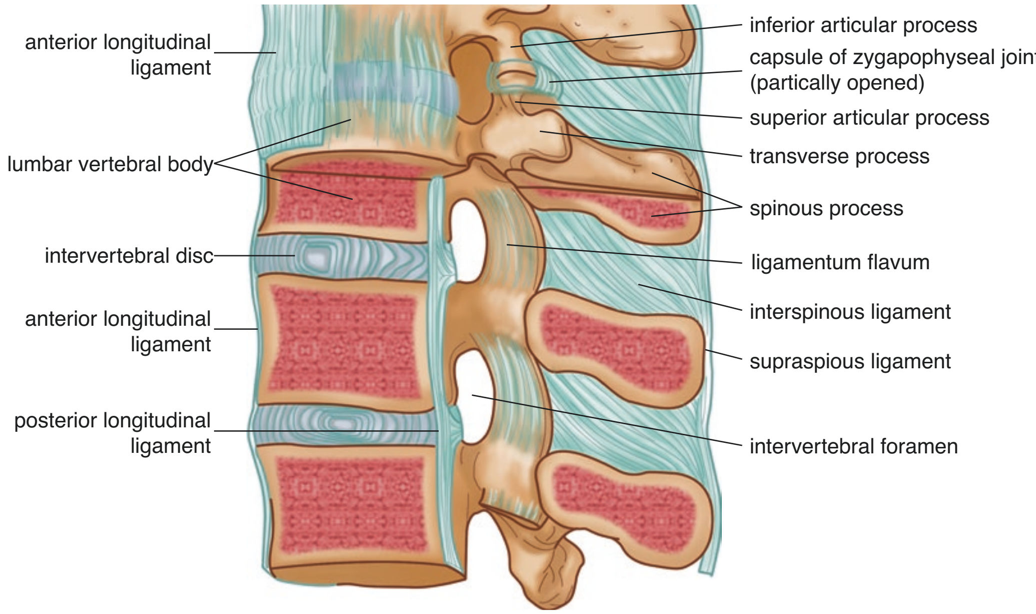

Fig. 2.5 The posterior ligament complex consists of the supraspinous ligament, interspinous ligament, posterior longitudinal ligament, capsule of the facet joint, and ligamentum flavum

4. The posterior ligament complex: It is an important item in the thoracolumbar injury classification and severity score (Vaccaro et al. 2005) (TLICS) system proposed by Vaccaro et al.:
   a. The posterior ligament complex consists of the supraspinous ligament, interspinous ligament, posterior longitudinal ligament, capsule of the facet joint, and ligamentum flavum (Fig. 2.5);
   b. Rupture of the posterior osteoligamentous complex is observed most frequently in flexion-distraction fractures and fracture-displacement injuries, as well as in a portion of burst fractures and occasionally in isolated compression fractures. Magnetic resonance imaging (MRI) serves as the best tool for assessing the integrity of the posterior osteoligamentous complex.
5. The channel for vertebral pedicle pin placement: The diameter of the vertebral pedicle and the position relationship between the vertebral pedicle and vertebral body are crucial for the pedicle screw internal fixation system. The diameter and angle of the vertebral pedicle gradually change from the upper thoracic spine to the lower lumbar spine (Zindrick et al. 1987) (Fig. 2.6).
   a. Horizontal width: The horizontal width shows an overall decreasing trend from the top down, with T7 exhibiting the smallest width.
   b. Vertical diameter: Overall, the lumbar vertebrae are taller than the thoracic vertebrae, with T11 displaying the greatest height.
   c. The inclination angle relative to the horizontal plane—This angle determines the angle at which the pedicle screws point to each other:
      - The thoracic spine has a greater inclination angle on its proximate side, which changes from 27° at the level of T1 to 1° at the level of T11 and to −4° at the level of T12.
      - The inclination angle increases from top to bottom in the lumbar region from 11° at the level of L1 to approximately 30° at the level of L5. However, due to a large size, the L5 vertebral pedicle is a good location for vertebral pedicle pin placement.

2.1.3 Mechanism of Injury

- Thoracolumbar fractures are primarily caused by high-energy violence.
- The violence, including compressive, separative, flexion-distraction, twisting, and shear forces, may be applied to the spine either separately or jointly (Eismont et al. 2009) (Fig. 2.7).
  – Axial compressive forces often cause burst fractures of the thoracolumbar region (junction).
  – Flexion (hyperflexion): The anterior components are compressed, and the posterior components are tensioned, which causes compression fractures of the vertebral body if the force is not too strong and may cause a rupture of the posterior ligament complex as the force increases.
  – Lateral compression: A lateral wedge-shaped compression injury often occurs.
  – Shear: The ligaments are severely ruptured, and the vertebrae above and below are displaced.
  – Extension (hyperextension): The articular process, vertebral lamina, and spinous process are fractured, which may be accompanied by an avulsion of the anterior edge of the vertebra.

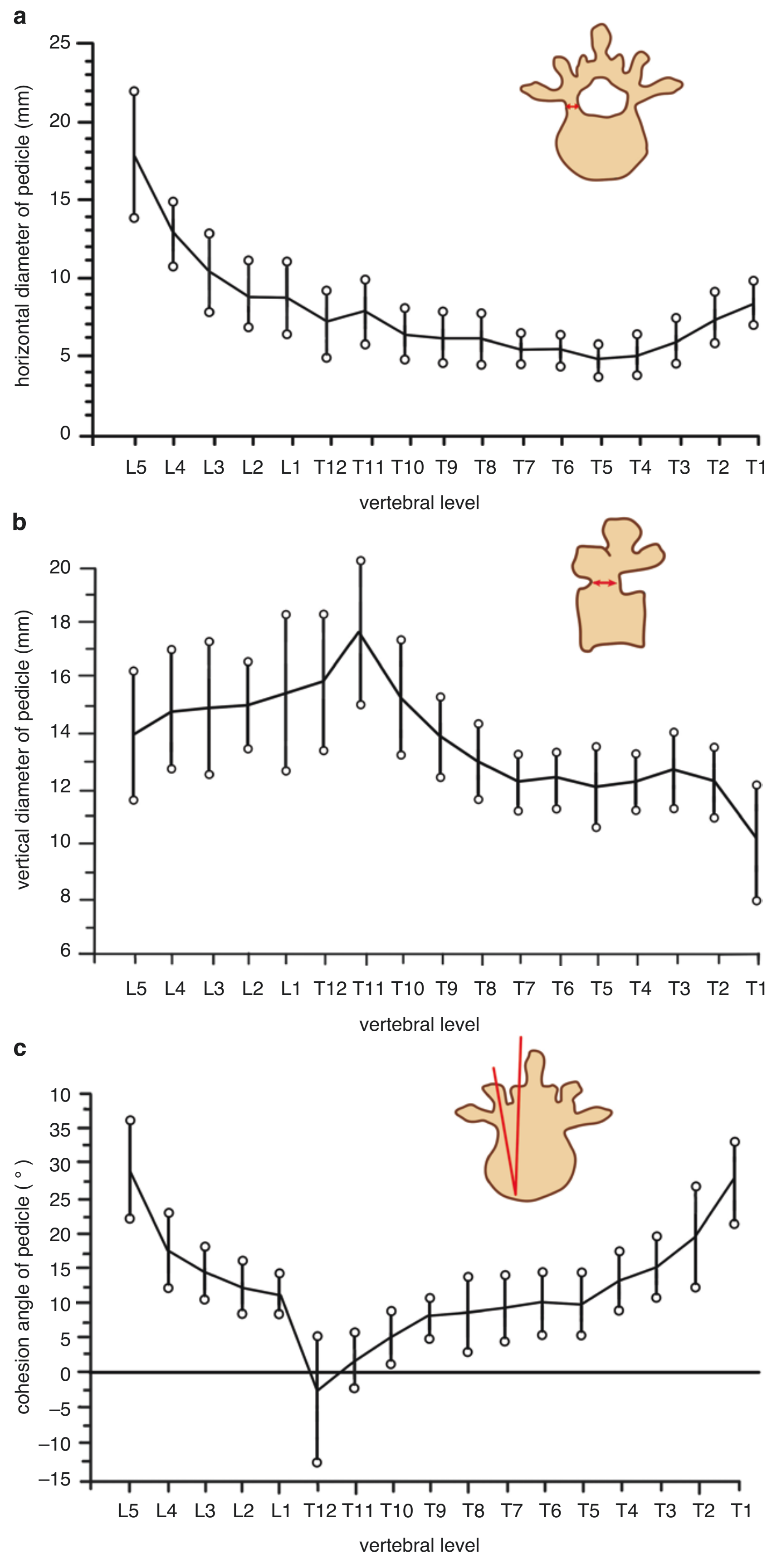

Fig. 2.6 (**a**) The horizontal diameter of the vertebral pedicles in different vertebral segments. (**b**) The vertical diameter of the vertebral pedicles in different vertebral segments. (**c**) The convergence angle of the vertebral pedicle in different vertebral segments

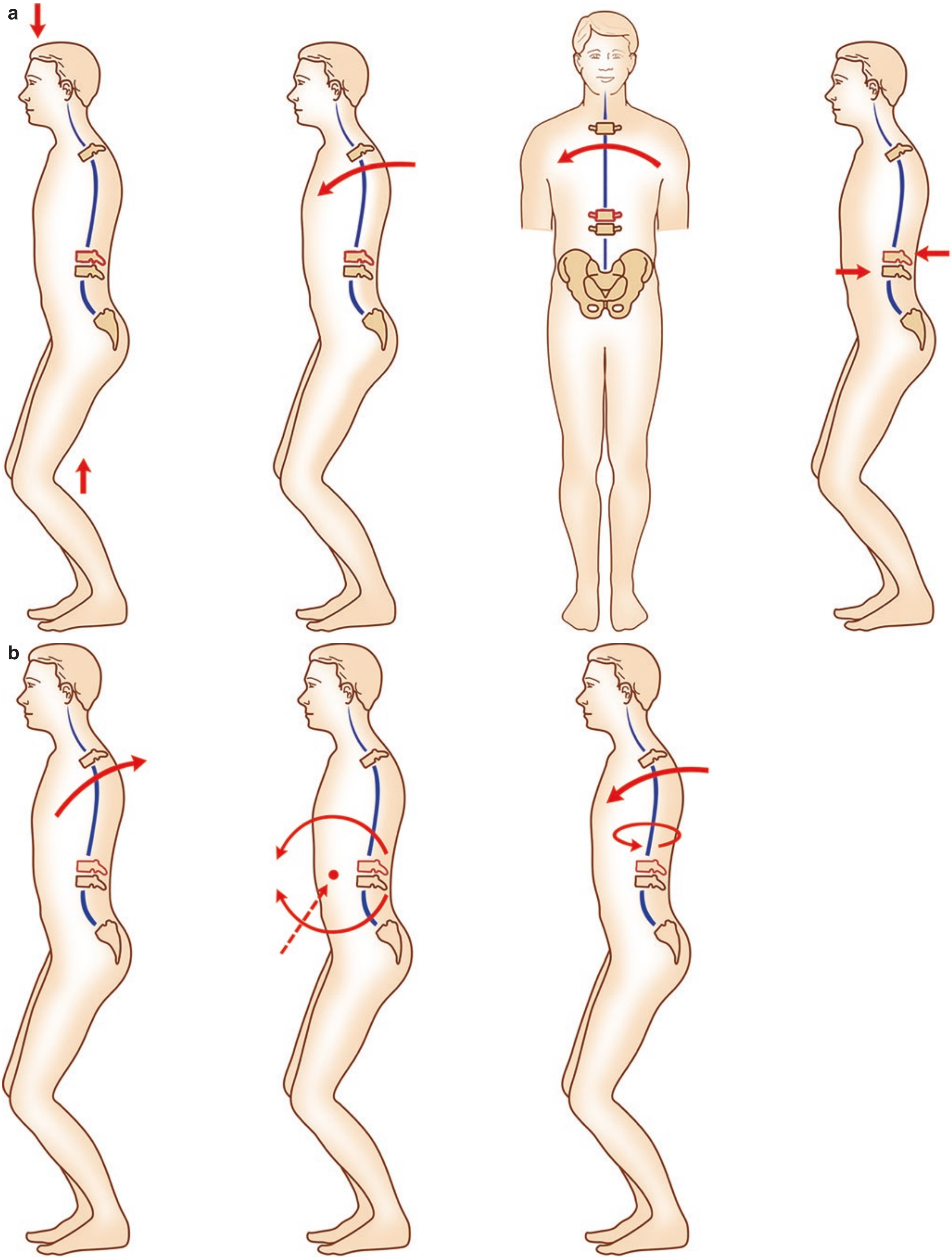

Fig. 2.7 Mechanism of thoracolumbar fracture injury. (**a**) Axial compression, flexion (hyperflexion), lateral compression and shear forces. (**b**) Extension (hyperextension), flexion-separation and flexion with rotation forces

– Flexion-separation: A tension force acts on the spine, causing rupture and avulsion of the intervertebral discs, ligaments, and bones, i.e., Chance injury.
– Flexion with rotation: The posterior articular processes, joint capsules, and ligaments are often injured; the spine is severely damaged.

2.1.4 Fracture Classification

1. Dennis classification (Denis 1983): This method classifies fractures according to radiological manifestations.
   a. Spine secondary fractures include the articular process, transverse process, spinous process, and isthmus fractures.
   b. Primary fractures of the spine:
      • Compression fractures:
        – A compression fracture is a fracture of the anterior edge of a vertebral body with an intact middle column.
        – It is usually stable.
        – A compression injury is unstable when the vertebral body is compressed >50%, the fractured vertebra has an angulation from >20–30°, or multiple adjacent vertebrae are compressed.
        – Compression fractures are divided into four types according to the involvement of the end-plates (Fig. 2.8):
          Type A involves both the superior and inferior end-plates.

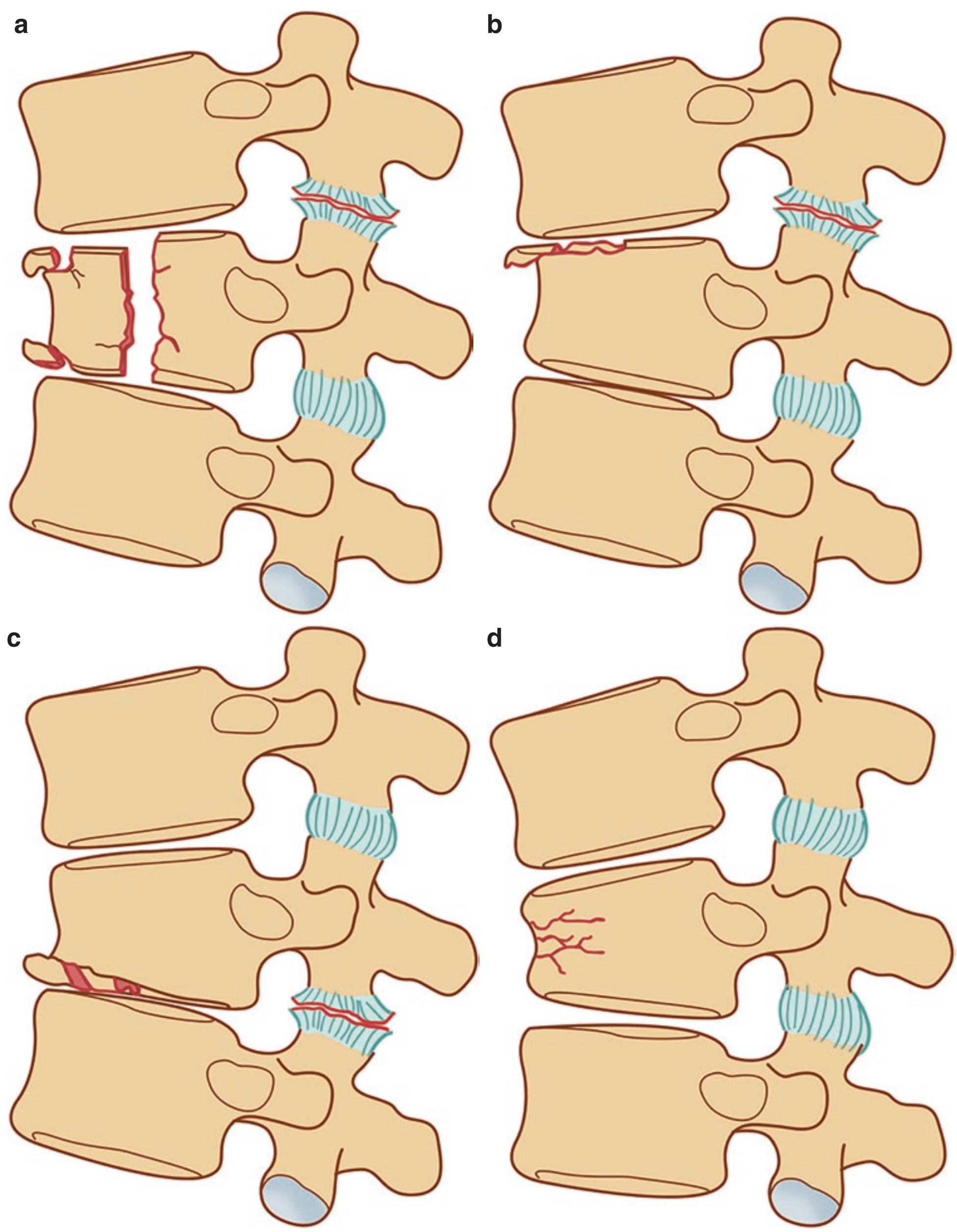

Fig. 2.8 Denis classification of compression fractures. (**a**) The Type A fracture involves both the superior and inferior end-plates. (**b**) Type B involves only the superior end-plate. (**c**) Type C involves only the inferior end-plate. (**d**) The Type D fracture is associated with buckling of the anterior edge of the bone cortex of the vertebral body while both the superior and inferior end-plates remain intact

Type B involves only the superior end-plate.
Type C involves only the inferior end-plate.
Type D shows buckling of the cortex at the anterior edge of the vertebral body while both end-plates remain intact.

- Burst fractures:
  - refer to the burst rupture of the posterior wall of the vertebral body (the middle column of the spinal cord).
  - are unstable if the posterior column is involved.
  - include five types (Fig. 2.9):

    Type A involves both the superior and inferior end-plates.
    Type B involves only the superior end-plate.
    Type C involves only the inferior end-plate.
    Type D is a Type A fracture associated with rotation of the fractured vertebra.
    Type E is caused by lateral violence and demonstrates an asymmetry of the affected vertebra on AP radiographs.

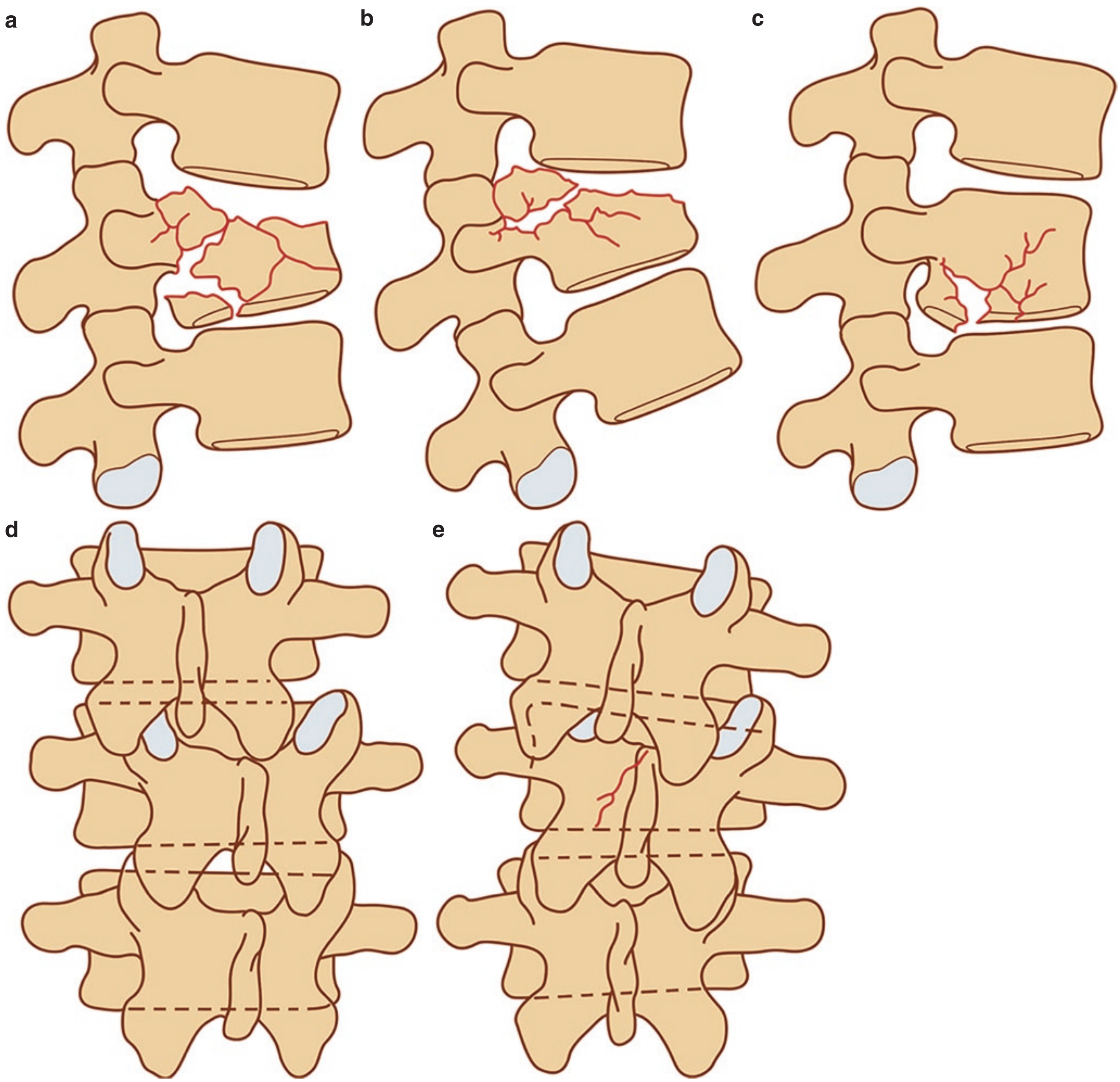

Fig. 2.9 Denis classification of burst fractures. (**a**) Type A involves both the superior and inferior end-plates. (**b**) Type B involves only the superior end-plate. (**c**) Type C involves only the inferior end-plate. (**d**) Type D is a Type A fracture associated with rotation of the fractured vertebra. (**e**) Type E is caused by a lateral violence and demonstrates an asymmetry of the affected vertebra on AP radiographs

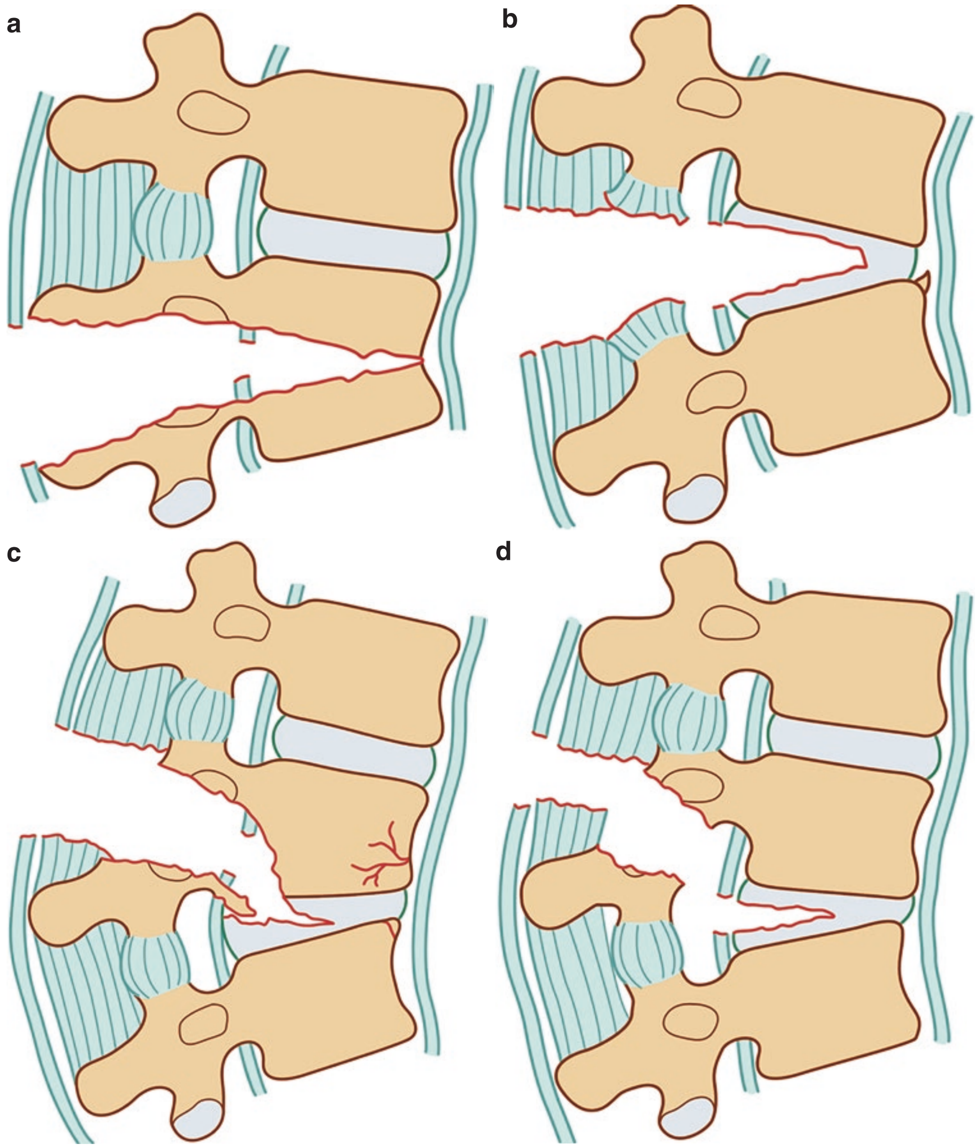

Fig. 2.10 Denis classification of flexion-hyperextension injuries. (**a**) Type A involves only a single spinal segment with the fracture line passing the vertebral body. (**b**) Type B involves only a single spinal segment with the fracture line passing the ligaments and the intervertebral disc. (**c**) Type C involves two spinal segments with the fracture line passing the vertebral body. (**d**) Type D involves two spinal segments with the fracture line passing the intervertebral disc

- Flexion-separation fractures (Chance fracture):
  - With the anterior column as a pivot, the posterior column and the middle column are ruptured under a tension force, which might be accompanied by a compression injury of the anterior column.
  - Most patients do not have any neurologic symptoms.
  - More than 50% of cases are associated with abdominal injury.
  - This type of fracture is unstable.
  - Chance fractures are divided into four types according to the structures passed by the fracture line (Fig. 2.10).

    Type A fractures involve only one single spinal segment with the fracture line passing the vertebral body.

    Type B fractures involve only one single spinal segment with the fracture line passing the ligaments and intervertebral disc.

    Type C fractures involve only two spinal segments with the fracture line passing the vertebral body.

    Type D fractures involve two spinal segments with the fracture line passing the intervertebral disc.
- Displaced fractures:
  - The fracture involves all three spinal columns and displays translation deformity.
  - This type of fracture is unstable.
  - The incidence rate of neurologic injury is highest among all types of thoracolumbar fractures.
  - They are further divided into three types (Fig. 2.11):

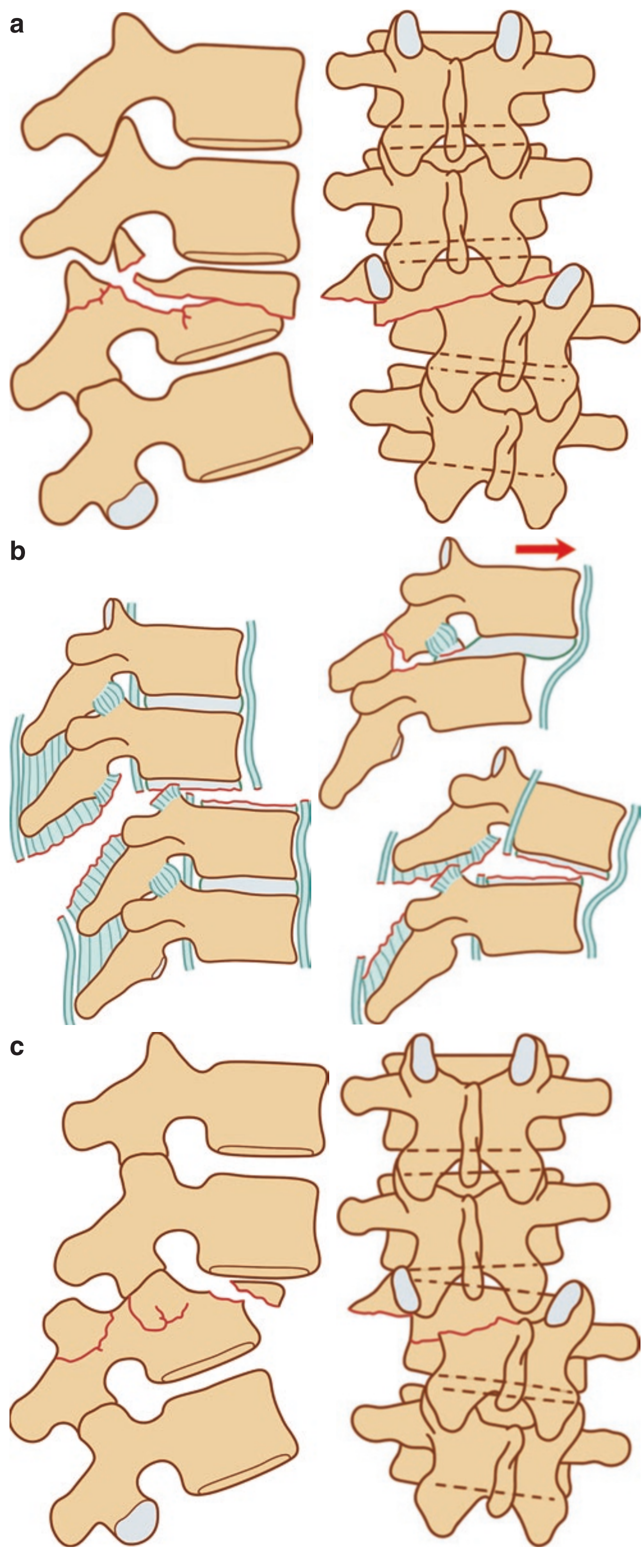

Fig. 2.11 Denis classification of spinal column fracture dislocations. Type **a** is a flexion-rotation injury. Type **b** is a shear injury. Type **c** is a bilateral facet joint dislocation

Type A: Flexion-rotation injury
Type B: Shear injury
Type C: Bilateral facet joint dislocation

2. Spinal column involvement in different types of injuries in the Denis classification (Table 2.1):

2.1.5 Assessment of Thoracolumbar Fractures

2.1.5.1 Clinical Assessment

- Ascertain the patient's injury history.
  - Query for the injury history and determine the mechanism of injury.
  - Query for witnessed head trauma.
  - Query for movement of the lower extremities and level of consciousness immediately following trauma.
- Perform a general physical examination.
  - Complicated injuries: The head, neck, chest, abdomen, pelvis, and extremities are examined to rule out the possibility of injury elsewhere.
  - Deformities, lacerations, and contusions of the skin and soft tissue are visually examined.
  - The injured area is palpated for further evidence, including the "step" sign, widening of the inter-spinous-process space, pain, tenderness, and percussion pain.
  - Fractures elsewhere in the body: The possibility of accompanying fractures elsewhere in the body must not be overlooked; in patients with lower extremity sensory deficits, the calcaneus, tibia, fibula, femoral neck, acetabulum, and other parts must be carefully examined for the possibility of fracture.
  - Special attention must be paid to abdominal contusion and ecchymosis, which suggests a high possibility of a Chance fracture (Chapman et al. 2008; Gertzbein and Court-Brown 1988). It is crucial to rule out the possibility of abdominal organ injuries, and ultrasound or CT scans should be performed if needed.
- Perform a neurologic examination.
  - The injured spinal segments might not be adjacent to each other; therefore, the neurologic examination should include the function of the cervical spinal cord to avoid a missed diagnosis of cervical spine injury.
  - Sensory examination.

    Sensations, including pain, temperature, and touch, are assessed according to the segmental distribution of the cutaneous nerves (Fig. 2.12).

    The diagnosis can be made by comparing sensations between the left and right sides of the body, between the upper and lower parts, and between the proximal and distal sides.

Table 2.1 Spinal column involvement in different types of injuries in the Denis classification

Fracture type	Involved column		
	Anterior column	Middle column	Posterior column
Compression fracture	Compression	Uncompression	Without or with separation
Bursting fracture	Compression	Compression	Without or with separation
Chance fracture	With or without compression	Separation	Separation
Fracture displacement	Compression and (or) forward rotation, shear	Separation and (or) forward rotation, shear	Separation and (or) forward rotation, shear

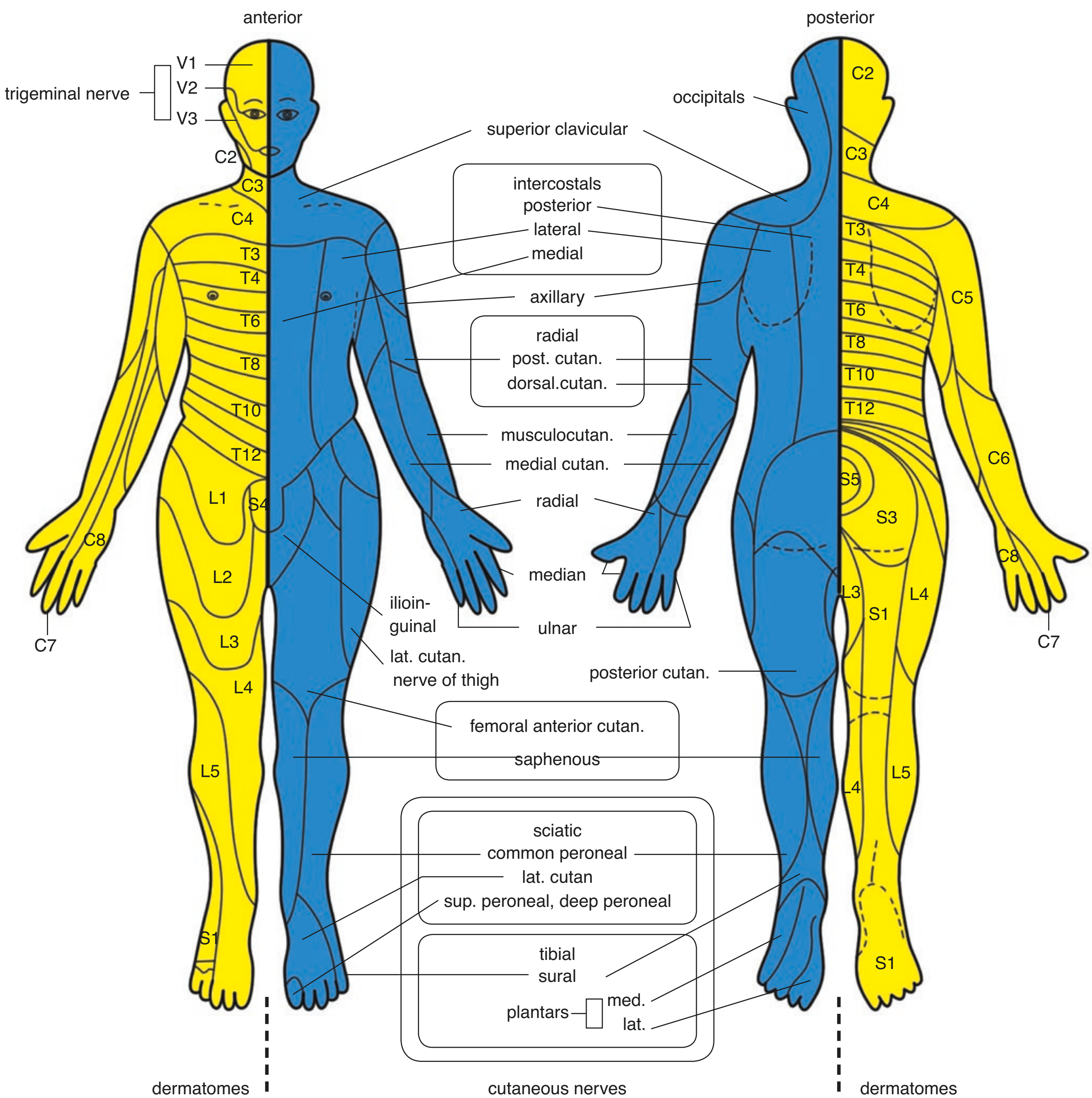

Fig. 2.12 A sensory dermatome body map corresponding to the spinal segments: The commonly used levels include T4-nipple, T6-xiphoid process, T10-navel, and T12-pubic symphysis

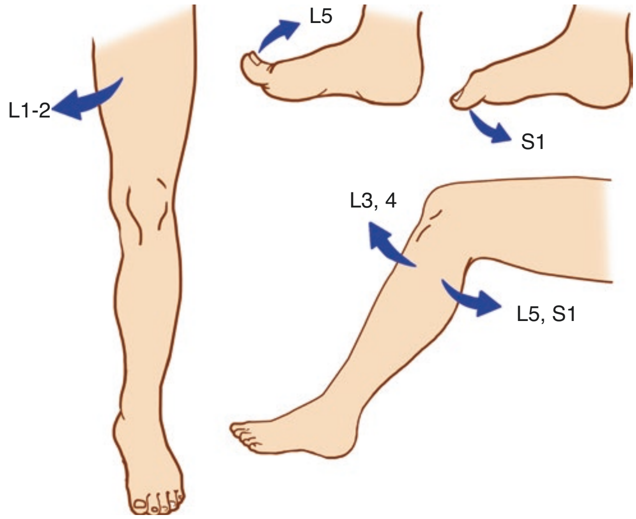

Fig. 2.13 The segmental relationship of the spinal cord to the motor function of the lower extremity: L1–L2 for hip adduction, L3–4 for knee extension, L5–S1 for knee flexion, L5 for hallux dorsiflexion, and S1 for hallux plantar flexion (This figure is a replicate of Fig. 1.11 in "Cervical spine fractures")

- Motor examination.
  Evaluate muscle strength and range of motion of the joints.
  The motion functions of different joints correspond to different spinal segments (Fig. 2.13).
- Reflex examination.
  Include tendon reflexes, the anal wink reflex, the cremasteric reflex, the bulbocavernosus reflex, the sacral sparing, and pathological responses (Figs. 2.14 and 2.15).
- American Spinal Injury Association (ASIA) score (Maynard et al. 1997): Please see the section "Clinical Assessment" of Chapter "Cervical Spine Fractures."

2.1.5.2 Radiographic Evaluation

- Radiography (Fig. 2.16):
  - Both thoracic and lumbar AP and lateral radiographs should be obtained.
  - AP radiography:
    Widening of the space between the vertebral pedicles on the two sides suggests translation of the vertebral burst fracture fragments towards the two sides.
    A blurred contour of the vertebral pedicle suggests a rupture of the vertebral pedicle.
    Lateral bending of the spine indicates a lateral compression displacement of the affected segment.
    An asymmetry between the two sides of the vertebral pedicles and the spinous process indicates a rotational displacement.
  - Lateral radiography:
    Height loss of the vertebral body suggests a compression and/or burst fracture.

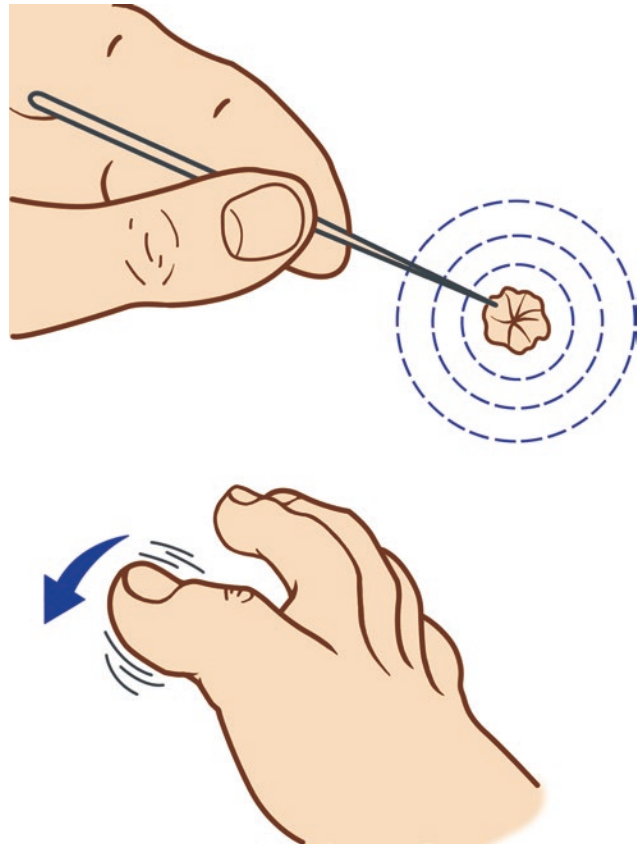

Fig. 2.14 Anal wink reflex and sacral sparing. Examination of the anal wink reflex provides evidence to identify the occurrence and recovery of spinal shock

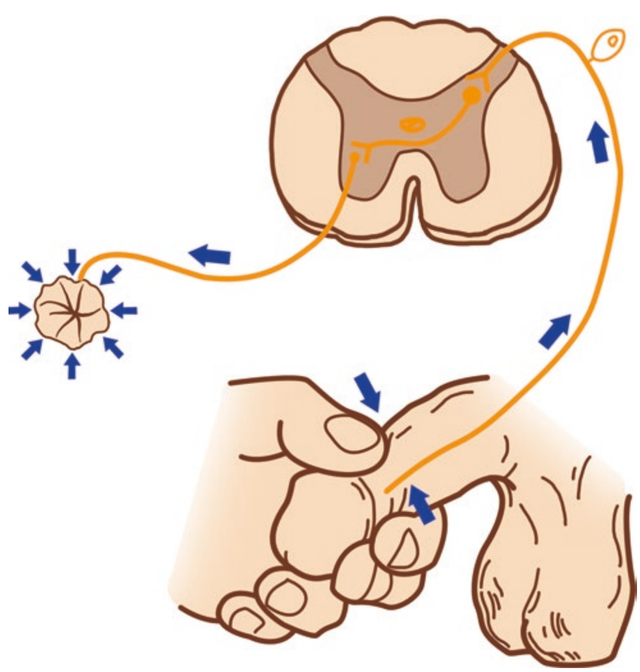

Fig. 2.15 The bulbocavernosus reflex. The bulbocavernosus reflex has a reflex center in the medullary cone and involves the three sacral nerve roots below the medullary cone. It refers to contraction of the anal sphincter in response to a stimulation (e.g., a squeeze) of the glans penis in a male or the clitoris in a female

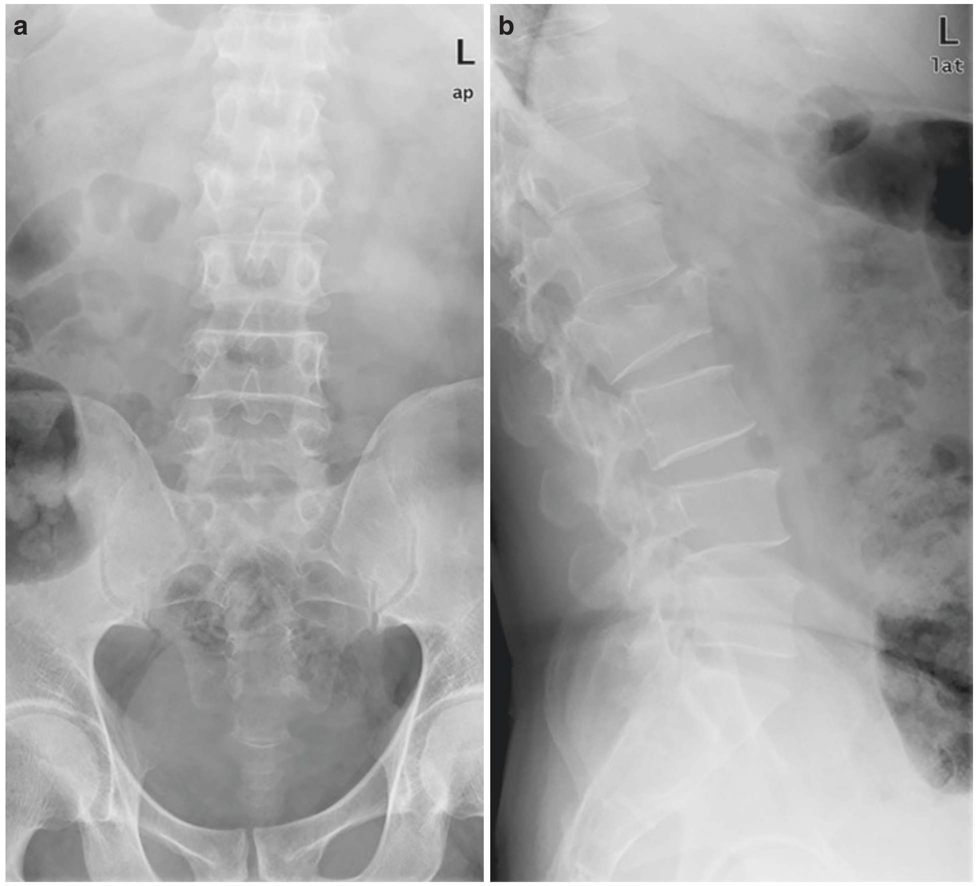

Fig. 2.16 A burst fracture of the L2 vertebral body. (**a**) An AP radiograph showing a height loss of the vertebral body and widening of the space between the vertebral pedicles on the two sides. (**b**) A lateral radiograph: The height of the L2 vertebral body is lost, and the posterior edge line has lost its continuity, accompanied by space-occupancy in the intervertebral foramen, suggesting that the posterior wall has ruptured and that the bone fragment may protrude into the spinal canal

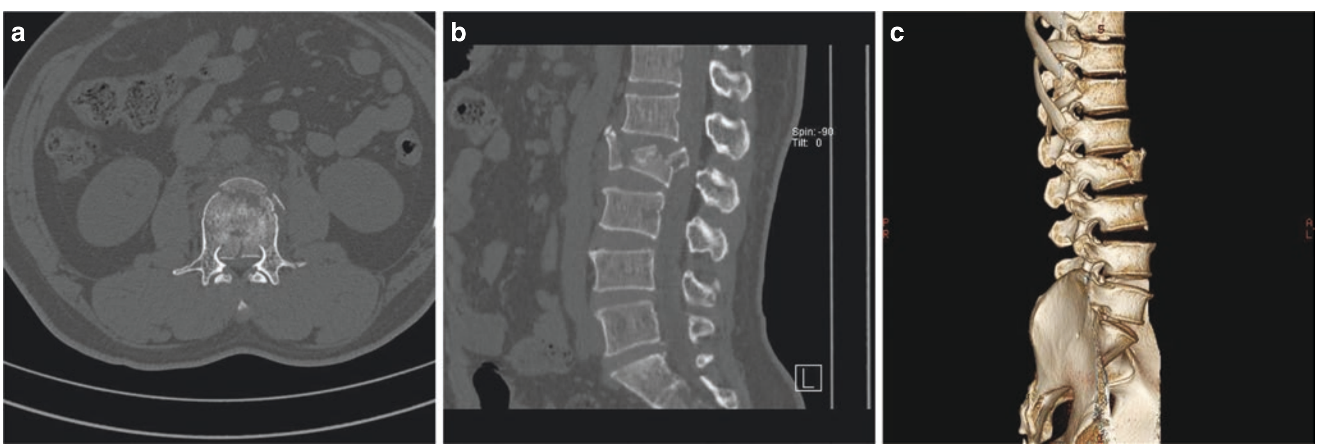

Fig. 2.17 Lumbar CT plain scanning and 3D reconstruction of the same patient in Fig. 2.16. (**a**) Cross-section scan of the L2 vertebral body: The posterior wall of the vertebral body protruded into the spinal canal and occupied >50% of the cross-sectional area of the spinal canal. The anterior column was fractured, and the pedicles remained intact. (**b**) Midline sagittal reconstruction: The posterior wall of the vertebral body protruded into the spinal canal and occupied >50% of the width of the spinal canal, accompanied by rotational displacement of the affected vertebra. (**c**) CT 3D reconstruction providing a full view of the fracture displacement stereoscopically

A change in the Cobb angle suggests a wedge compression fracture.
Disruption of the posterior edge line of the vertebral body and the high-density mass in the intervertebral foramen suggests a space-occupying fragment in the spinal canal.

- CT (Fig. 2.17):
  – CT scanning can be used to precisely evaluate bone damage on multiple planes.
  – For burst fractures, axial CT scans reflect the severity of the space-occupying effect by the fragments in the spinal canal (Vaccaro et al. 2001).

Fig. 2.18 MRI has an extremely high resolution for identifying soft tissue damage. T2-weighted fat-suppressed MRI is helpful for assessments of intramedullary hemorrhage, edema, spinal cord compression, intervertebral disc herniation, etc. (There are no separate caption for Fig. 2.18)

Table 2.2 Stability scoring for the thoracic and thoracolumbar regions

Essentials of assessment	Score
Destruction or failure of anterior structure	2
Destruction or failure of posterior structure	2
Destruction of Sternocostal joint	1
Radiological evaluation	4
Sagittal displacement > 2.5mm	2
Sagittal angulation > 5°	2
Spinal cord or cauda equina injury	2
Dangerous loading anticipated	1

Total score ≥ 5 indicates instability. The dangerous loading anticipated is scored according to the characteristics of different occupations and different types of activities (White and Panjabi 1900)

- Sagittal reconstruction can evaluate the spinal canal damage caused by a vertebral translation.
- The CT technology serves as the best tool for examining the vertebral pedicle, vertebral lamina, articular process, and transverse process.

- MRI (Fig. 2.18):
  - MRI can provide more detailed data regarding soft tissue damage.
  - T2-weighted MRI and T2-weighted fat-suppressed MRI serve as useful tools for injury assessment, including intervertebral disc herniation, posterior ligament complex injury, epidural hematoma, and spinal cord edema.

2.1.5.3 Stability Assessment

- Spinal instability refers to the abnormality that under a normal load, the spine loses its intervertebral stability, which causes nerve injury and ultimately chronic pain or malformation (White and Panjabi 1990).
- Stability assessment of the thoracic, thoracolumbar, and lumbar regions was performed according to Tables 2.2 and 2.3.

Table 2.3 Stability scoring for the lumbar spine

Essentials of assessment	Score
Instability of anterior structure	2
Instability of posterior structure	2
Radiological evaluation	4
X-ray photograph in flexion and extension position	
Sagittal displacement > 4.5mm or 15%	2
Sagittal rotation	2
L1/2, L2/3, L3/4 > 15°	
L4/5 > 20°	
L5/S1 > 25°	
Normal X-ray photograph	
Sagittal displacement > 4.5mm or 15%	2
Sagittal angulation > 22°	2
Spinal cord or cauda equina injury	2
Cauda equina injury	3
Dangerous loading anticipated	1

Total score ≥ 5 indicates instability (White and Panjabi 1900)

2.2 Surgical Treatment

2.2.1 Surgical Indications

1. Treatment goals:
   a. Avoid further nerve injury and promote the recovery of neurologic deficits.
   b. Ensure long-term stability of the spine and minimize the number of vertebrae involved in fusion.
   c. Enable early movement of the patient to avoid immobilization-associated complications.
   d. Reduce acute and chronic pain.
2. Indications for surgery:
   a. TLICS system:

Table 2.4 TLICS score scale

Project	Score
Morphological changes	
Compression fracture	1
Bursting fracture	2
Displacement, rotation	3
Traction injury	4
Neurological function	
Complete	0
Nerve root injury	2
Spinal cord, conus medullaris injury	
Incomplete injury	3
Complete injury	2
Cauda equina injury	3
Posterior ligamentous complex	
Complete	0
Uncertain injury	2
Injury	3

- The TLICS system (Table 2.4) evaluates the severity of the thoracolumbar spine injury based on injury-caused morphological changes, neurologic functions, and the condition of the posterior ligament complex, and guides treatment planning.
- Use of TLICS in surgical decision-making (Vaccaro et al. 2005):
  - Decision-making criteria in selecting conservative or surgical treatment: Conservative treatment is recommended when the total TLICS score, which is the sum of the highest scores of the three principle items, is ≤3; surgical treatment is recommended when the total TLICS score is ≥5; the decision is made according to the patient's injury conditions and willingness and the doctor's preference when the TLICS score is at the cut-off level of 4.
  - Decision-making criteria in selecting surgical approaches: For incomplete nerve injury caused by compression of the posterior vertebral wall fragment, a fully anterior decompression must be performed. When the posterior ligament complex is injured, stability reconstruction should be performed via the posterior approach because the complex structure has a poor ability to self-repair. In patients with both of the above situations, the anterior and posterior approaches can be jointly adopted.
  - The significance of TLICS scoring in selecting the surgical approach is controversial.

b. Surgical indications for different types of fractures in the Denis classification (Denis 1983):
- Minor fractures: They can be treated non-surgically, such as thoracolumbosacral orthosis.
- Compression fractures:
  - Stable compression fractures can be treated primarily by wearing a supporting device.
  - For unstable compression fractures, open reduction and internal fixation is performed to prevent the progression of kyphosis and neurologic deficits via the posterior approach.
  - Vertebroplasty is considered after failed conservative treatment.
- Burst fractures:
  - Stable burst fractures are treated with spinal hyperextension orthosis.
  - For unstable burst fractures without neurologic injury:

    Surgical treatment, primarily indirect decompression and internal fixation via the posterior approach, is recommended when the posterior protrusion is >25°, vertebral height loss is >50%, and intra-spinal canal space-occupancy is >40%.

    Fractures with severe anterior collapse or old injury are treated with subtotal corpectomy and supporting material implantation (bone graft or titanium cage) via the anterior approach.
  - For unstable burst fractures associated with neurologic injury:

    The posterior process fragment(s) and intervertebral disc(s) are thoroughly removed via the anterior approach.

    The number of vertebral segments involved in decompression, the amount of graft required, and the necessity for joint use of the anterior and posterior approaches for fixation are decided according to the injury condition.
- Chance fractures:
  - Denis Type A fractures associated with kyphosis <15° and without neurologic injury are treated with spinal hyperextension orthosis.
  - Chance fractures passing ligaments:

    They often heal with scar formation.

    Conservative treatment usually fails due to low healing strength.

    The primary treatment is surgical fixation via the posterior approach.

    Whether there is an intervertebral disc herniation should be determined by MRI prior to surgery.

- Displaced fractures:
  – They are highly unstable.
  – They are often associated with interlocking of the posterior joint; therefore, pedicle screw fixation via the posterior approach is commonly used.
  – The anterior approach or a joint anterior and posterior approach can be used if needed.

3. Timing of surgery.
   a. The timing of surgery for treating spinal injury remains controversial.
   b. Most researchers believe that progressive neurologic injury is the indication for emergency decompression (Chapman and Anderson 1994).
   c. For non-progressive, incomplete, and complete spinal injuries, some researchers recommend surgery as early as possible, while others recommend delayed surgery, i.e., surgery after recession of spinal edema. For complete spinal injury, it is generally believed that early surgery can shorten the hospital stay of the patient (Chipman et al. 2004; Gaebler et al. 1999).
   d. The necessity for early decompression relies on the potential benefit to the recovery of neurologic deficits, the patient's general condition, accompanying injuries, and the hospital condition (e.g., operating room, treatment team).

2.2.2 Surgical Techniques

2.2.2.1 Open Reduction and Internal Fixation Via the Posterior Approach for Thoracolumbar Fractures

1. Body position and preoperative preparation:
   a. General anesthesia via nasotracheal vs. orotracheal intubation.
   b. The patient lies in the prone position on a radiolucent operating table, with a C-arm or CT system set up for intraoperative radiographic monitoring.
   c. Cushions are placed beneath the upper chest and at the level of the anterior superior iliac spines to suspend the abdominal area.
   d. To avoid overpulling and damaging the brachial plexus, the shoulder joints should not be abducted >90°. In addition, the elbows and wrists should be protected by soft cushions to avoid compressing and injuring the ulnar and median nerves.
   e. The knees are bent and placed on soft cushions to relax the sciatic nerve.
   f. Both feet are relaxed with all toes suspended.
2. Operative incision according to the projection on the body surface: The affected vertebra is identified and located radiographically prior to surgery. With the spinous process of the affected vertebra as the midpoint, a central longitudinal incision is created along it and the adjacent spinous processes (Fig. 2.19).
3. Surgical approaches (Fig. 2.20):
   a. The skin and subcutaneous tissue are cut layer by layer to expose the lumbodorsal fascia and spinous process.
   b. The fascia and periosteum of the spinous process is sharply dissected closely along the spinous process using an electric knife, and a subperiosteal separation is performed closely along the spinous process and vertebral lamina using a periosteum stripper. If the lambdoidal ridge is clearly visible, the sacrospinous muscle is laterally separated up to the lateral facet joint at both sides; otherwise, the sacrospinous muscle is separated laterally up to the transverse process.
   c. The sacrospinous muscles on both sides are pulled aside to expose the vertebral lamina using an auto-

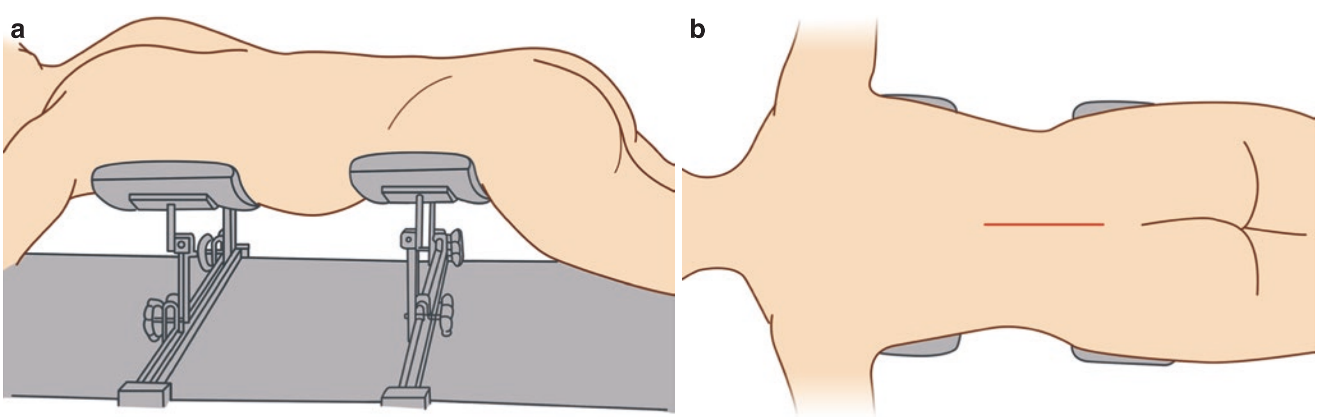

Fig. 2.19 (**a**) Body position for surgery: The patient lies in the prone position on a radiolucent operating table with cushions beneath the upper chest and at the level of the anterior superior iliac spines to suspend the abdominal area. (**b**) The surgical incision is determined according to the location and range of the lesioned area. With the spinous process of the diseased vertebra as the center, a median longitudinal incision is created along the spinous process line and extended appropriately to the distal and proximal ends as required

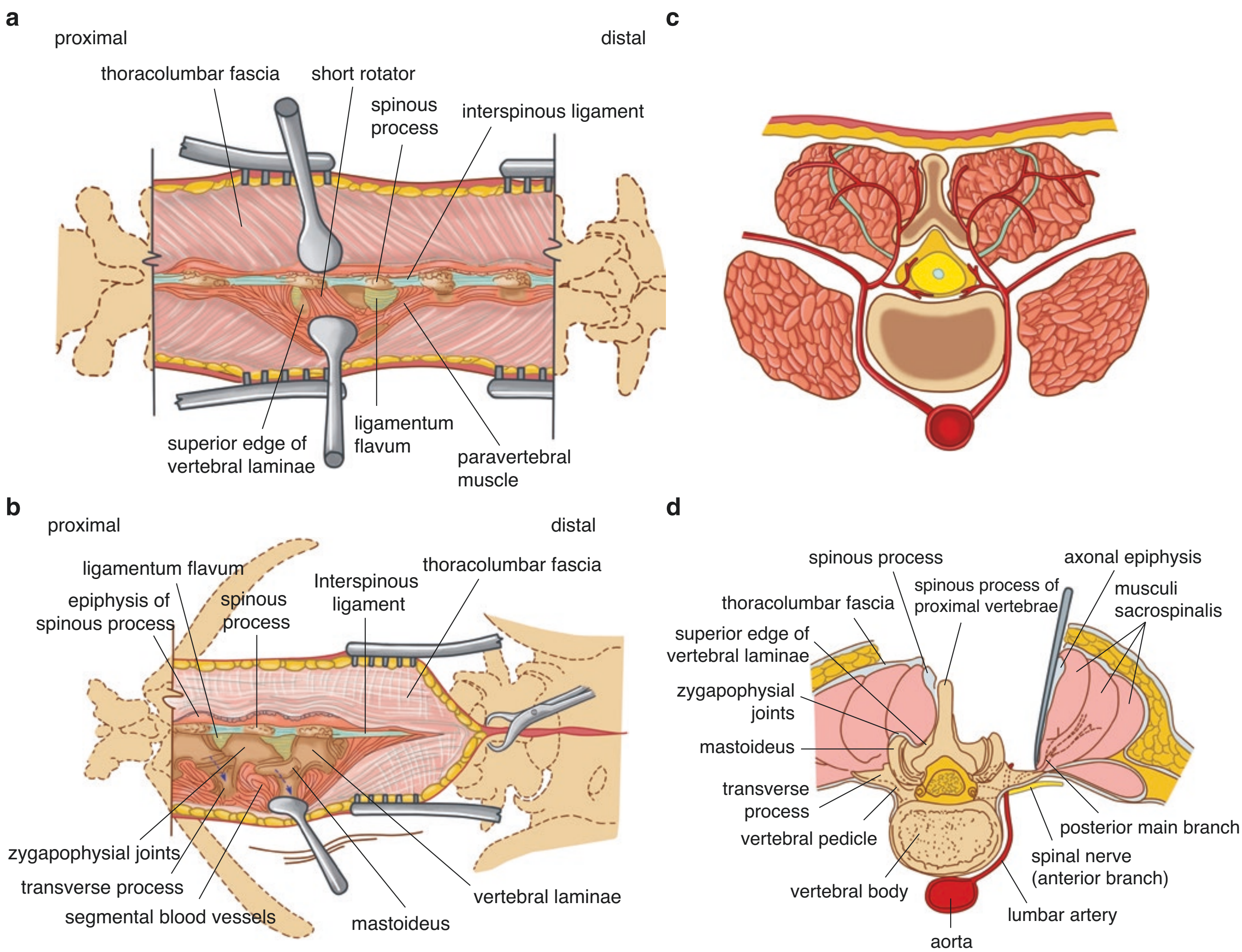

Fig. 2.20 Schematic diagram of the thoracolumbar posterior approach. (**a**) The skin and subcutaneous are cut open layer by layer to expose the lumbodorsal fascia and spinous process, the fascia and periosteum of the spinous process are sharply incised with an electric knife, and the paravertebral muscle is separated subperiosteally. (**b**) The paravertebral muscle is dissected from proximal to distal with a periosteal stripper. Attention should be paid to protecting the joint capsule of the two vertebrae above and below the lesioned vertebra. (**c**) The segmental vessels supplying the paravertebral muscles perforate on the cross-section between the superior and inferior transverse processes. (**d**) During the process of exposing the vertebral lamina, it is important that the bleeding from the segmental blood vessels is stopped by electrocoagulation in a timely manner

matic retractor. There are abundant segmental vessels exiting between the transverse processes; hence, electrocoagulation should be performed in a timely manner to stop bleeding.

d. The residual soft tissue on the spinous process, vertebral lamina, and capsule of the facet joint is further removed.

4. Fracture reduction and fixation:
   a. Determination of the pedicle screw entry point (Fig. 2.21):
      - Thoracic spine:
        – The entry point is the intersection of the horizontal line passing the upper ridges of the transverse processes and the inferolateral rims of the superior articular processes.
      - Lumbar spine:
        – The lambdoidal ridge technique (Du et al. 2002): The entry point is the apex of the lambdoidal ridge, which avoids overexposure of the transverse process and reduces damage
        – The Magerl method (Magerl 1984): The entry point is the intersection of the horizontal line passing the midpoints of the transverse processes and the line perpendicular to the lateral rims of the articular processes.
   b. Direction of pedicle screw placement (Fig. 2.21):

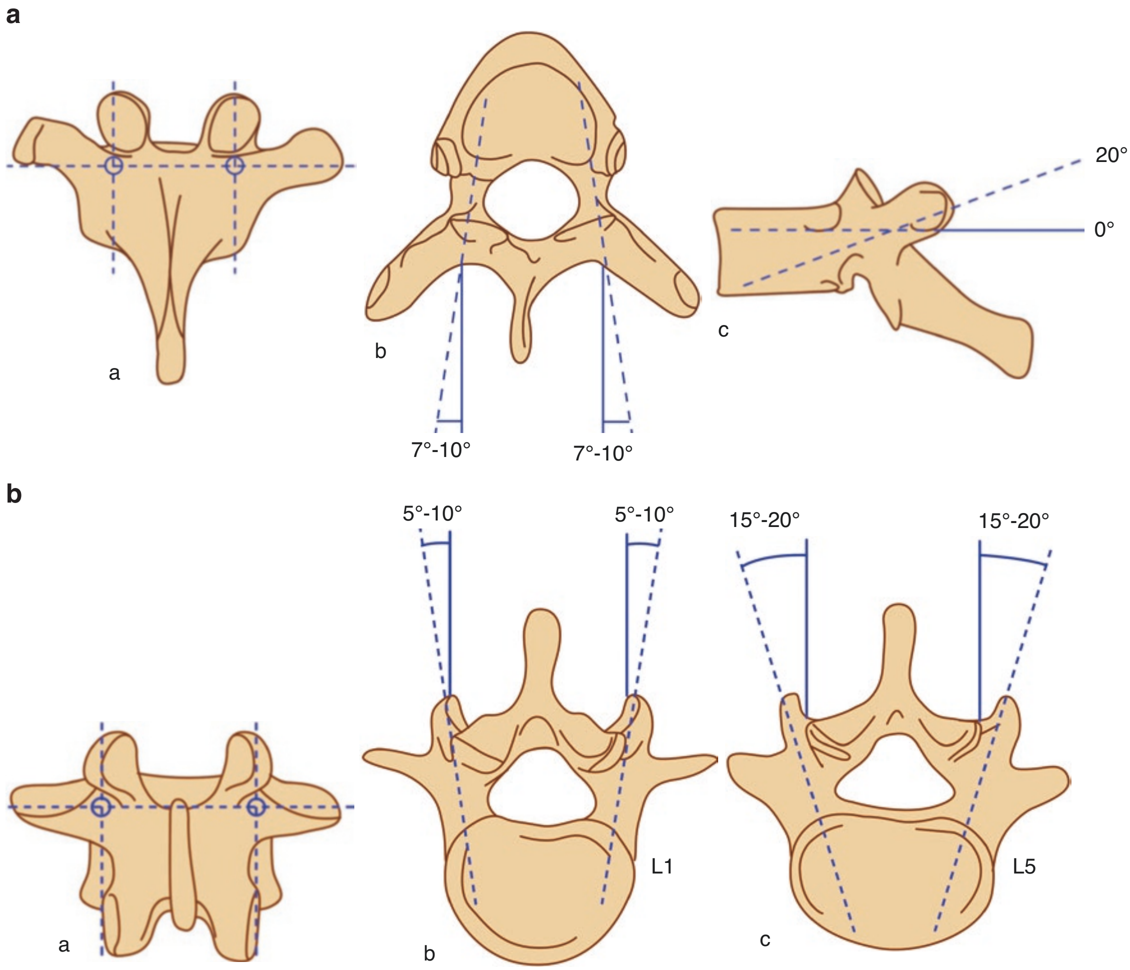

Fig. 2.21 (**a**) The entry point and direction of thoracic pedicle screws: The entry point is located below the superior articular process and at the intersection of the horizontal line of the superior spine of the transverse process and the inferolateral edge of the superior articular process (**a**); the screw tilts laterally by 7–10° (**b**), inclining to the head side by 0–20° (**c**). (**b**) The entry point and direction of lumbar pedicle screws: The entry point is located at the vertex of the lambdoidal ridge, or at the intersection of the horizontal line passing the midpoint of the transverse process and the vertical line through the lateral edge of the articular process (**a**); the convergence angle of the screw is 5–10° at the upper lumbar spine (**b**). The convergence angle of the L5 screw is increased to 15–20° (**c**)

- Lower thoracic spine (taking T10 as an example): On the coronal plane, the pedicle screw should point to the center at an angle of 7–10° relative to the sagittal line; on the sagittal plane, the screw points to the caudal side at an angle of 10–20°.
- Convergence angle of the lumbar pedicle screw: The lumbar pedicle screw on each side has a convergence angle of 5–10° at the upper lumbar spine and 15–20° at L5.

c. Pedicle screw placement technique: Below is an example of Schanz screw placement for reduction and fixation (Fig. 2.22).
   - The bone cortex at the planned entry point is opened using a vertebral pedicle taper or nibbled out with a bone rongeur.
   - A vertebral pedicle probe is inserted at the entry point and advanced for approximately 3 cm along the channel in the vertebral pedicle. Special attention should be paid to the tilt angle when probing, which varies among different vertebral segments.
   - A ball-tipped probe is used to verify whether the wall of the vertebral pedicle is intact and whether the cortex at the end of the channel is penetrated.
   - A Kirschner wire is inserted along the channel, and its appropriate position, angle, and length are confirmed with C-arm fluoroscopy or CT fluoroscopy.
   - After the Kirschner wire is pulled out, a Schanz screw is screwed in using a T-handle. Lateral C-arm fluoroscopy or CT fluoroscopy is used to determine whether the screw has penetrated the cortex at the

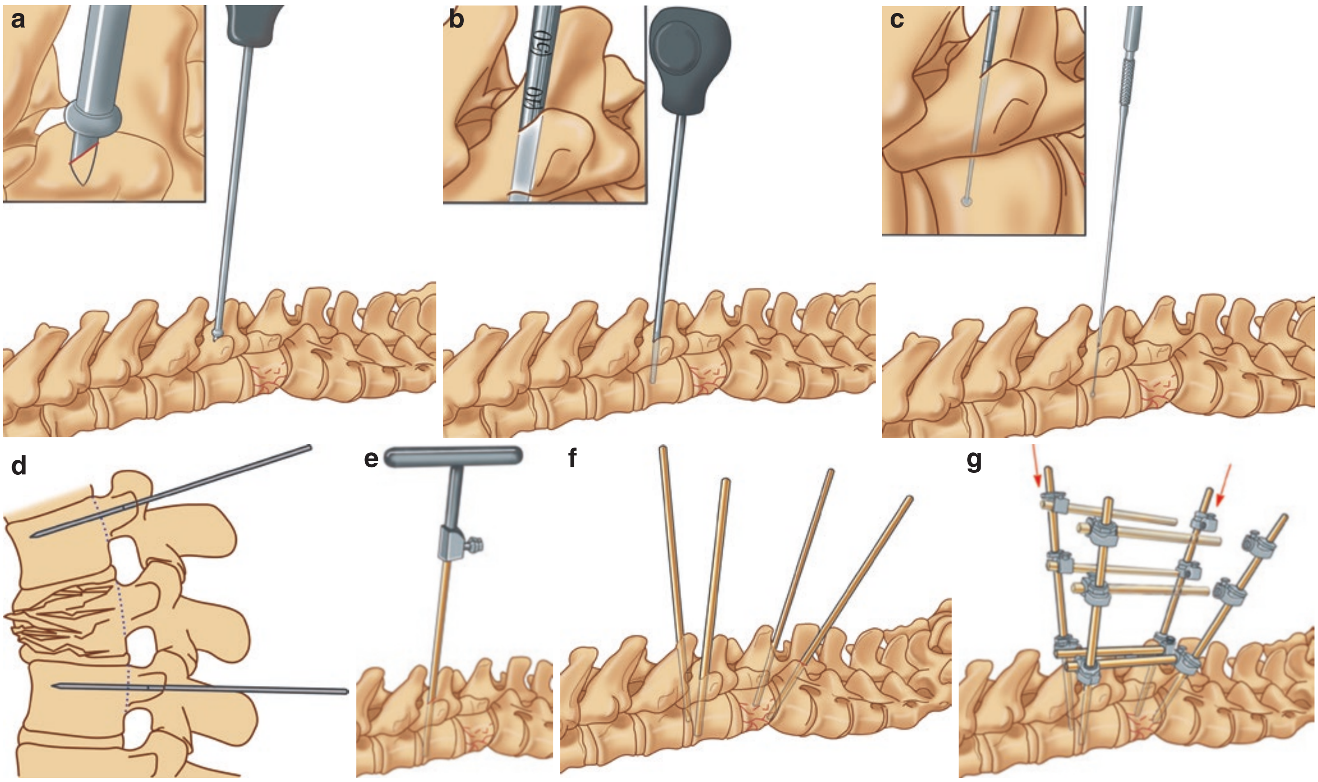

Fig. 2.22 (**a**) The cortical bone at the entry point is opened using a sharp taper. (**b**) The pedicle probe is inserted approximately 3–4 cm in depth. (**c**) The ball-tipped probe is used to examine whether the wall of the pedicle is intact and whether the track breaks through the anterior surface of the vertebral body. (**d**) A Kirschner wire is inserted along the track, and its appropriate position is confirmed radiographically. (**e**) The Schanz screw is advanced with a T-shaped handle. (**f**) Four Schanz screws are placed sequentially. (**g**) The connecting rods are installed; after reduction, the connecting rods and screws are locked

end of the channel, and AP images are obtained to determine whether the screw has crossed the midline.

d. Fracture reduction technique.
   - The primary step of the posterior approach to reduce the fractured vertebra is to distract the vertebrae above and below apart. Vertebral distraction can tighten the posterior longitudinal ligament, and then the restitution force of the tightened ligament pushes and reduces the fragment protruding into the spinal canal. In addition, vertebral distraction helps to restore the height of the affected vertebra.
   - The reduction method varies based on the actual situation of the fracture:
     – Fractures with an intact posterior wall (Fig. 2.23):

       The rear ends of the Schanz screws are pulled closer to each other to restore the natural lordosis of the spine using a hollow cylindrical sleeve.

       The pivot point for distracting vertebrae is on the posterior wall of the affected vertebra.

       The nuts are locked by the hollow cylindrical sleeve to fix the angle between the Schanz screws and the fixation rods.

       With a rod holder or C ring as support, the vertebrae above and below the fractured vertebra are distracted to restore the normal height of the vertebra, followed by locking of the nuts.

       A transverse connector is installed to enhance the stability if necessary.

       After all bolts are tightened again, the Schanz screws are trimmed to an appropriate length using a trimmer.
     – Fractures with a damaged posterior wall (Fig. 2.24):

       The damaged posterior wall of the affected vertebra cannot be a pivot point for distraction; as a result, the pivot point must be posteriorly shifted onto the fixation rod.

       By placing a C-ring or a rod holder at the sites approximately 5 mm away from the clamp on the fixation rod, the kyphosis can be corrected by approximately 10°.

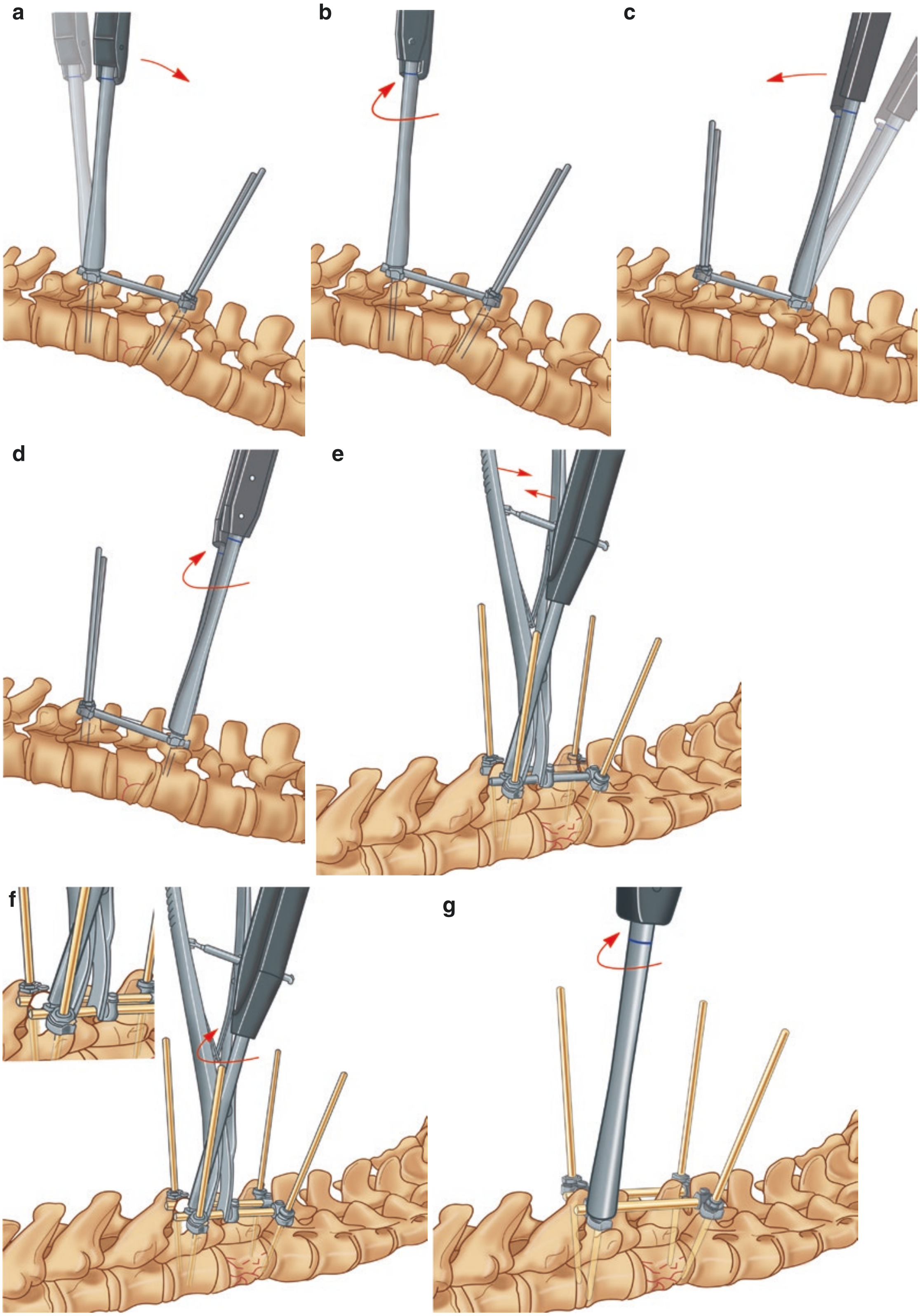

Fig. 2.23 The reduction method for a compression fracture with an intact posterior wall. (**a**, **b**) First, in the vertebral body proximal or distal to the fractured vertebra, a hollow cylindrical sleeve is used to hold the rear end of the Schanz screw to restore lordosis of the spine, followed by locking the nut and securing the angle between the Schanz screw and the fixation rod. (**c**, **d**) The above procedures are repeated on the other side of the fractured vertebra. (**e**, **f**) The C-rings are installed on the connecting rods and distracted open with the distractor. The vertebral height is restored under fluoroscopy, followed by locking the nut and fixing the positions of the Schanz screws and connecting rods. (**g**, **h**) After restoring the lordosis angle and the height of the vertebral body, it is crucial to ensure that all the nuts are locked firmly. (**i**) The Schanz screws are trimmed to the appropriate length with a cutter. (**j**) A transverse rod is installed to increase stability if necessary

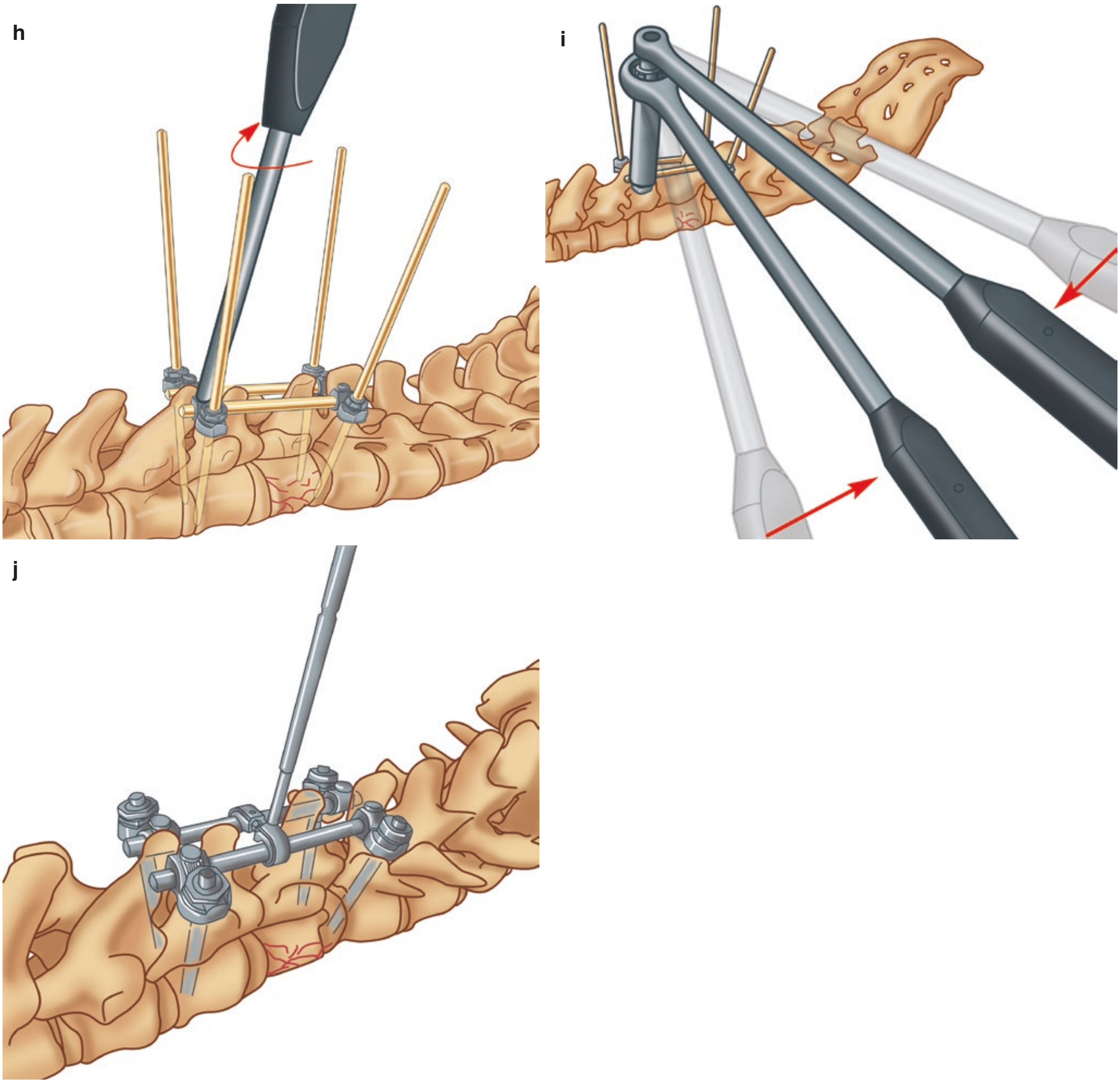

Fig. 2.23 (continued)

During restoration of the natural lordosis of the spine, the fixation clamps are moved closer to shift the pivot point from the posterior wall of the vertebra to the fixation rod.

Distraction is performed with a distractor to restore the height of the affected vertebral segment following the method same as described above.

– Reduction of Chance fractures:

The implants act as tension band.

First, natural lordosis of the spine is restored following the method same as described above.

Next, a C-ring is placed on the connecting rod.

After slight compression is applied with a retractor, the nuts are locked (Fig. 2.25).

– Advantages of intraoperative CT scanning in repairing ligaments:

In the Chinese People's Liberation Army General Hospital (the 301 Hospital), the operating room is equipped with a CT system for intraoperative scanning, which demonstrates the quality of ligament repair during reduction via the posterior approach and dynamically and quantitively evaluates

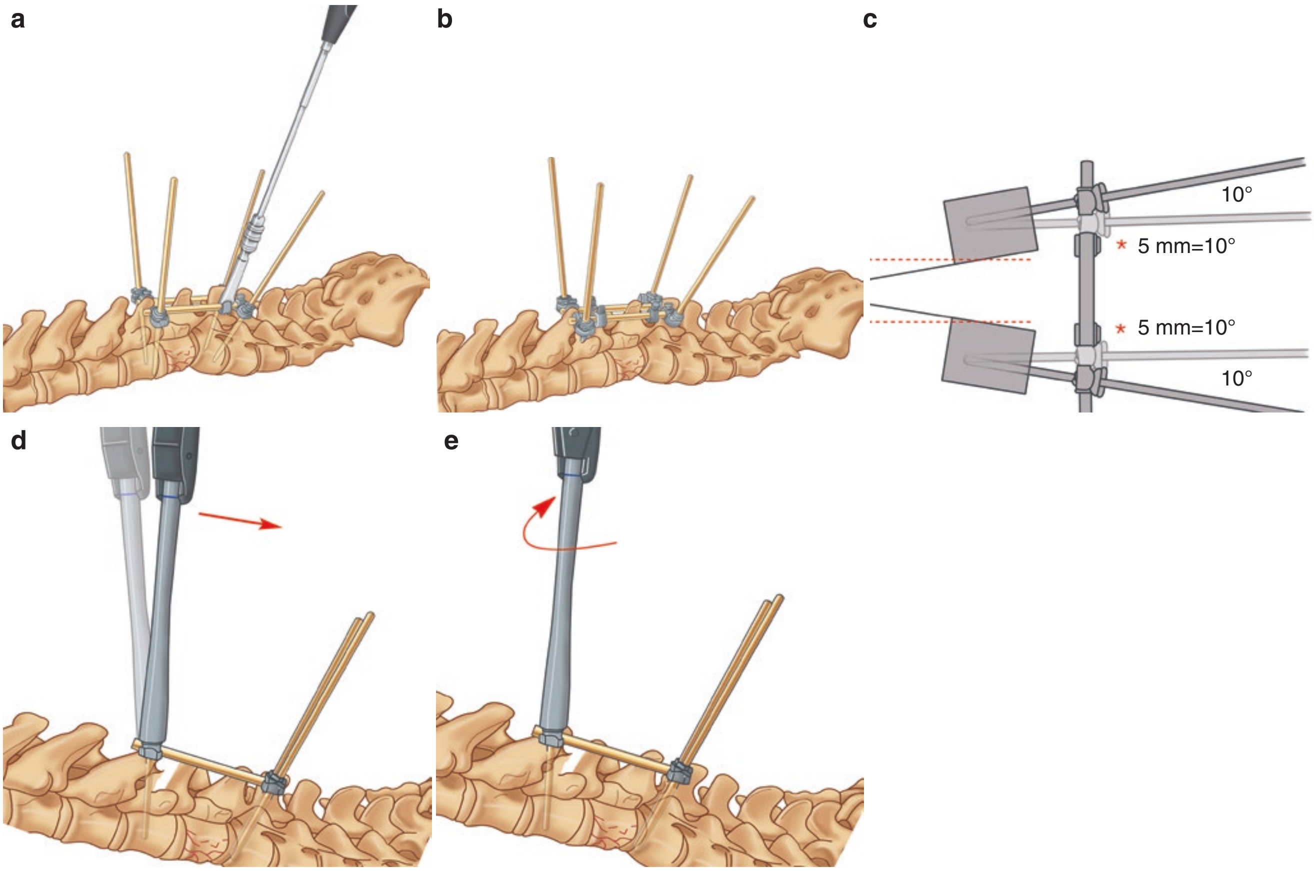

Fig. 2.24 Reduction of fractures with an incomplete posterior wall. (**a**, **b**) Four C-rings are placed on the fixation rod. (**c**) The C-rings are placed 5 mm away from the fixation clamp, which can be used to correct the kyphosis by 10°. (**d**, **e**) The natural lordosis of the spine is restored and fixed with a hollow cylindrical sleeve

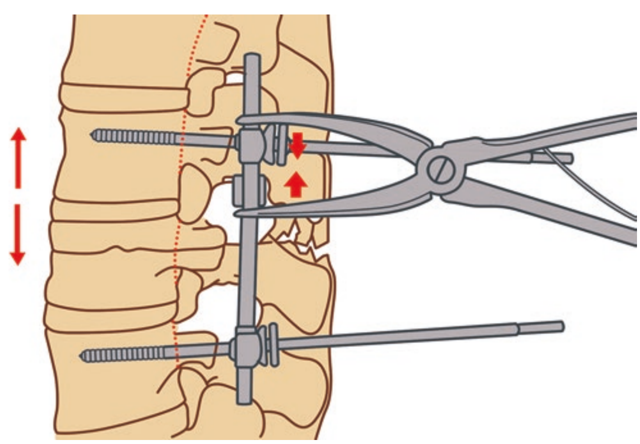

Fig. 2.25 A C-ring is placed between the two fixation clamps. After the segment between the fixation clamp and the C-ring is slightly compressed, the screws are locked firmly

the severity change of the space-occupancy of the fragment protruding into the spinal canal.

After fracture reduction, intraoperative CT scanning can precisely evaluate the quality of ligament repair, thereby decreasing the necessity of the second surgery for unsolved space-occupying in the spinal canal detected by CT scanning after surgery. Similarly, intraoperative CT scanning can precisely identify the protruding fragment in the canal that can be reduced via the posterior approach alone, thus avoiding the unnecessary trauma resulting from the joint use of the anterior and posterior approaches for compression.

When intraoperative CT scanning reveals the presence of the space-occupying fragment in the spinal canal after distraction, full decompression via the anterior approach should be immediately performed.

Intraoperative CT scanning can also be used to three-dimensionally observe the direction and depth of pedicle screw placement and accurately measure the distraction angle and height of the affected vertebra (Figs. 2.26 and 2.27).

5. Incision closure: After a drainage tube is placed, the lumbodorsal fascia and subcutaneous tissue are sutured using

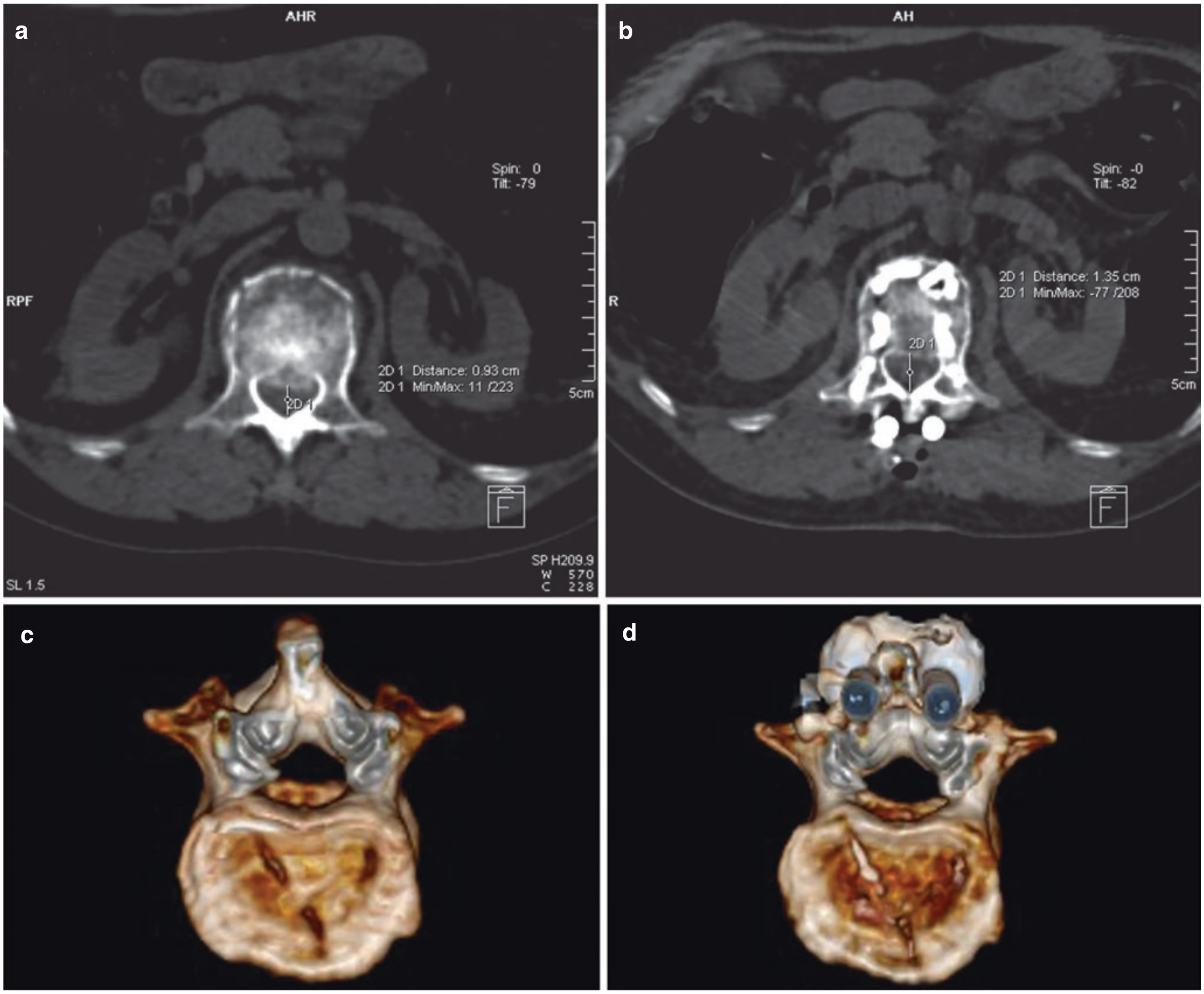

Fig. 2.26 (**a**, **b**) Intraoperative CT measurement of the sagittal diameter of the spinal canal before and after distraction: The anterior sagittal diameter is 93 mm before distraction and 135 mm after distraction. (**c**, **d**) The reduction of the posterior wall fragment can be clearly observed in the 3D reconstructed image. (**e**, **f**) Median sagittal reconstruction: The posterior wall fragment rotated and protruded into the spinal canal before surgery. After distraction, the restitution force of the ligaments rotated and reduced the bone fragment, thereby restoring the sagittal diameter of spinal canal. (**g**) Intraoperative CT scanning was used to measure the depth and angle of Schanz screw insertion, as well as to determine whether the screws protruded from the inner wall of the pedicle and injured the spinal cord

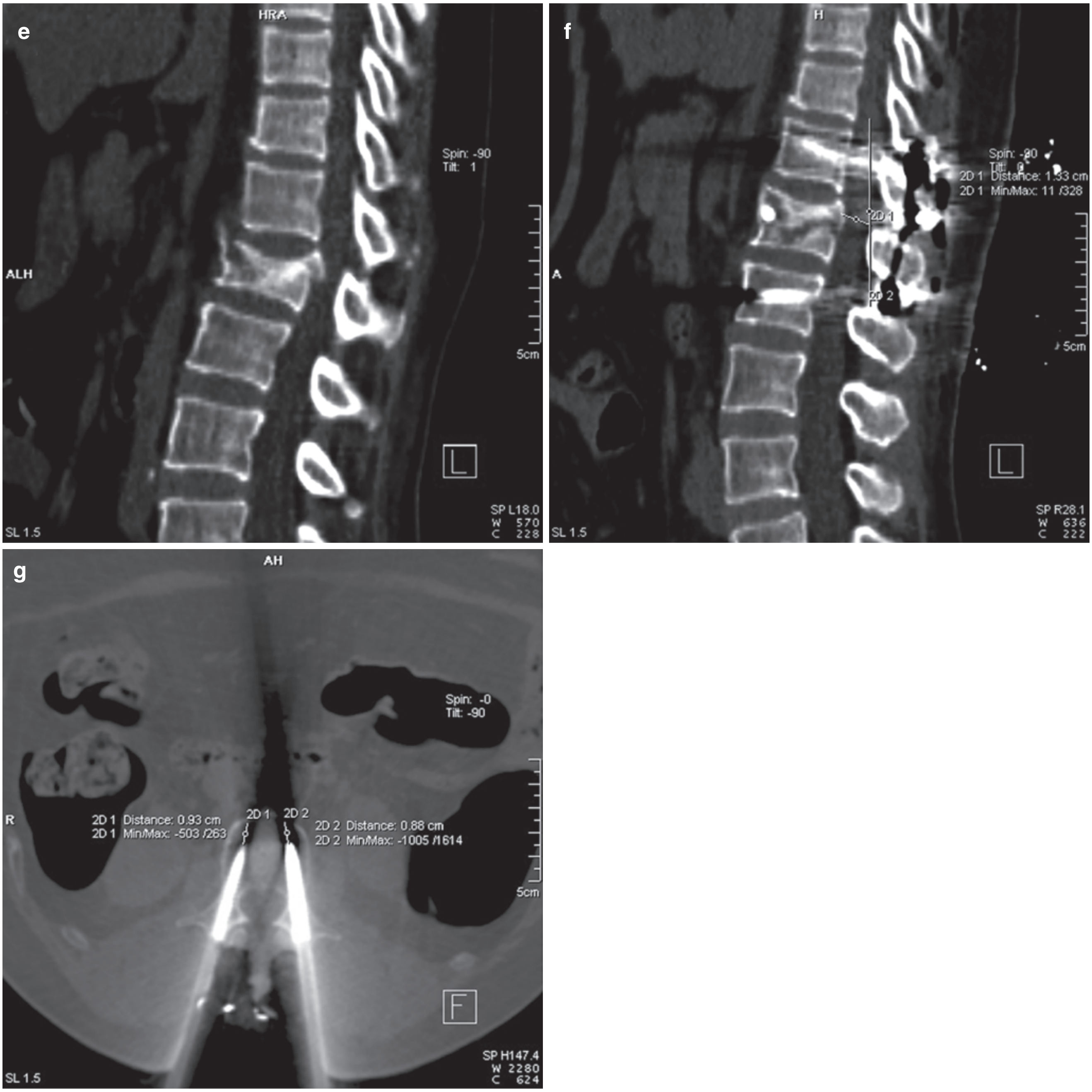

Fig. 2.26 (continued)

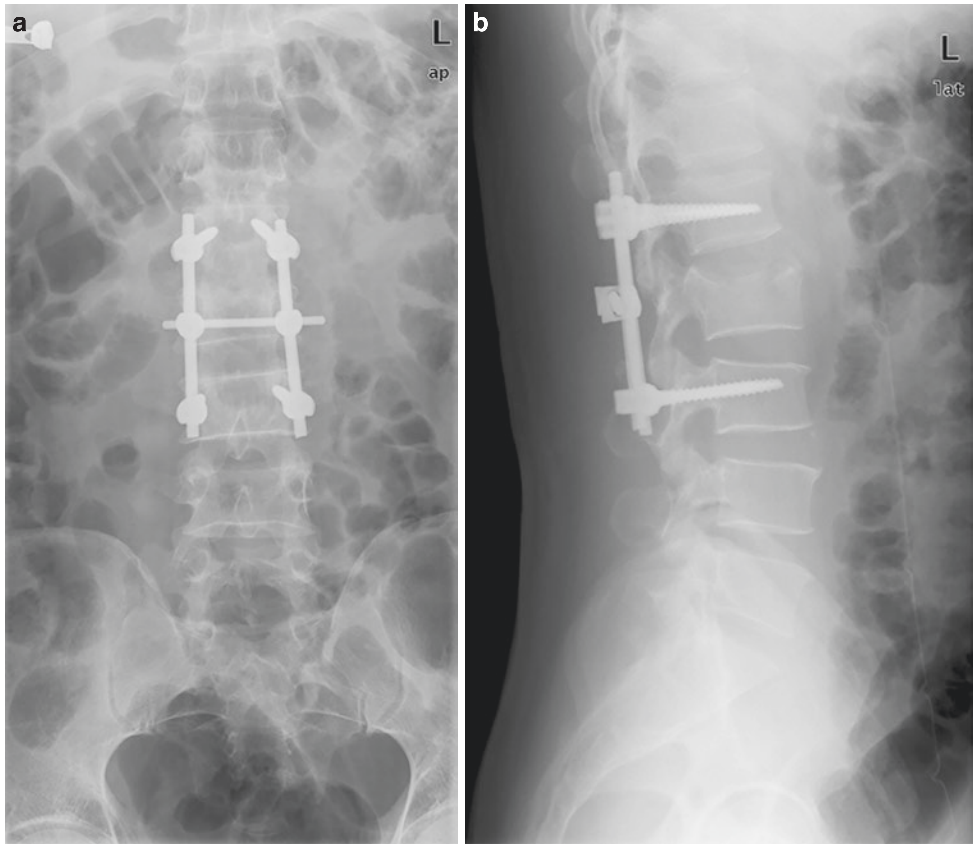

Fig. 2.27 A patient with burst fracture of the L2 vertebral body, for whom the preoperative imaging data are shown in Figs. 2.16, 2.17, and 2.18. The patient underwent open reduction and internal fixation via the posterior approach, in which the adjacent two vertebral bodies were distracted to restore the height of the fractured vertebral body and lumbar lordosis, and the space-occupying fragment in the spinal canal was reduced. (**a**) A postoperative AP radiograph. (**b**) A postoperative lateral radiograph

either an interrupted stitch with silk suture or intradermal stitch with an absorbable suture, and the surgical incision is finally closed.

6. Postoperative management:
   a. The patient lies supine, but the body is flipped periodically to avoid pressure sores within the first 24 h after surgery.
   b. The drainage tube is removed at 48 h postoperatively.
   c. At 4–6 weeks postoperatively, the patient can stand up and move while wearing an orthopedic corset.
   d. At 12–18 months postoperatively, the stability of the spine is assessed, and the timing for the removal of internal fixators depends on the actual situation.

2.2.2.2 Open Reduction and Internal Fixation Via the Anterior Approach for Treating Lumbar Fractures

- Body position and preoperative preparation:
  – The patient undergoes general anesthesia through orotracheal intubation.
  – The patient lies in the right lateral decubitus position. Access to the surgical field is at the left side to avoid obstruction caused by the liver and vena cava.
  – The waist of the patient is positioned at the site of the operating table where the table can be folded, which increases the distance between the twelfth rib and lilac crest and thereby facilitates the operation.
  – A cushion is placed under the armpit to protect the nerves and vessels from compression.
- Incision projection on the body surface: The position of the incision slightly varies with the location of the affected vertebra (Fig. 2.28).
- Surgical approaches (Fig. 2.29):
  – The subcutaneous tissue, fascia, musculus obliquus externus abdominis, musculus obliquus internus abdominis, musculus transversus abdominis, and transversalis fascia are dissected sequentially along the skin incision.
  – After the peritoneum and extraperitoneal fatty tissue are identified, the peritoneum is flipped anteriorly to avoid being damaged in subsequent procedures.
  – The psoas major is an important anatomic landmark of the retroperitoneal space. A series of critical anatomic structures, including the genitofemoral nerve (GFN) and ureter, can be found on the surface of the psoas major. For protective purposes, the ureter is pulled anteriorly along with the peritoneum.
  – The psoas major is bluntly separated from above the lumbar vertebra and pulled laterally. Subsequently, the vessels associated with the affected segment are exposed, ligated, and severed to expose the affected vertebra.
- Decompression and fixation:
  – The vertebral pedicle is carefully dissected with a small periosteum stripper; the vertebral pedicle is nib-

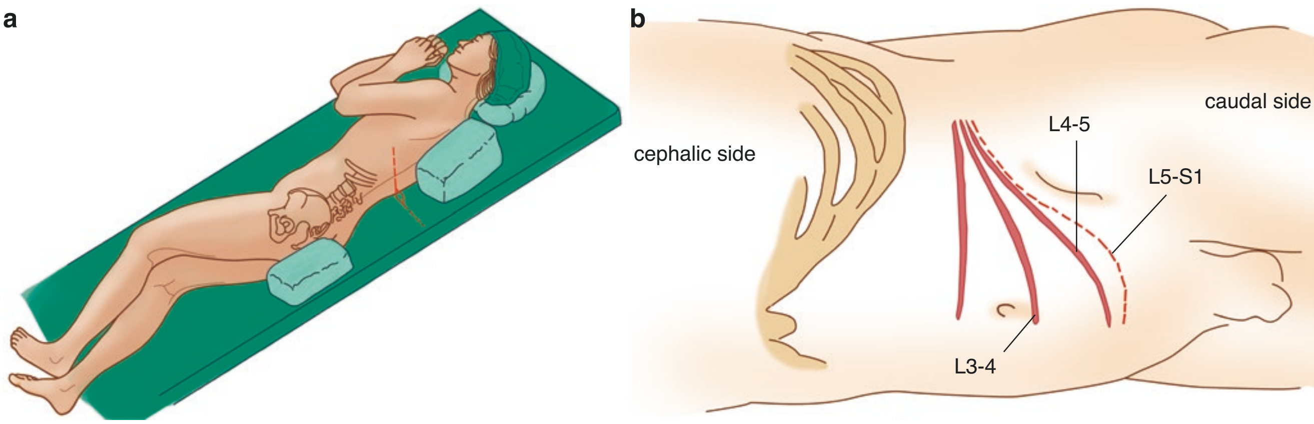

Fig. 2.28 Body position and surgical incision of the anterior approach to the lumbar spine. (**a**) The patient lies in the right lateral decubitus position, and to help improve exposure, the waist is positioned to be at the site of the operating table where the table can be folded. (**b**) Different incisions for exposing different vertebrae

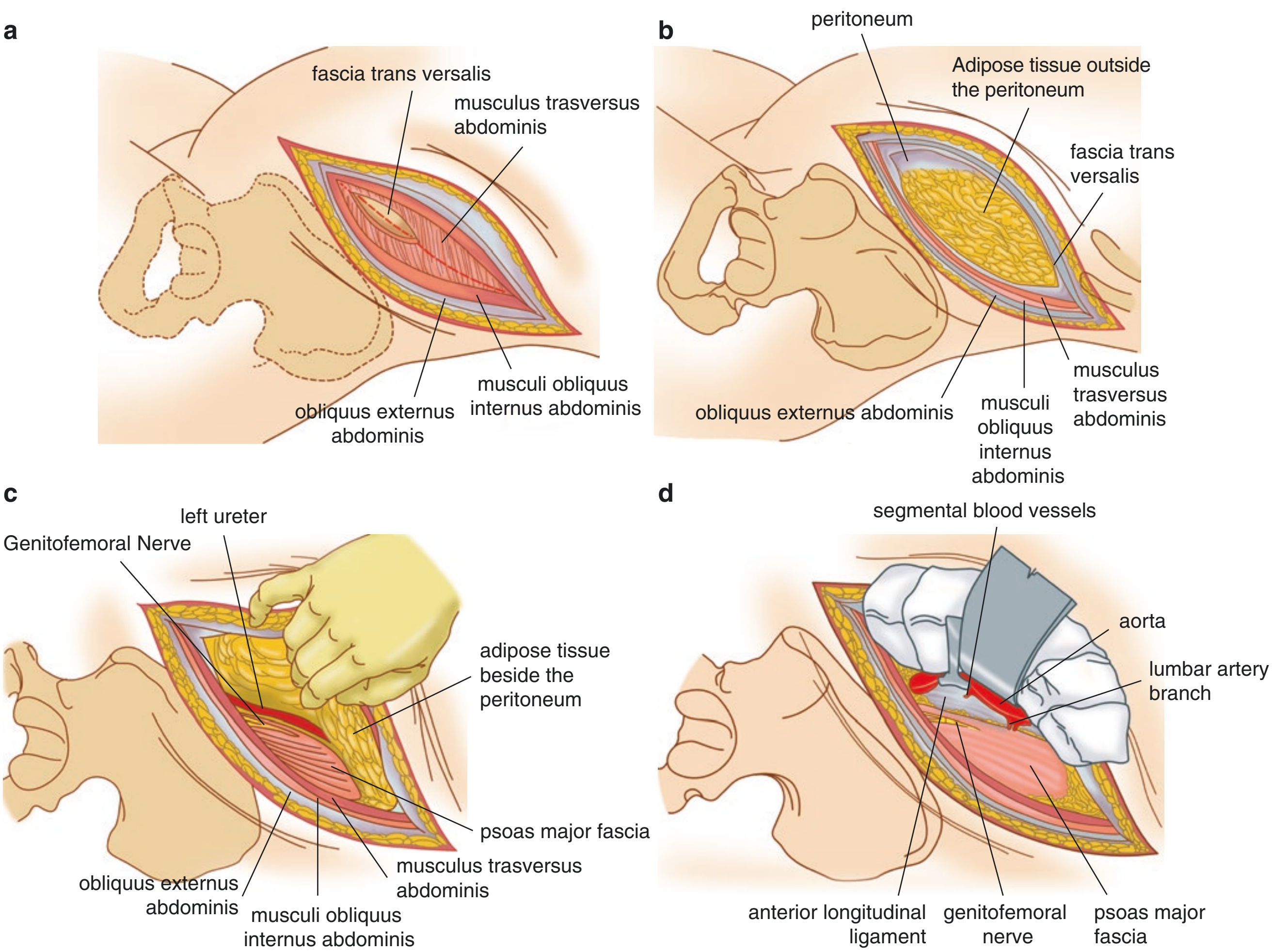

Fig. 2.29 Anatomical schematic of the anterolateral approach to the lumbar spine. (**a**) The skin, subcutaneous tissue, musculus obliquus externus abdominis, musculus obliquus internus abdominis, musculus transversus abdominis, and transversalis fascia are dissected sequentially along the skin incision. (**b**) The peritoneum is flipped anteriorly. Special attention should be paid to protecting the peritoneum and internal organs. (**c**) The important structures such as the genitofemoral nerve (GFN) and ureter can be found on the surface of the psoas major, which should be pulled anteriorly together with the peritoneum for protection. (**d**) The blood vessels of the involved segments are ligated and severed sequentially, and then the affected vertebral body is exposed

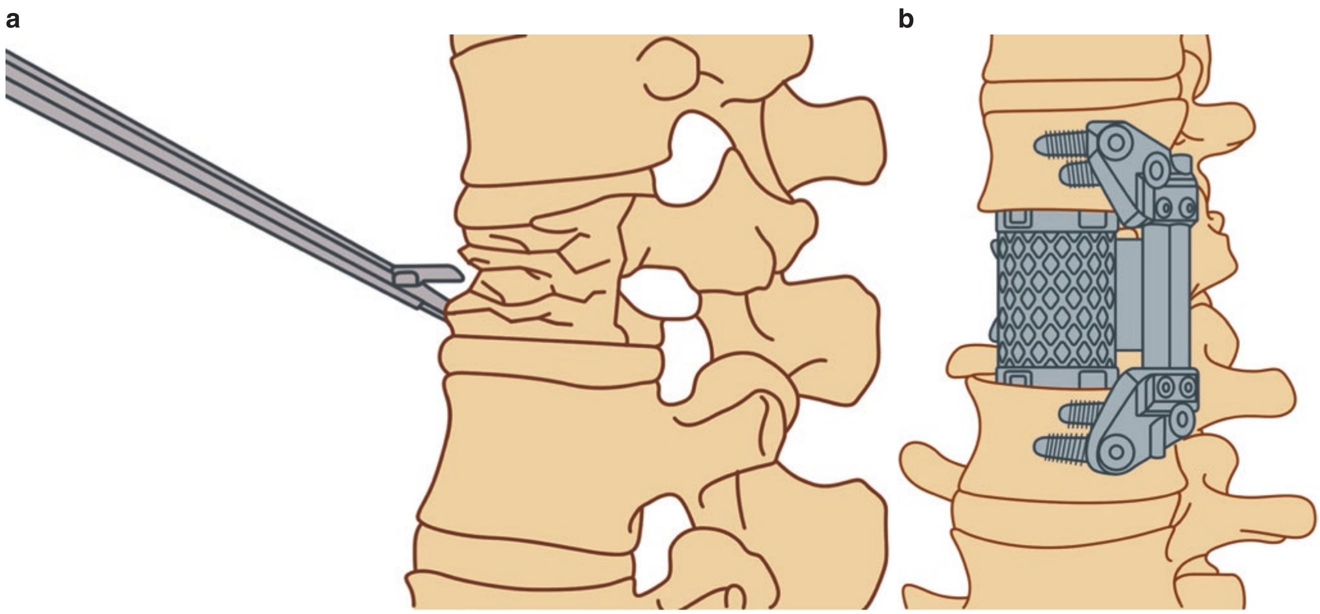

Fig. 2.30 (**a**) The lesioned vertebral body is nibbled off up to the end of the pedicle with a rongeur. (**b**) The mechanical stability of the anterior and middle columns of the spine is reconstructed using a titanium cage and a lateral screw-rod fixation system

bled out with a bone rongeur if exposure of the endorachis is required.
  - After the intervertebral foramen is identified by tracing along the vessel-nerve bundle, the intervertebral foramen above and below the affected vertebra are dissociated from the surrounding structure up to the affected segment, and then, both the intervertebral discs above and below the affected vertebra are removed. Next, the vertebral body is nibbled out with a bone rongeur up to the end of the vertebral pedicle. It is necessary to examine the intervertebral disc above to avoid any residual ruptured fragment.
  - For full decompression, the posterior longitudinal ligament is cut to expose the dural sac without damaging the nerve root.
  - After removal of the vertebral body, a series of methods, including a lateral pin-rod system, fusion cage, titanium cage, and autologous bone grafting, can be considered to reconstruct the mechanical stability of the anterior and middle columns of the spine (Fig. 2.30).
- Incision closure: The incision is sutured layer by layer according to the anatomical structure after placing a drainage tube at the surgical site.
- Postoperative management:
  - A patient-controlled intravenous analgesia (PCIA) pump can be administered.
  - Movements while wearing a supporting device are allowed beginning at postoperative day 2.
  - The drainage tube can be removed on postoperative day 2.
  - Follow-up AP and lateral radiographs are obtained after surgery (Fig. 2.31).

2.2.3 Experience and Lessons

- Clinical decision:
  - The need for long-segment fixation: Most burst fractures can be reduced by posterior distraction that tightens the structures, including the posterior longitudinal ligament. However, for patients with severe kyphosis and an unstable spine, long-segment fixation might be a better option that achieves higher stability. The disadvantage is that the fixation stress is concentrated at the sites above and below the fixed segments, which might cause a loss of motion range of the lumbar spine and subsequent degeneration of the joints.
- Surgical operations:
  - Subperiosteal stripping: It is crucial to create access to expose the surgical field by subperiosteal stripping rather than dissociation in the muscular layer, as the latter could cause massive bleeding. A good practice is either sharp subperiosteal dissociation using a periosteum stripper or electric knife or blunt subperiosteal separation using gauze.
  - After the segmental arteries are derived directly from the aorta, they travel between the transverse processes and supply blood to the paravertebral muscles. Therefore, bleeding often occurs during separation near the transverse processes, which can be stopped using a bipolar electrocoagulator.

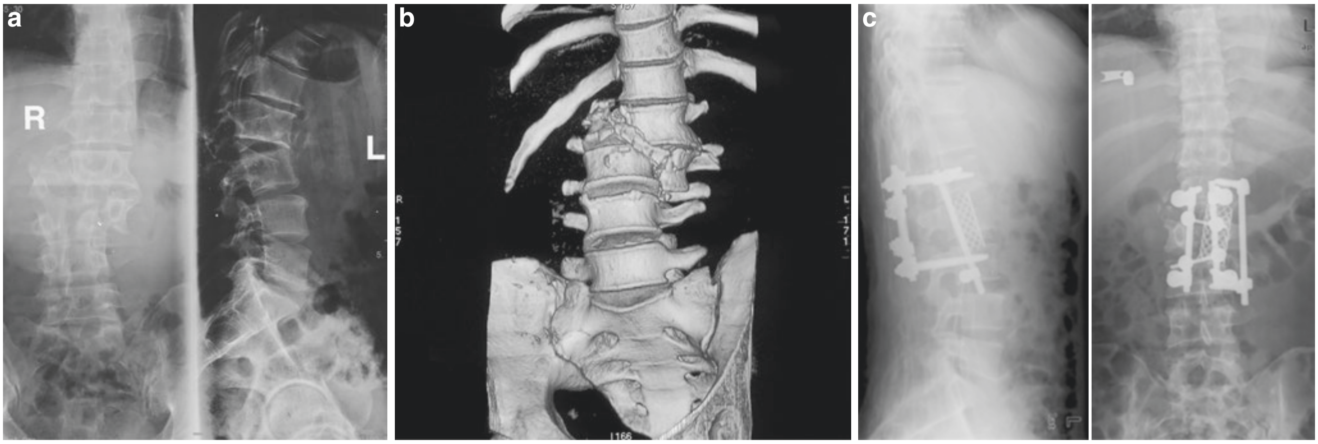

Fig. 2.31 A 37-year-old male patient who was injured from a fall. (**a**) A preoperative radiograph: The L2 vertebral body had a burst fracture and dislocation. (**b**) Preoperative CT 3D reconstruction: The L2 vertebral body was comminuted and luxated to the lateral side. The lower edge of the L1 vertebral body almost overlapped with the upper edge of the L3 vertebral body. (**c**) The anterior and posterior approaches were jointly used. The subtotal corpectomy, decompression of the spinal canal, implantation of a titanium mesh cage, and screw-rod fixation were conducted via the anterior approach. The pedicle screw fixation was performed via the posterior approach

- During Kirschner wire insertion and the subsequent radiographic examination prior to pedicle screw placement, the Kirschner wires can be wrapped with bone wax to reduce intramedullary bleeding.
- Position of the vertebral pedicle screws: Examination with a ball-tipped probe is critical and ensures that the vertebral pedicle is intact and that the planned screw channel does not break the anterior vertebral body prior to placement of a vertebral pedicle. In addition, the vertebral pedicle screws on both sides must not cross the midline while they are advanced as deep as possible up to the subchondral bone to enhance their anchorage. After vertebral pedicle placement, both AP and lateral radiographs are obtained to ensure that all screws are at the correct positions.
- Necessity for fixation of the affected vertebra:

  It has been reported that, in a portion of patients who need long segment fixation, vertebral pedicle screw placement into the affected vertebra can enhance the stability of the spine, and therefore, an additional short-segment fixation is acceptable (Mahar et al. 2007);

  Wang et al. reported a fixation method for the affected vertebra that places the pedicle screws in positions slightly higher than the adjacent vertebrae and then connects the screws with a rod. The advantage of this method is that the affected vertebra can be pushed anteriorly to promote recovery of the natural lordosis.
- Minimally invasive placement of pedicle screws:

  With the advancement of intraoperative radiographic monitoring technologies and the increasing recognition of the minimally invasive surgery, a number of companies, including K2M and Synthes, have designed and manufactured devices for the placement of pedicle screws and rods through a small percutaneous incision.

  However, there is a lack of studies comparing the outcomes of traditional and minimally invasive surgery. We believe that minimally invasive surgery will be greatly developed with the future advancement of technologies and improvement of devices.
- Spinal canal decompression:

  The necessity for decompression depends on the presence of neurologic deficits rather than the severity of space-occupancy in the spinal canal.

  In patients without neurologic deficits, even a space-occupying effect of 50% or more in the spinal canal does not necessitate decompression because the fracture fragment protruding into the canal can be naturally absorbed and reconstructed.

  Decompression is recommended for patients with neurologic deficits. Decompression may be performed indirectly via the posterior approach, directly via the anterior approach or via laminectomy.

    Laminectomy is recommended in patients whose spinal compression is caused by entry of the vertebral lamina fragment or the damaged ligamentum flavum into the spinal canal and in patients who require decompression for a single nerve root (Fig. 2.32).

    The space-occupancy in the spinal canal is often caused by the protruding posterior wall fragment of the vertebra. When the fragment is larger than 50% of the cross-sectional area of the spinal

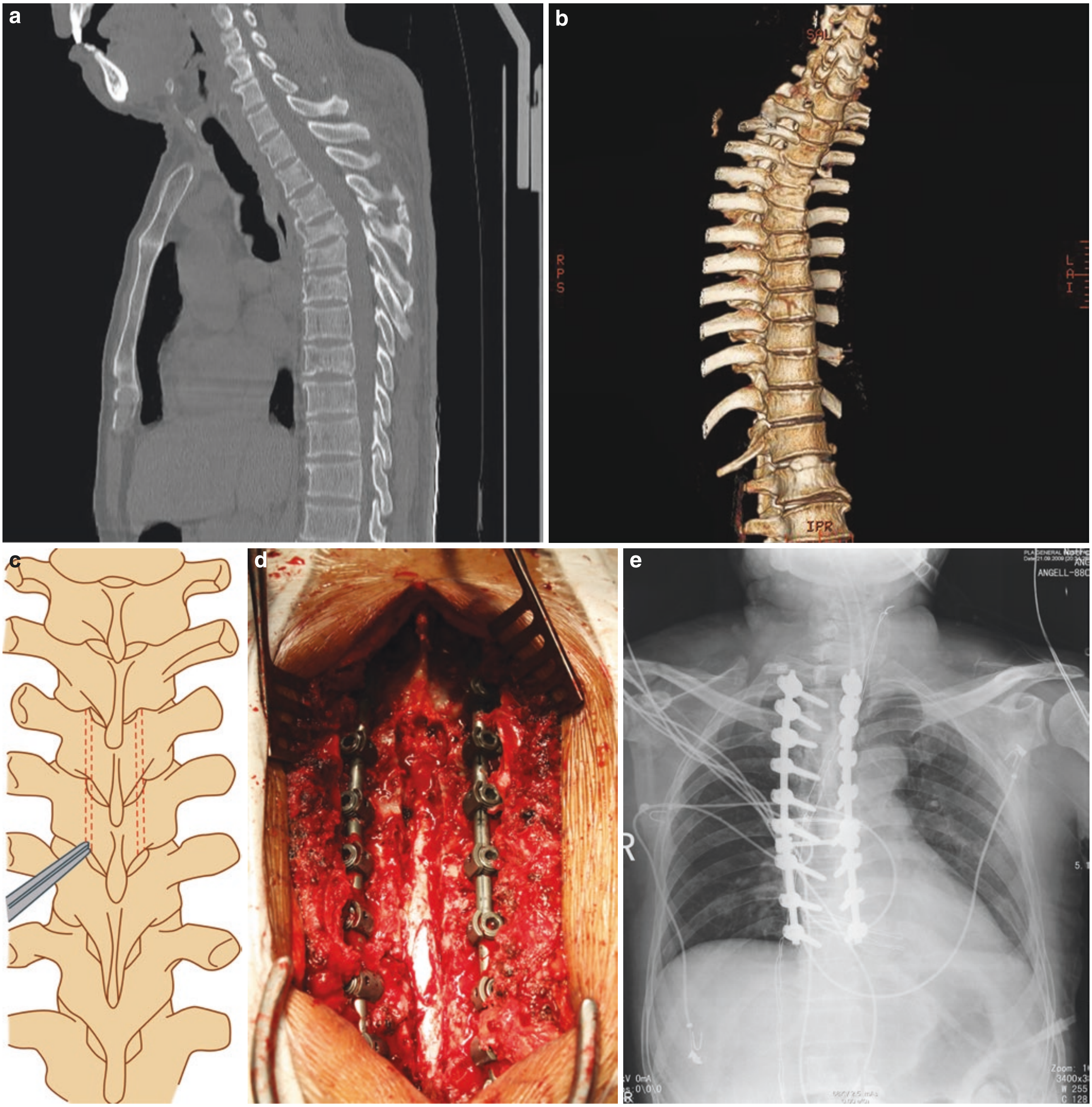

Fig. 2.32 Multiple fractures of the thoracic spine. (**a**) Preoperative CT sagittal reconstruction: The T4, T6, and T8 vertebrae were fractured, with spinal stenosis of the T4 segment. (**b**) Preoperative CT 3D reconstruction. (**c**, **d**) Laminectomy for decompression via the posterior approach: First, a high-speed burr drill was used to create an opening in the vertebral lamina, and then the vertebral lamina was nibbled off with a small rongeur to fully decompress the compressed spinal segment. (**e**) A postoperative AP radiograph

canal and has a reversion angle >45°, it is difficult to indirectly reduce the fracture via restitution of ligaments, and instead, a direct reduction via the anterior approach is required (Kaneda et al. 1997).

In lumbar segments, especially the segments distal to the end of medullary cone where it is relatively safer to pull nerve roots, decompression via the vertebral pedicle can be considered (Fig. 2.33).

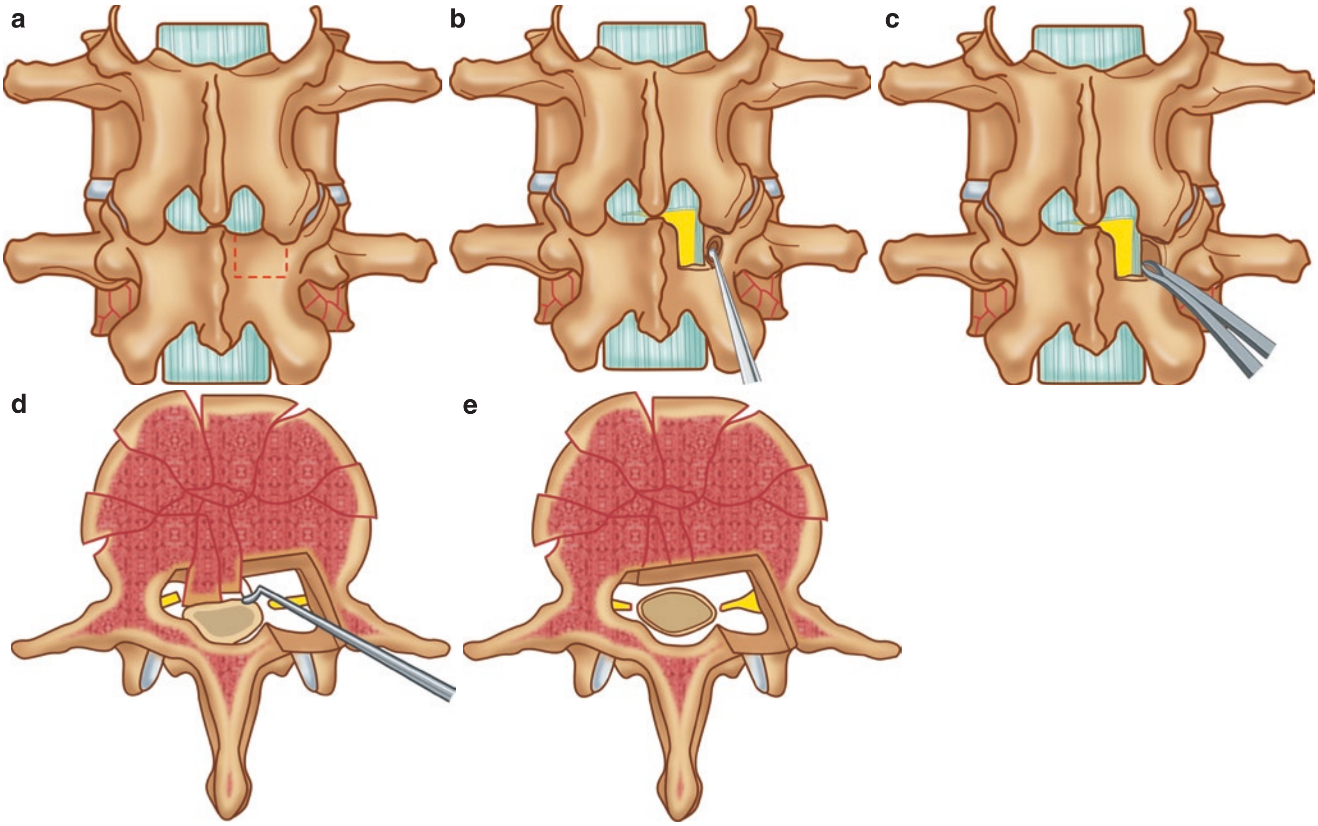

Fig. 2.33 Schematic diagram of transpedicular decompression using the posterior approach to the lumbar spine. (**a**) A portion of the vertebral lamina at the pedicle is removed. (**b**) A channel is created in the pedicle with a burr drill. (**c**) The inner wall of the pedicle is nibbled off with a small rongeur. (**d**, **e**) The bone fragment protruding into the spinal canal is pressed down with a reverse curette to reduce the compression on the spinal cord

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