Lumbar Pedicle Screw Fixation Techniques and Their Applications

9

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Abstract

All three columns of the lumbar spine are stabilized in the posterior lumbar transpedicular internal fixation technique. This technique has been widely used in the treatment of lumbar degenerative disease and lumbar fracture. Anatomic characteristics of the lumbar vertebral body, the entry point, entry angle, entry depth of the lumbar pedicle screw, and operative details are demonstrated to guarantee proper positioning of the screw. The characteristics, clinical indications and contraindications, and the surgical technique of CD HORIZON LEGACY internal fixation system are introduced in detail. The applications of these techniques are presented in typical clinical cases. Pearls and pitfalls of lumbar pedicle screw fixation are summarized at the end of this chapter.

Keywords

Lumbar spine · Pedicle screw fixation · Surgical technique

9.1 Unit 1: Lumbar Pedicle Screw Fixation Techniques and Their Applications

9.1.1 A Historical Review and Anatomic Parameters

9.1.1.1 A Historical Review of Lumbar Pedicle Screw Techniques

Reconstruction of lumbar stability evolved from wire technique and hook and rod technique to pedicle screw technique, with the following milestones:

In 1891, Hadra first used silver wire to internally fix the spine in a patient with vertebral fracture and Pott's disease [1].

In 1945, Harrington used Harrington rod for correction of idiopathic scoliosis, which has ever since offered an effective treatment for vertebral scoliosis [2].

In 1949, Michele and Krueger reported the anatomic features of pedicles and described transpedicular screw entry into the vertebral body via a posterior approach [3] (Figs. 9.1 and 9.2).

In 1961, the French surgeon Raymond Roy-Camille initiated the treatment of unstable thoracolumbar fracture by internal fixation with pedicle screws and also developed a complete pedicle screw and plate system for treating unstable thoracolumbar fractures [4] (Fig. 9.3).

In 1983, Denis proposed the "three-column theory" in which the vertebra is divided into the "anterior, middle, and posterior columns." The pedicle is a channel that runs through and connects the three columns. This theory has exerted far-reaching effects on the development of pedicle screw techniques [5].

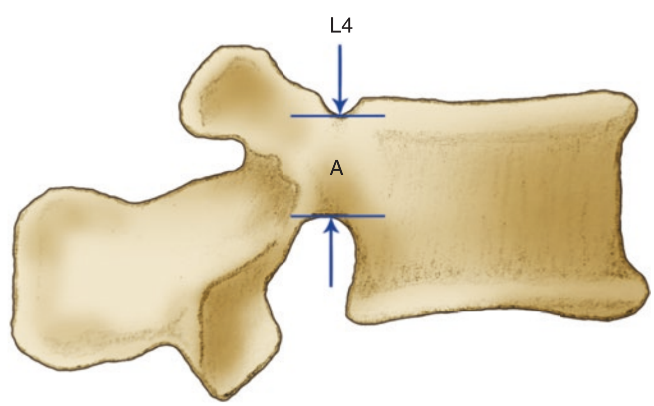

Fig. 9.1 Anatomic features of the lumbar pedicle: (*a*) vertical diameter, 0.7–1.5 cm

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W. Lei, Y. Yan (eds.), *Internal Fixation of the Spine*, https://doi.org/10.1007/978-981-16-1562-7_9

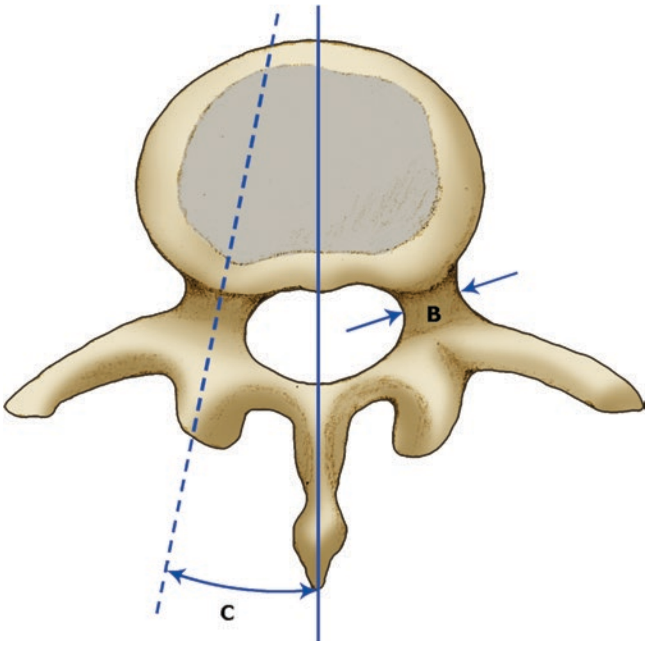

Fig. 9.2 Anatomic features of the lumbar pedicle: (*b*) horizontal diameter, 0.7–1.6 cm; (*c*): the angle between the two lines is less than 10°

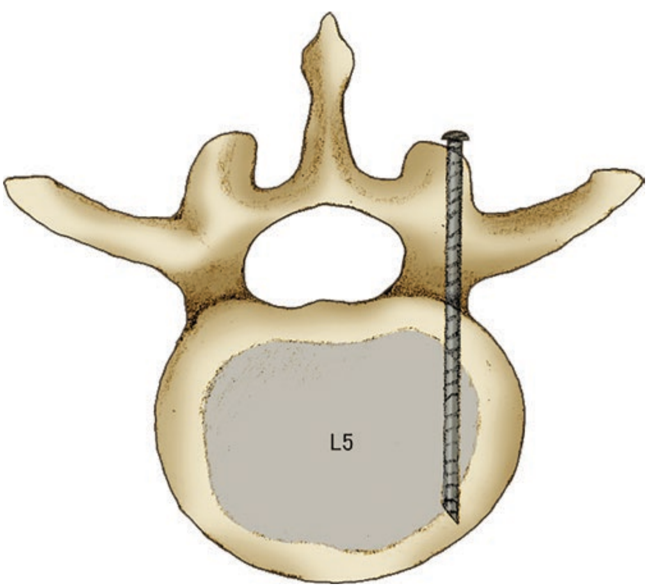

Fig. 9.3 The pedicle screw and plate system developed by Raymond Roy-Camille

In 1983, Steffee introduced the variable screw placement system as a means of transpedicular fixation of the unstable spine [6].

In 1983, French surgeons Cotrel and Dubousset invented Cotrel-Dubousset instrumentation, which replaces laminar hook with pedicle screws for lumbar fixation. The double-rod system was recommended for scoliosis patients, from which the concept of vertebral three-dimensional correction evolved [7].

The appearance of pedicle screws is an important milestone in the history of vertebral internal fixation surgery. Biomechanically, compared to hook and wire fixation, internal fixation with pedicle screws could provide three-column stabilization. Therefore, the technique provides powerful mechanical action in fracture reduction and correction; meanwhile, it does not need to enter the vertebral canal such as infralaminar wire and laminar hook, lessening the risk of nerve injury. In 1999, the US FDA approved this technique as one of the classical vertebral internal fixation techniques via the posterior approach.

9.1.1.2 Anatomy of the Lumbar Pedicle

Gross Anatomy

The gross anatomy of the lumbar vertebra is shown in Fig. 9.4.

Anatomic Data of the Lumbar Pedicle

The width of the lumbar pedicle gradually increases from L1 to L5, but variations exist among individuals (Fig. 9.5) [8–10]. In Zindrick's study [8], the height of the lumbar pedicle is 15.4 ± 2.8, 15.0 ± 1.5, 14.9 ± 2.4, 14.8 ± 2.1, and 14.0 ± 2.3 mm from L1 to L5. The width of the lumbar pedicle is 8.7 ± 2.3, 8.9 ± 2.2, 10.3 ± 2.6, 12.9 ± 2.1, and 18.0 ± 4.1 mm from L1 to L5. In Panjabi's study [9], the height of the lumbar pedicle is 15.9 ± 0.8, 15.0 ± 0.5, 14.4 ± 0.6, 15.5 ± 0.6, and 19.6 ± 0.8 mm from L1 to L5. The width of the lumbar pedicle is 8.6 ± 0.9, 8.3 ± 0.7, 10.2 ± 0.6, 14.1 ± 0.4, and 18.6 ± 1.0 mm from L1 to L5. In Ebraheim's study [10], the height of the lumbar pedicle is 14.1 ± 1.3, 14.0 ± 1.2, 13.9 ± 1.4, 12.8 ± 1.7, and 11.4 ± 1.4 mm from L1 to L5. The width of the lumbar pedicle is 7.5 ± 1.5, 8.2 ± 1.3, 9.8 ± 1.1, 12.7 ± 1.9, and 18.0 ± 2.4 mm from L1 to L5.

There is a medial inclination angle in the axial plane of the pedicle, which gradually increases from L1 to L5 [9, 11]. The medial inclination angle steadily rises in the cephalad-caudal direction. The range of the angle is from 0° to 10°, and the maximum medial inclination angle is approximately 27°, and is found at the L5 vertebral body in the horizontal

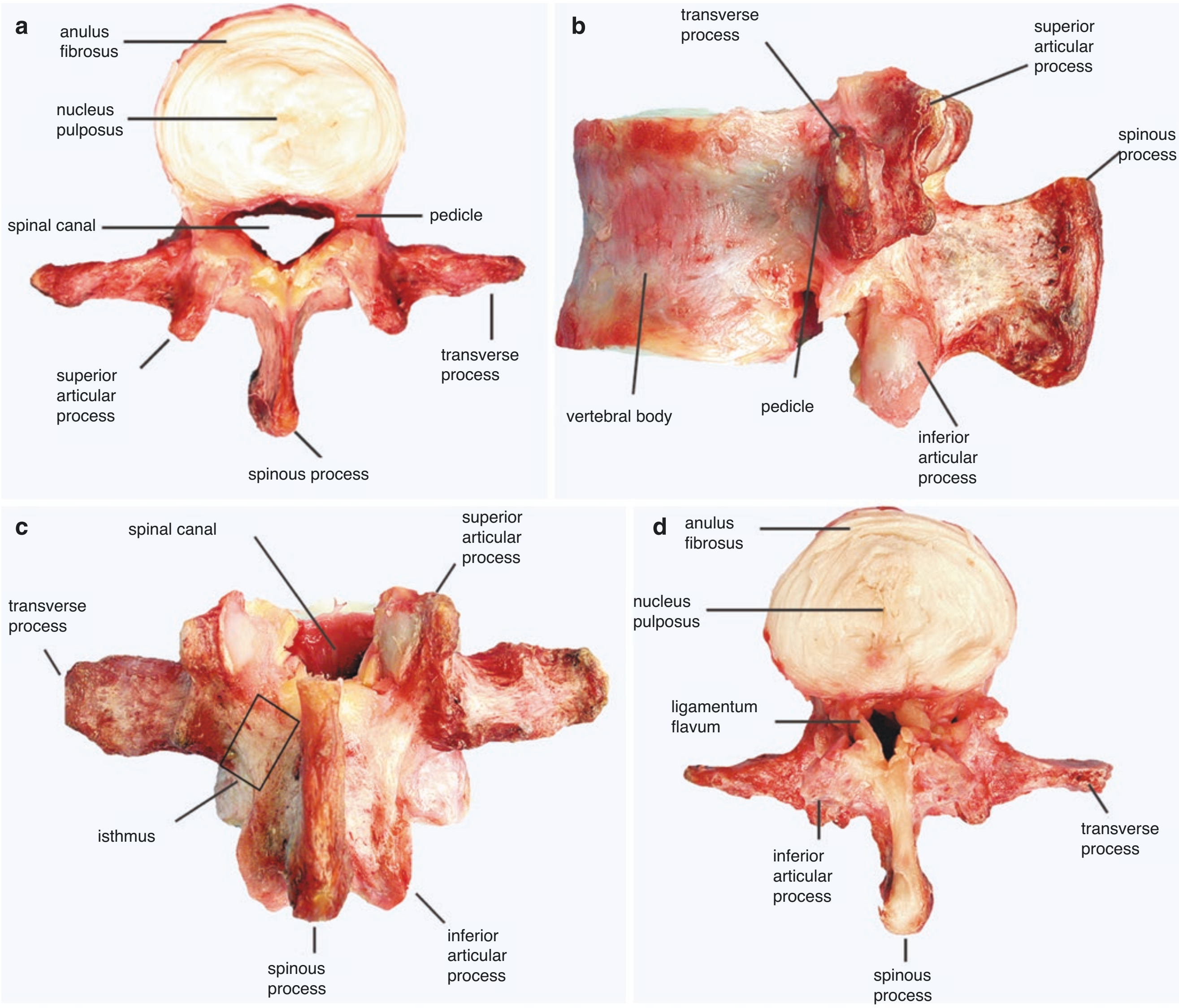

Fig. 9.4 The anatomic structures of the lumbar vertebra. (**a**) Superior view; (**b**) Inferior view; (**c**) Lateral view; (**d**) Posterior view

plane. In Panjabi's study [9], the medial inclination angle of the right lumbar pedicle is 16.5 ± 5.02°, 17.1 ± 3.75°, 19.8 ± 2.33°, 18.4 ± 1.66°, and 25.9 ± 1.73° from L1 to L5. The medial inclination angle of the left lumbar pedicle is 12.4 ± 1.87°, 11.2 ± 2.02°, 17.1 ± 1.56°, 14.7 ± 2.16°, and 23.2 ± 1.48° from L1 to L5.

9.1.1.3 Lumbar Pedicle Screw Techniques

Determining the Entry Point of Lumbar Pedicle Screws

1. Intersection method

The screw entry point is located at the intersection of a horizontal line passing through the midpoint of the transverse process and a vertical line tangential to the lateral border of the superior articular process. The approach requires partial exposure of the transverse process. Because of greater stripping and abundance of adjacent vessels, bleeding is more profuse [12] (Fig. 9.6).

2. The ^ vertex point method

There is a specific anatomic feature in the posterior lumbar spine-^ vertex point. ^ vertex point is the entry point of pedicle screw (Fig. 9.7). This method does not require exposure of the transverse process.

Entry Angle of Lumbar Pedicle Screws

The pedicle screw should have a medial inclination of 5°–10° relative to the sagittal plane at L1–L3 and a medial inclination of 10°–15°at L4–L5 [12] (Fig. 9.8).

Fig. 9.5 Three-dimensional (3D) CT reconstruction of the lumbar pedicle. (**a**) The coronal section; (**b**) The sagittal section; (**c**) The oblique position

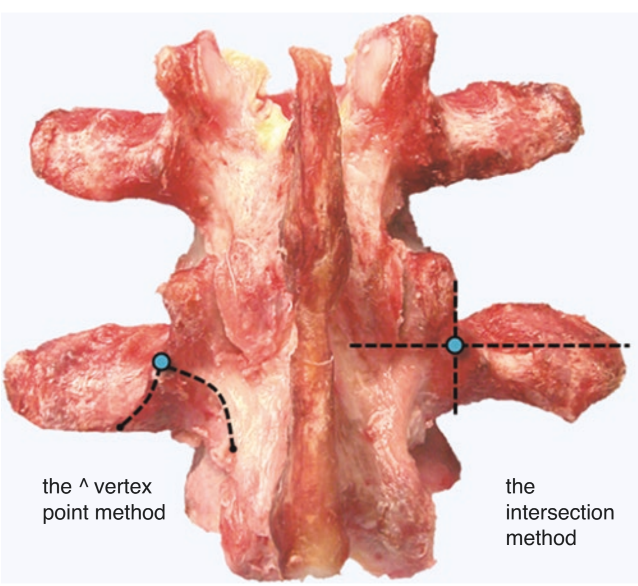

Fig. 9.6 Methods for determining screw entry points

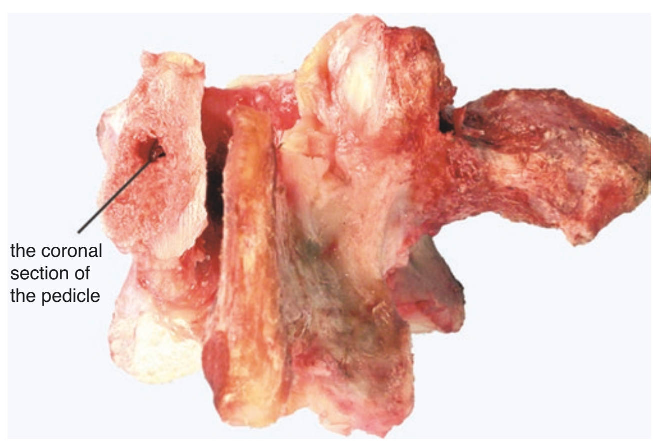

Fig. 9.7 The coronal section of the pedicle

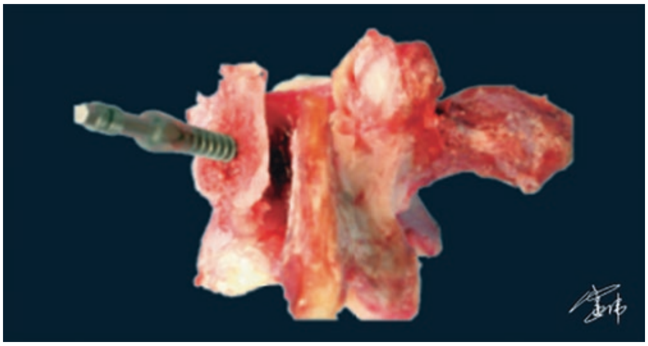

Fig. 9.8 Screw entry angle

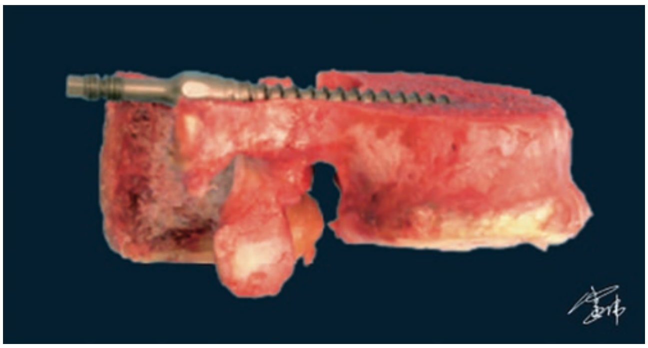

Fig. 9.9 The pedicle screw is parallel to the endplate

At L1–L4, the pedicle screw should be parallel with the lumbar endplate, that is, vertical to the center of gravity line of the vertebral body. Because the L5 vertebral body is oblique, the entry direction should be inclined toward the caudal direction and has an angle of 10° relative to the horizontal plane [12] (Fig. 9.9).

Entry Depth of Lumbar Pedicle Screws

The entry depth is generally around 45 mm. On lateral X-ray, the depth of the positioning pin should not exceed 80% of the anteroposterior diameter of the vertebral body. The most commonly used screws are 6.5 mm in diameter (Fig. 9.10).

9.1.1.4 Surgical Steps

Determine Screw Entry Point (Fig. 9.11)

Prepare Screw Trajectory

1. Disrupt the bone cortex: A mill, a rongeur, or a burr is used to disrupt the cortical bone at the screw entry point (Fig. 9.12).
2. Drill the screw hole: A screw hole is gradually drilled in the cancellous bone of the pedicle and vertebral body using a drill bit with a drill guide at the above-mentioned angle and depth. During drilling, the surgeon should have an obvious manual feedback of having entered into the cancellous bone. If resistance is encountered, the surgeon should consider whether the entry point or entry angle is correct. If the surgeon con-

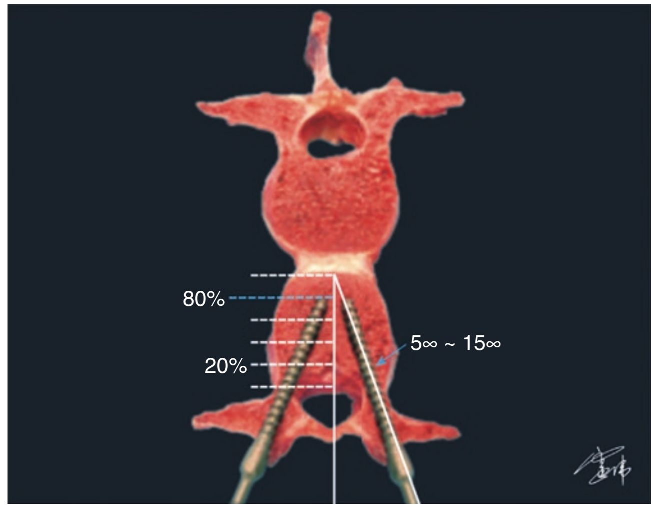

Fig. 9.10 Entry depth of lumbar pedicle screws

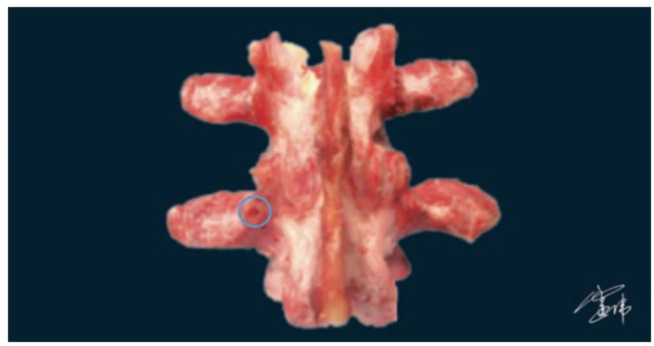

Fig. 9.11 Determining the screw entry point

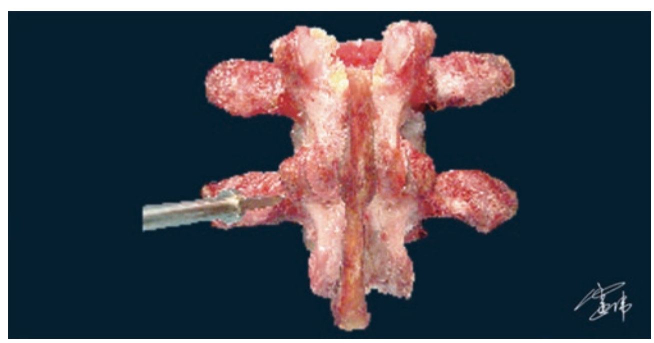

Fig. 9.12 Disrupting the bone cortex

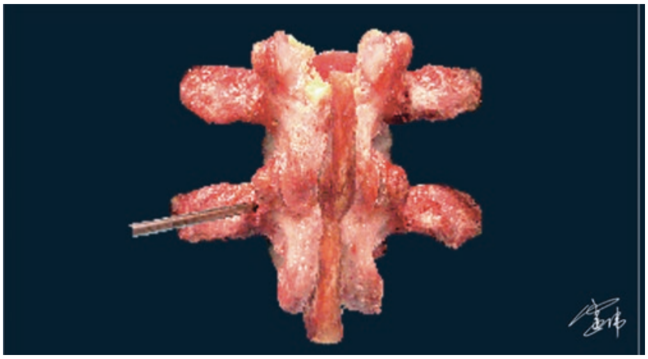

Fig. 9.13 Drilling the screw hole

tinuously feels resistance or changes in bone density during insertion, the surgeon should determine by X-ray whether the burr has disrupted the lateral wall of the pedicle (Fig. 9.13).

3. Probe insertion depth: A blunt pedicle probe is advanced into the vertebral body via the pedicle screw path. When the walls of the screw path are probed, the surgeon should have the manual feedback of probing the cancellous bone and make sure that the integrity of the walls is not violated. If resistance or discontinuity is encountered during probing, the surgeon should consider whether the entry angle is correct and verify by X-ray that the probe is within the pedicle under fluoroscopic guidance (Fig. 9.14).
4. Determining the location: After the hole is drilled, a metal probe is put in the screw hole and located under fluoroscopic guidance. Adjustment is made until satisfaction is achieved under fluoroscopic guidance (Fig. 9.15).

Screw Insertion

Appropriate screws are selected based on the screw trajectory and intraoperative need for correction. Suitable screws are inserted into the prepared screw path using a screwdriver. Screws should be fully inserted and enter 80% of the vertebral body; the screw path should be parallel to the endplates (Fig. 9.16).

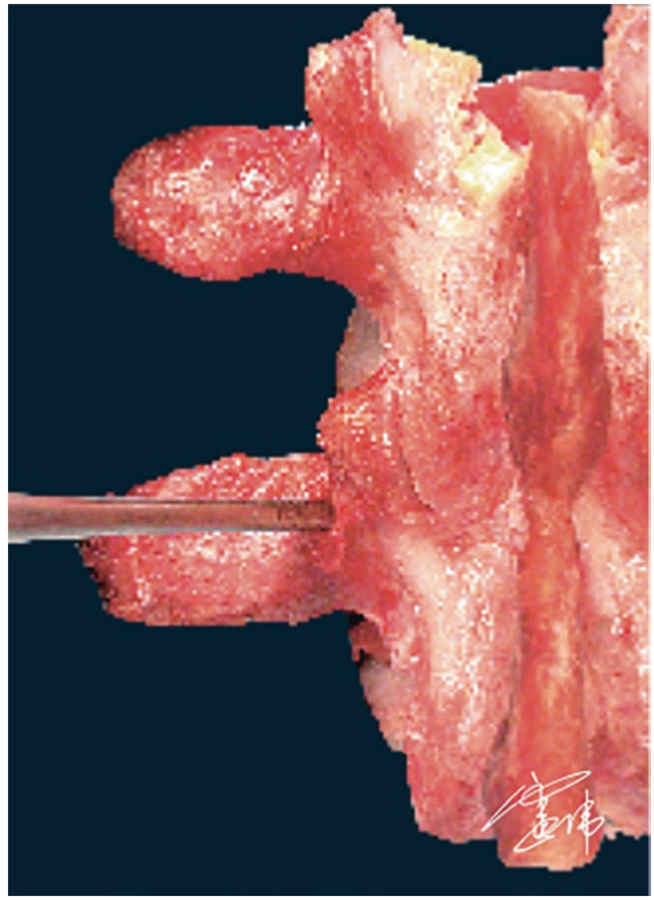

Fig. 9.14 Probing insertion depth

Fig. 9.15 Determining the location

9.2 Unit 2: The CD HORIZON LEGACY Plate Internal Fixation System via a Lumbar Posterior Approach

9.2.1 Implants

1. Screws (Fig. 9.17)
   a. Fixed angle screws
   b. Variable angle screws

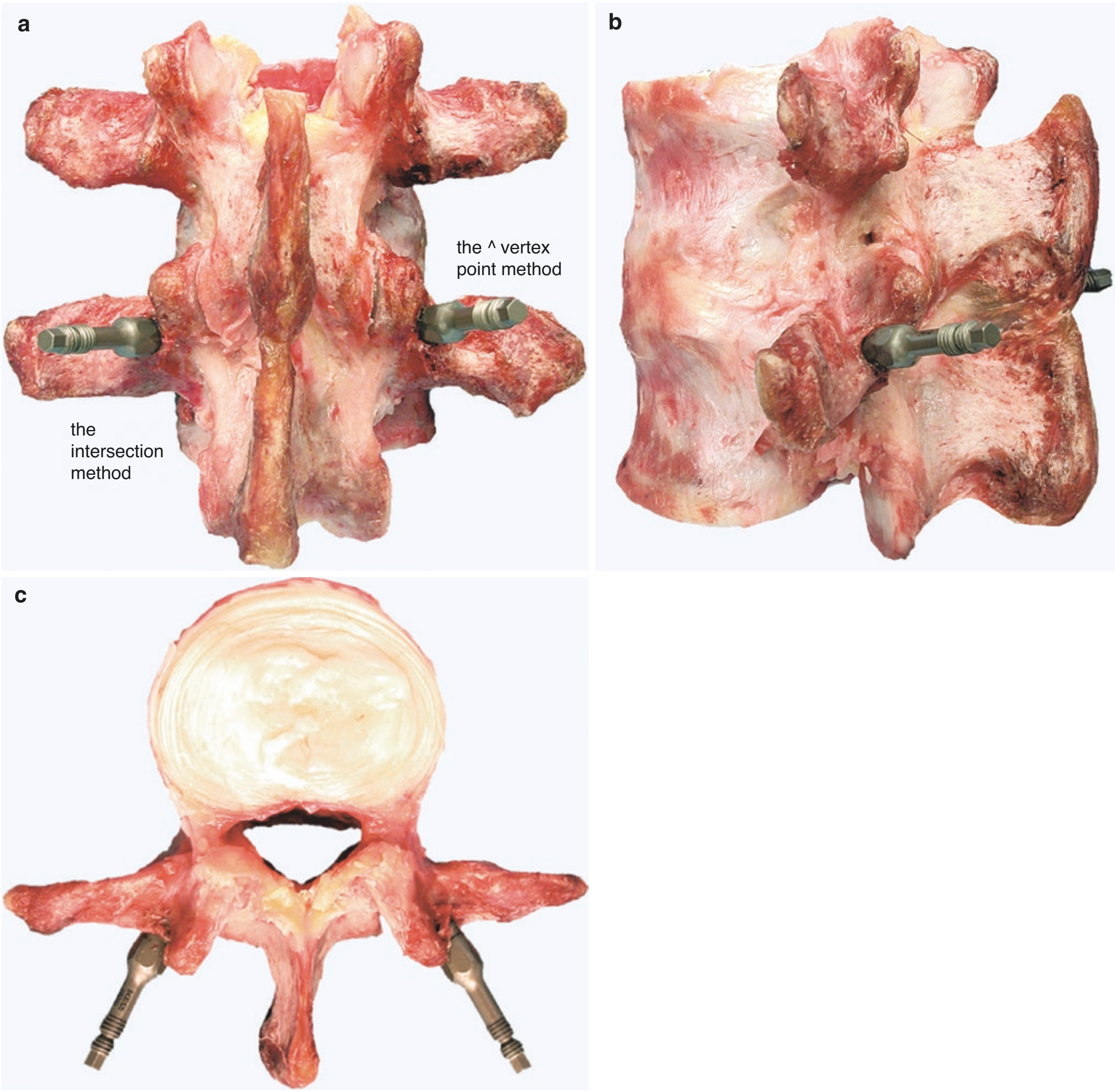

Fig. 9.16 Screw insertion. (**a**) Posterior view; (**b**) Oblique view; (**c**) Axial view

Fig. 9.17 Screws. (**a**) Fixed angle screw; (**b**) Multi-axial screw; (**c**) Multi-axial Reduction Screw

2. Laminar hooks (Fig. 9.18)
    a. Pedicle hook: For use for segments above T_{10}.
    b. Wide blade hook: It is the most frequently used hook type and is for use in the vertebral lamina or the transverse process.
    c. Thin blade hook: For use in the vertebral lamina or patients with a smaller spinal canal.
    d. Angled blade hook: It is mainly for use in the upper thoracic segments or patients with a smaller spinal canal.
    e. Angled laminar hook: For use in the infralaminar position, mainly in L_3, L_4, and L_5.
    f. Extended body hook: It is for use as a reverse hook, mainly in the infralaminar position.
    g. Thoracic laminar hook: It is for use in combination with pedicle hook at T_1, T_2, or T_3.
    h. Offset hook: It is for use in combination with pedicle screws.

9.2.2 Features of the System

1. The system uses patented G4 locking technology-reverse angle locking screws, which is easy to assemble and has a strong holding power, and a smaller implant notch (Figs. 9.19 and 9.20). Its clinical adoption has been increasing, with the following distinct features of the system:
    a. The entire system has a smaller profile.
    b. The adjacent superior articular process is preserved.
    c. It allows greater space for bone graft.
2. The design features of this system are its effectiveness, ease of use, and excellent handgrip of the silicone handle.
3. The system offers many options for the surgeon who can choose different combinations according to individual patient characteristics. The variety of implants include straight or curved rods of different diameters, fixed angle and universal angle screws of different diameters, bone hook, fixed angle, and universal screws. This system can be used for the thoracolumbar spine.

9.2.3 Clinical Indications and Contraindications

9.2.3.1 Indications

It is suitable for posterior thoracic, lumbar, and lumbosacral fixation.

1. Trauma
    a. Fracture and traumatic spondylolisthesis
    b. Correction of fracture malunion
2. Degenerative diseases
    a. Severe or recurrent lumbar disc hernia
    b. Vertebral instability or spondylolisthesis
    c. Stability reconstruction following laminectomy for spinal stenosis

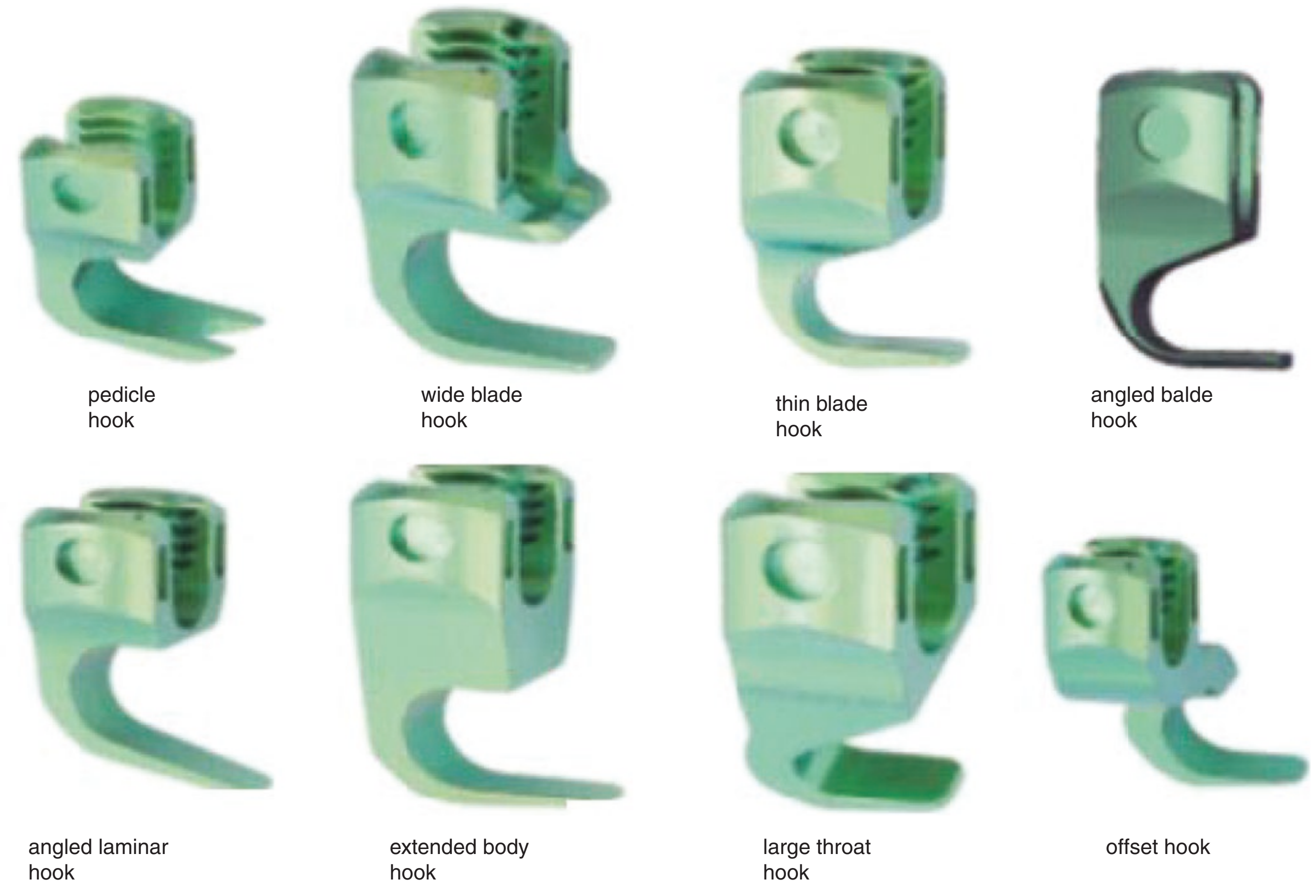

Fig. 9.18 Types of laminar hooks

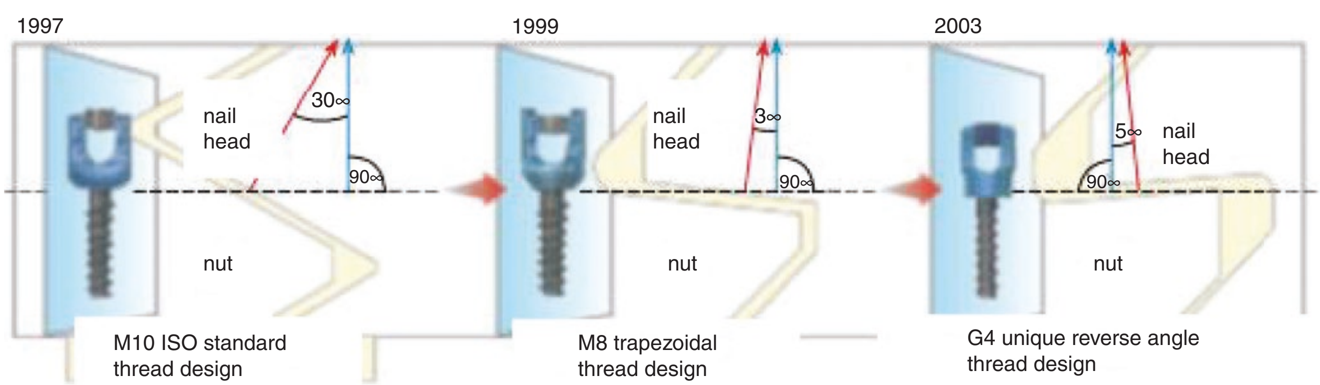

Fig. 9.19 G4 patented locking technology

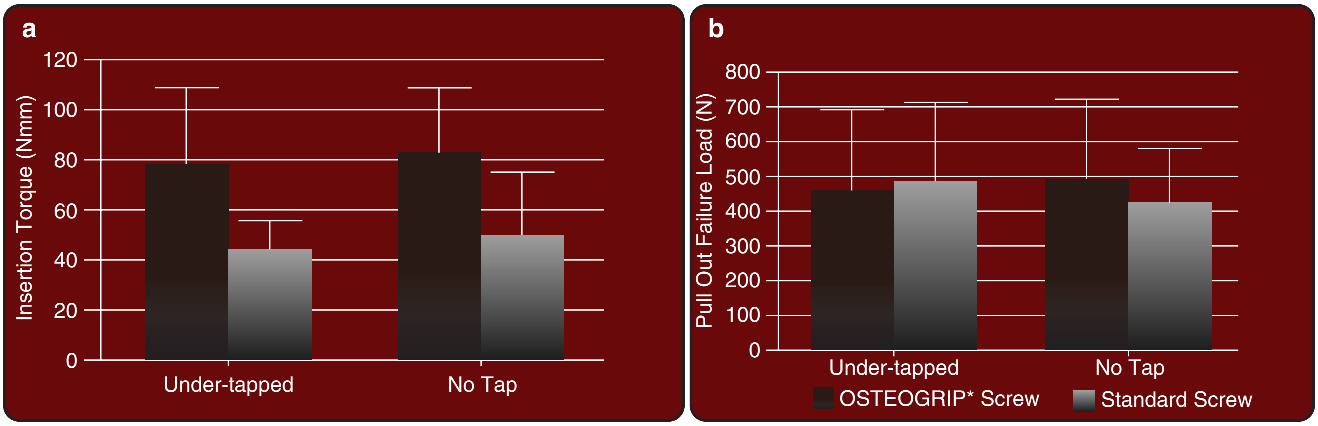

Fig. 9.20 Insertional torque (**a**) and pullout (**b**) study

3. Tumors
   a. Benign or malignant vertebral tumors or resection of metastatic tumor followed by reconstruction and posterior stabilization
   b. Laminectomy for intraspinal tumor followed by reconstruction and posterior stabilization
4. Infectious diseases
   a. Discitis or mild intervertebral disc space infection
   b. Vertebral tuberculosis debridement followed by reconstruction and posterior stabilization
5. Congenital diseases and malformations
   a. Correction of congenital vertebral scoliosis
   b. Correction of idiopathic vertebral scoliosis
   c. Correction of vertebral kyphosis

9.2.3.2 Contraindications

It cannot be used alone for anterior stabilization.

9.2.4 Surgical Techniques

9.2.4.1 CDH SOLERA Degenerative Surgical Technique

1. Universal screw placement

For pedicle preparation, screws of appropriate lengths are selected, and the hex head screwdriver is inserted into the screw head (Fig. 9.21a). Then, the screwdriver sleeve is rotated into the screw head (Fig. 9.21b). The hex head and thread sleeve provide durable support for universal screw placement. In addition, self-retaining screwdriver may also be used by inserting the inner hex head of the screwdriver into the screw head.

Screw position is assessed by fluoroscopy in the anteroposterior and lateral view. Intraoperative EMG monitoring may be undertaken if available. After a screw is fully placed, it should be parallel to the upper endplate and reaches 50–80% of the vertebral body height. For sacrum fixation, especially in patients with osteoporosis, screw fixation through two cortices can be employed. Some surgeons even recommend screw fixation through three cortices (to reach the anterior cortex via S1 endplate) in order to provide stronger fixation. The sleeve is withdrawn once a screw is properly placed.

9.2.4.2 Rod Contouring and Placement

Once correct screw placement has been verified radiographically, the selected rods were measured and contoured in the sagittal and coronal planes. To measure the rod length required for the construct, a rod template may be used (Fig. 9.22). A rod cutter (handheld or tabletop) may be used to cut the appropriate rod length.

The titanium alloy rods have an orientation line that serves as a reference point during contouring. To prevent the rod from rotating during contouring, it is helpful to clamp the rod with Dual Action Rod Grippers at both ends (Fig. 9.23). Note: Prior to implantation of the rod, break off the VERIFYI® Implant Tracking Tag and retain it in the Tag Sorter; thus, it can be scanned at the end of the surgery.

For non-hyperkyphotic deformities, the rod is first placed on the concave side. The contoured rod is then introduced into the previously placed screws. There are several methods and instruments for facilitating fully seating the rod into the saddle of the implant. Forceps Rocker Method: When only a slight height difference exists between the rod and the implant saddle, use of the Forceps Rocker is an effective method for reducing (or seating) the rod into the implant. To use the Forceps Rocker, the sides of the implant are grasped with the rocker cam above the rod and then lever backward over the rod (Fig. 9.24, left). Forceps

Fig. 9.21 Universal screw placement. (**a**) The screwdriver is inserted. (**b**) The sleeve is rotated into position

Fig. 9.22 Rod template

Rocker Method: The levering action allows the rod to be fully seated into the saddle of the implant. To introduce the set screw, the Dual Ended Set Screw Starter is then used (Fig. 9.24, right). Beale Rod Reducer: The Beale Rod Reducer may be used to seat the rod in situations where the rod rests at the top of the implant. The Beale Rod Reducer attaches to the four implant slots (Fig. 9.25, left). Once the Beale Rod Reducer is attached to the implant, the reducer handles are squeezed slowly, allowing the sleeve to slide down, and the rod is then seated into the implant saddle. Note: Prior to implantation of the set screw, break off the VERIFYI® Implant Tracking Tag and retain it in the Tag Sorter; thus, it can be scanned at the end of the surgery. The set screw is then placed through the reducer tube and into the implant head with the Provisional Driver or a Dual Ended Set Screw Starter. The set screw is provisionally tightened with the Provisional Driver in the extended position (Fig. 9.25, right).

Fig. 9.23 Clamping the rod with Dual Action Rod Grippers

9.2.4.3 Compression/Distraction

Distraction and/or compression is performed to place the hooks in their final position once the rod is secured in the implants. The Hinged Translator, Multilevel Hook Compressor, Distractor, and Provisional Driver are used to perform these maneuvers (Fig. 9.26). Compression maneuvers are most often carried out directly on two hooks (Fig. 9.27). Another option is to use the Hinged Translator for compression. To ensure that the foot of either instrument is placed against the implant body and not against the set screw, care should be taken. It is preferable that compression

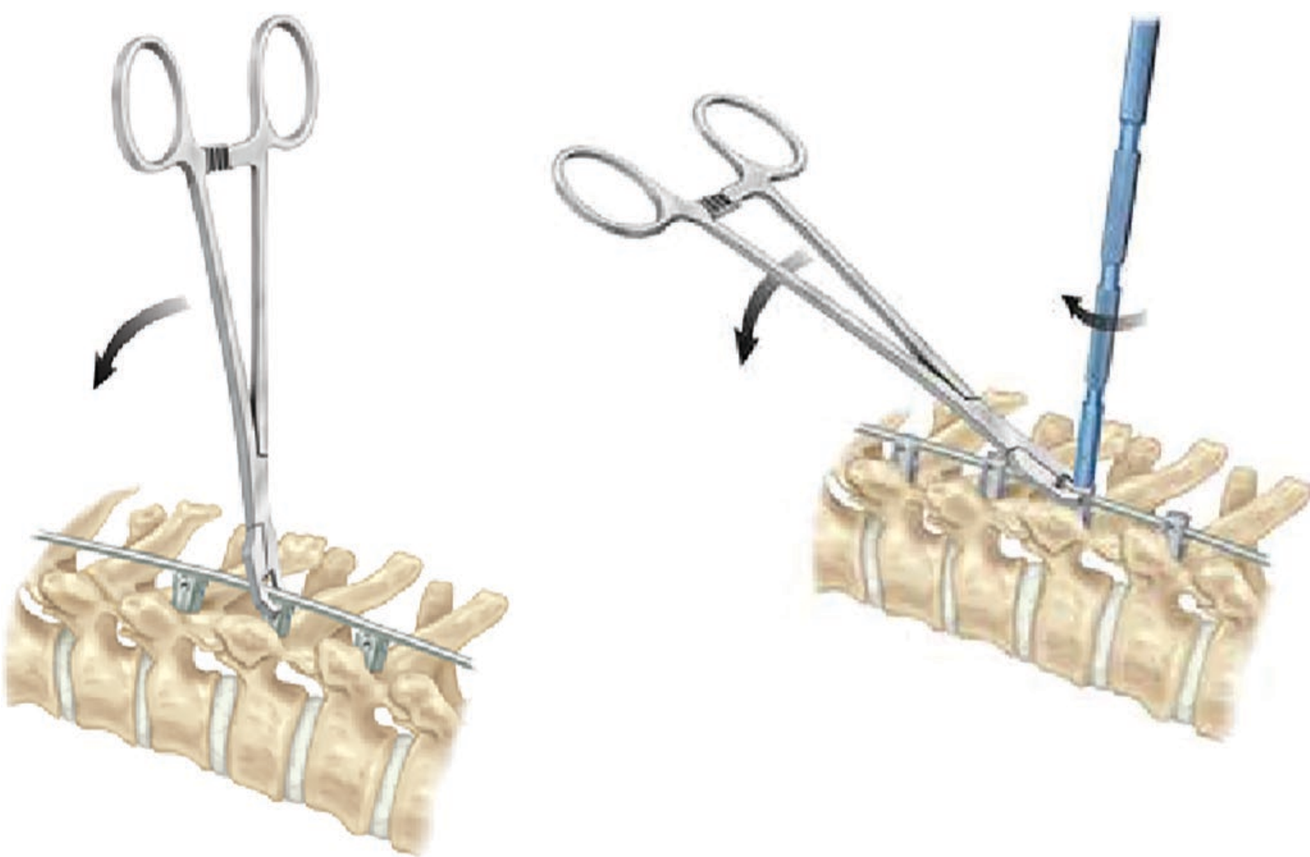

Fig. 9.24 Using the Forceps Rocker, *left*; Using the Dual Ended Set Screw Starter, *right*

Fig. 9.25 *Left*, the Beale Rod Reducer attaches to the four implant slots. *Right*, the set screw with the Provisional Driver is provisionally tightened in the extended position

be released just prior to the set screw being broken off or finally tightened. This technique will help to ensure that the implant head and rod are normalized to one another and, therefore, allows for the rod to be fully seated in the implant head during final tightening. The set screw is tightened with the Provisional Driver after these maneuvers are completed. Note: Screw operation is similar to hook.

9.2.4.4 Final Tightening and Decortication

The set screws which lock the rods into place are sheared off using the Counter Torque and the Self-Retaining Break-Off Driver (Fig. 9.28). Having the appropriate locking torque built into it, the break-off set screw should not require additional tightening. The final tightening torque range is 9–10.5 Nm or 80–93 in-lbs for 4.75-mm implants and 10.50–12.50 Nm or 92–110 in-lbs for 5.5-/6.0-mm implants. To prevent overtightening of the set screw which could reduce the strength of the connection, the Torque Indicating Driver should be used if additional manipulation of the set screw is desired after the break-off is achieved. To use the 4.75-mm or the 5.5-/6.0-mm Torque Indicating Driver, the Quick Connect T-Handle is attached to the Torque Indicating Driver and passed through the Counter Torque and into the inner portion of the set screw (Fig. 9.29). The handle is turned until the slot reaches the line on the right side of the scale to ensure the correct torque limit has been achieved (Fig. 9.30). The

Fig. 9.26 The Hinged Translator, Multilevel Hook Compressor, Distractor, and Provisional Driver are used to carry out these maneuvers

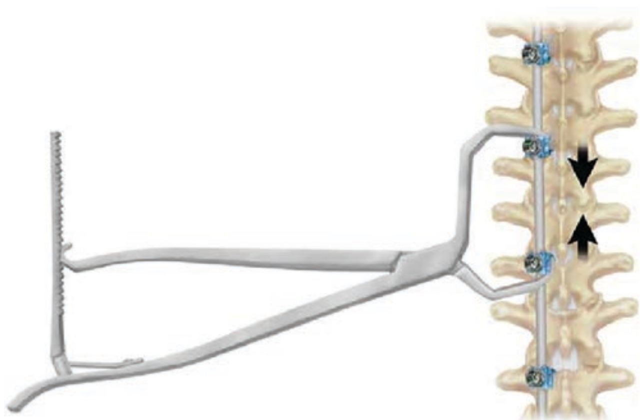

Fig. 9.27 Compression maneuvers are most often performed directly on two hooks

Fig. 9.28 Using the Counter Torque and the Self-Retaining Break-Off Driver

posterior elements are decorticated with a burr and the bone graft is placed.

9.2.4.5 Graft Placement

Despite internal fixation, bony fusion remains critical to the success of the surgical outcome. Careful decortication of the transverse processes, the facet joints, and the pars interarticularis should be accomplished using a high-speed burr. Some surgeons may choose to perform decortication prior to internal fixation in certain instances if poor visualization hampers decortications. Preservation of the facet capsules of the unfused adjacent levels is advantageous (Fig. 9.31).

Whether the autograft or allograft bone is utilized, precise placement of the graft onto the decorticated bone is essential. This can only be done with excellent visualization of the decorticated bone surfaces. Attention should be paid to the development of a pseudoarthrosis due to interposing muscle

Fig. 9.29 The Quick Connect T-Handle is attached to the Torque Indicating Driver

Fig. 9.30 The handle is turned until the slot reaches the line on the right side of the scale to ensure the Correct Torque limit has been achieved

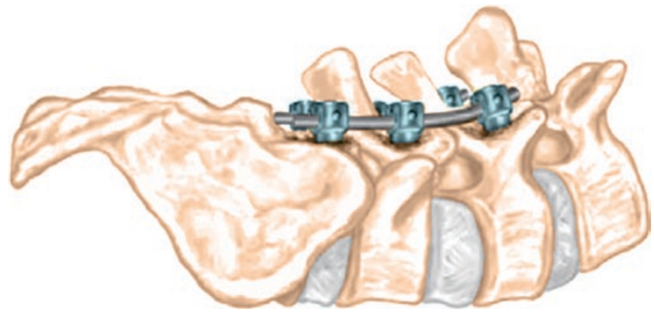

Fig. 9.31 Preservation of the facet capsules

tissues in fusion between transverse processes. If the facet architecture is not retained, the graft should be impacted into the facet to obtain a facet fusion. Once instrumentation is complete and the graft l is placed, the construct should be checked radiographically (Fig. 9.32).

9.2.4.6 X10 CROSSLINK Plate Placement

X10 CROSSLINK plates significantly increase the torsional stability of internal fixation. Internal fixation of longer segments necessitates placement of an X10 CROSSLINK plate at each end to increase construct rigidity. Two measuring devices are available to determine the proper length of X10 CROSSLINK plate for use: the measuring card (Fig. 9.33, left) and the measuring caliper (Fig. 9.33, right).

Prior to plate placement, the X10 CROSSLINK plate set screws are backed out to prevent binding onto the rods of the construct during placement. If the set screw is backed out too far, it will disengage from the plate, but it can easily be reinserted. A surgeon has several X10 CROSSLINK plate placement options.

9.2.4.7 In Line Plate Holder Method

The midline nut is provisionally tightened to facilitate X10 CROSSLINK plate placement. The In Line Plate Holder is used to select, grip, and position the plate to capture the far rod. In addition, the Torque-Limiting Set Screwdriver is used to tighten the ipsilateral set screws (Fig. 9.34). Thereafter, the midline nut is loosened, and a CROSSLINK plate is placed on the opposite end onto the other rod. Next, the midline nut is tightened on the screw head, and a 7-N·m torque is used to shear off the screw head. Finally, the midline nut is tightened using a 9-N·m torque (Fig. 9.35). Following placement of the plate onto one rod, the set screw is tightened using the 7/32″ Torque-Limiting Set Screwdriver until it is firmly attached to the rod.

Caution: The midline nut is *not* a break-off set screw.

9.2.4.8 Implant Positioner Method

With the use of Implant Positioners, appropriate X10 CROSSLINK plates are selected (Fig. 9.36). Ensure that both Implant Positioners fit securely onto both rod set screws.

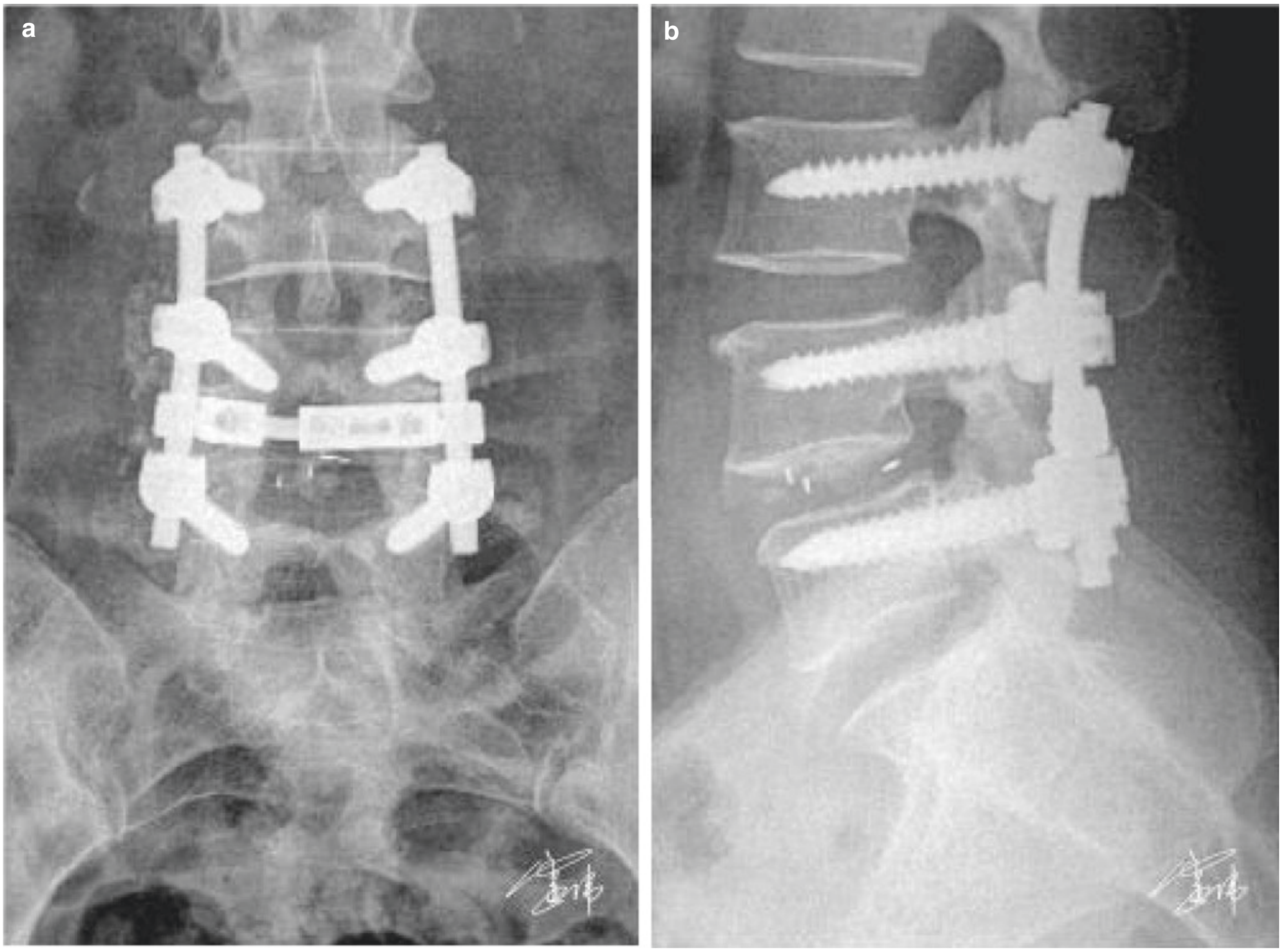

Fig. 9.32 The implant construct is checked radiographically. (**a**) Anteroposterior view. (**b**) Lateral view

The Implant Positioners can be used to sequentially articulate the CROSSLINK plate around the rod (Fig. 9.37).

9.2.4.9 Forceps Plate Holder Method

With the use of the Forceps Plate Holder, the appropriate X10 CROSSLINK Multi-Span Plate is selected and gripped (Fig. 9.38).

Ensure that both crossbars on the X10 CROSSLINK plate are gripped using the Forceps Plate Holder. The plate is then placed to capture the far rod (in relation to the surgeon) of the two rods to be stabilized. The far rod's set screw is provisionally tightened using the Torque-Limiting Set Screwdriver to anchor the device to this rod (Fig. 9.39).

The Forceps Plate Holder is removed from both crossbars and placed on the crossbar that is able to move. The second side of the plate to the rod is then anchored and the set screw is provisionally tightened. Next, after the Forceps Plate Holder is removed, the midline gut is provisionally tightened. To minimize torque transfer to the construct during final tightening, a Counter Torque may be placed on the X10 CROSSLINK Multi-Span Plate. The screwdriver shaft is introduced through the Counter Torque. Using the Torque-Limiting Set Screwdriver, the set screws are sheared off. The midline nut then undergoes final tightening with the same screwdriver.

If the CROSSLINK plate cannot be precisely seated against the rod, the set screw protrudes outward. Ensure that the CROSSLINK plate l abuts against the rod in the maneuvering space. The set screw can be manipulated and slightly backed out by rotating the Implant Positioners, allowing the rod to fully seat in the ventral opening. To provisionally

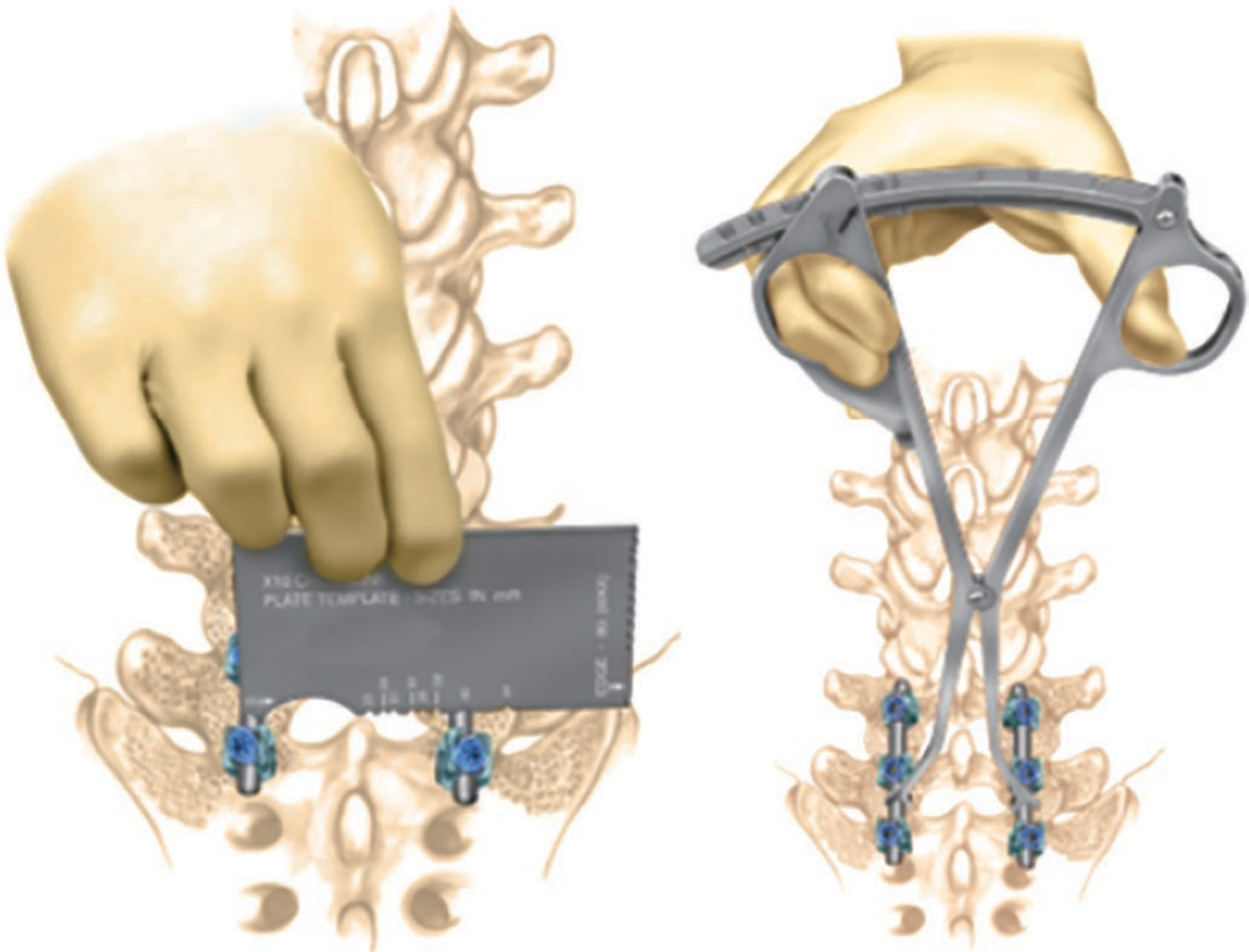

Fig. 9.33 The measuring card (*left*) and the measuring caliper (*right*)

tighten the X10 CROSSLINK plate to the rod, the Implant Positioners can be used once precise contact has been achieved between the plate and the rod. The same process is carried out for the other side of the plate. With the rod before final tightening and set screw break-off, both halves of the plate should precisely articulate (Fig. 9.40).

The Implant Positioner is removed, and the midline nut is provisionally tightened by the Torque-Limiting Set Screwdriver. To minimize torque transfer to the construct during final tightening, a Counter Torque may be placed on the X10 CROSSLINK Multi-Span Plate. The screwdriver shaft is introduced through the Counter Torque. The set screws are sheared off by using the screwdriver. The midline nut then undergoes final tightening with the same screwdriver. Before the wound is closed, ensure that the set screws are symmetrically seated in the screw heads, there is no bone graft displacement, and the number of screw heads that are sheared off is correct.

9.2.5 Pedicle Screw Surgery for Deformity Correction Using the SOLERA System

The set screws are kept loose (or only locked at one end); then with the left and right Coronal Benders, the concave rod is slowly straightened (Fig. 9.41). Each straightening of the concave rod is performed over a pedicle screw. In order for viscoelastic relaxation with subsequent curve correction to occur, several passes may be required. The apical set screws are tightened and appropriate compression or distraction is

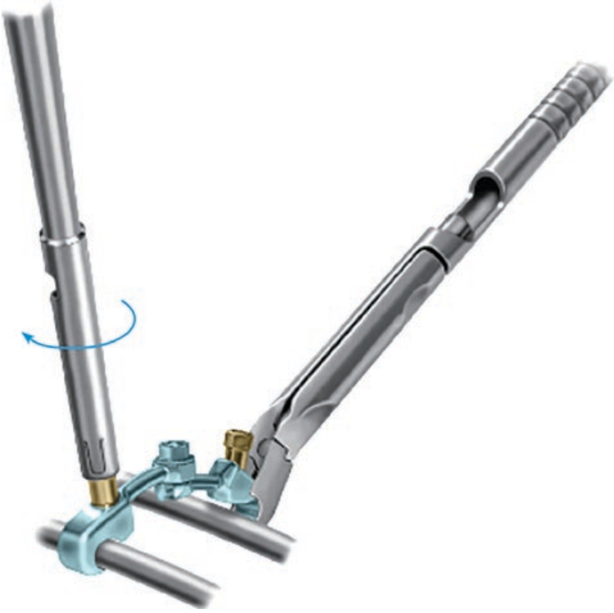

Fig. 9.34 The In Line Plate Holder Method

Fig. 9.35 The midline nut is tightened

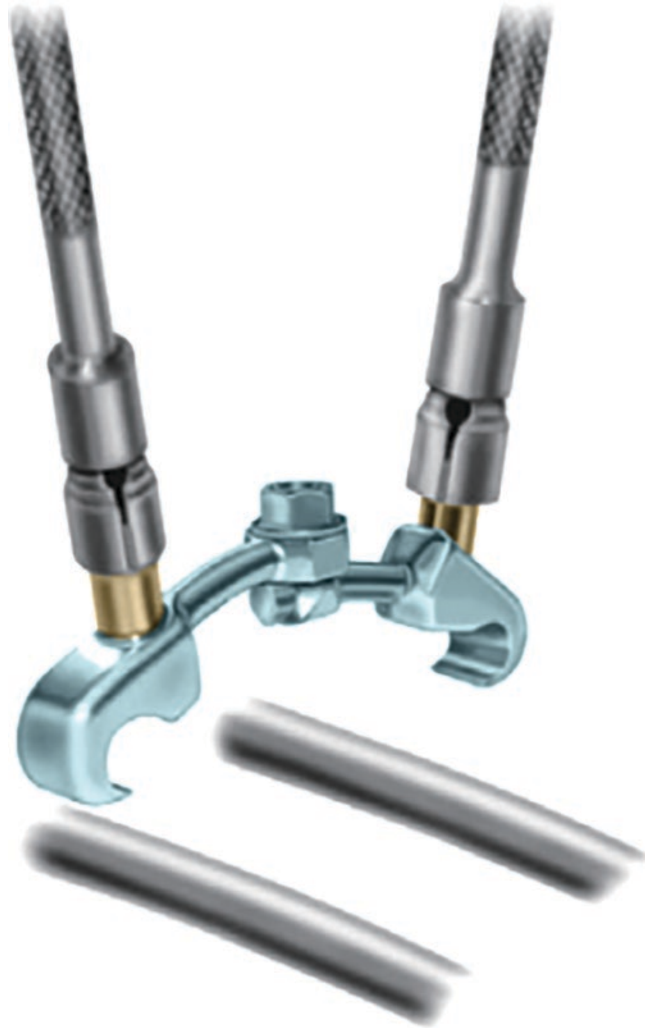

Fig. 9.36 CROSSLINK plate placement

performed. The bone-to-screw interface should be watched with all correction maneuvers.

9.2.5.1 Hinged Translator

During correction maneuvers, the Hinged Translator can be used in place of either a compressor or a distractor. The straight leg of the instrument will push the implant, while the hinged leg engages on the rod acting as rod gripper. Careful attention should be paid to the bone-to-screw interface during any correction maneuver.

To make hinged leg and straight leg touching each other, the rack is disengaged prior to placing the Hinged Translator on the rod (Fig. 9.42). A left and a right translator are included in the set for facilitating the compression and dis-

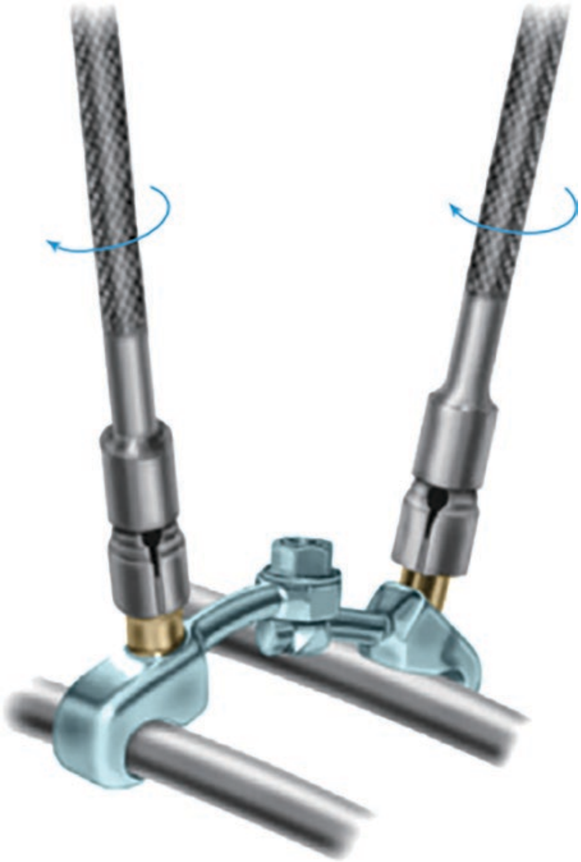

Fig. 9.37 Securing the CROSSLINK plate

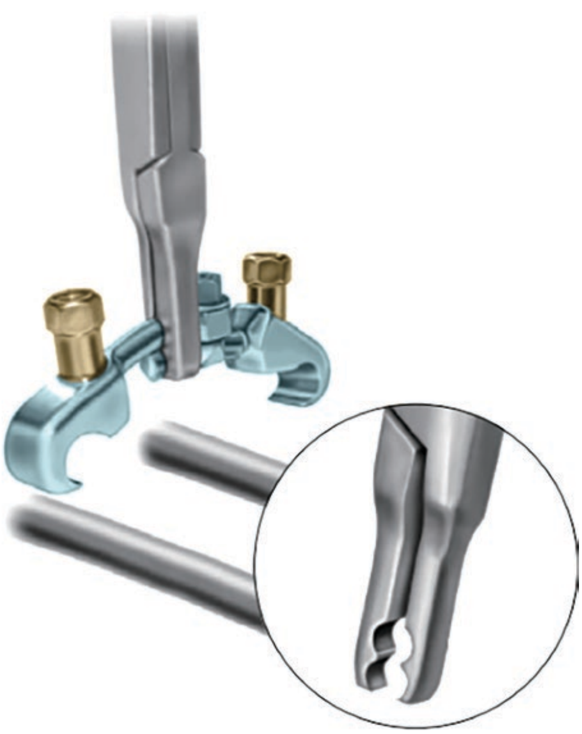

Fig. 9.38 Forceps Plate Holder method

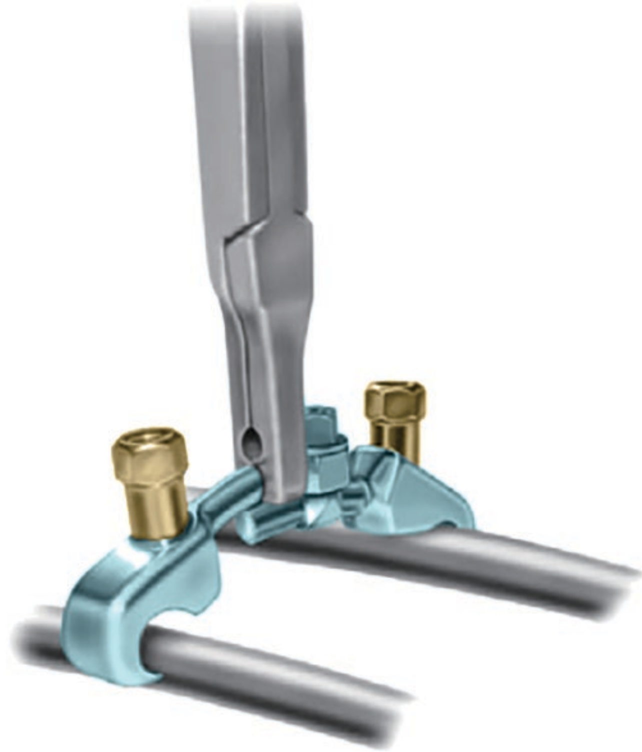

Fig. 9.39 CROSSLINK plate placement

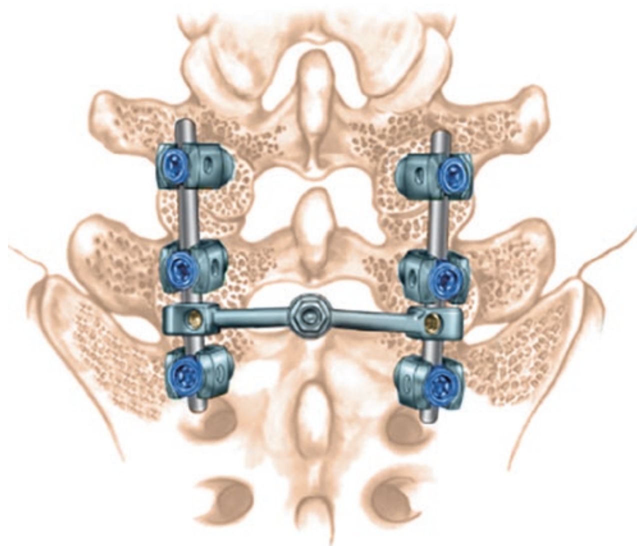

Fig. 9.40 Tightening the CROSSLINK plate

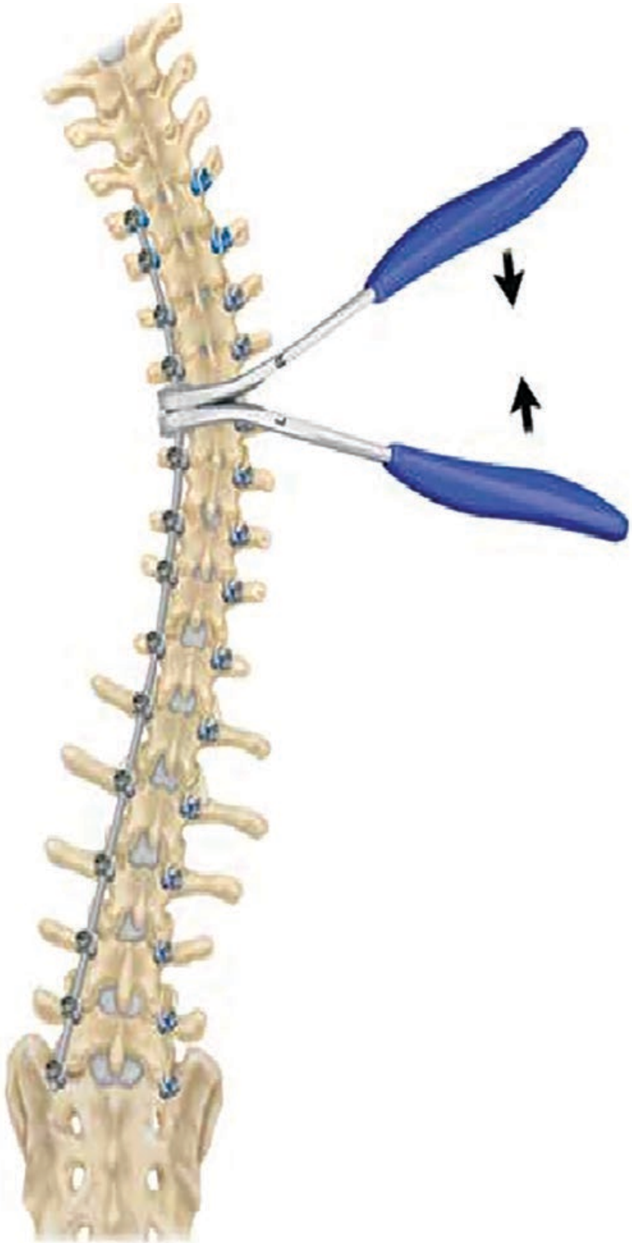

Fig. 9.41 Left and right Coronal Benders

Fig. 9.42 Hinged Translator

traction maneuvers around the bony anatomy. The arrow on the rack of the Hinged Translator shows the direction in which the implant will be moved.

Example for Compressing the T8–T9 Segment: The T9 set screw is provisionally tightened. The instrument is placed along the rod with the straight leg below and immediately against the T9 screw prior to squeezing the handles (Fig. 9.43). The handles are squeezed to begin compression (Fig. 9.44). Example for Distracting the T8–T9 Segment: The T8 set screw is provisionally tightened. The instrument is placed along the rod with the straight leg below and immediately against the T8 screw prior to squeezing the handles (Fig. 9.45). The handles are squeezed to begin distraction (Fig. 9.46).

Fig. 9.43 Place the instrument

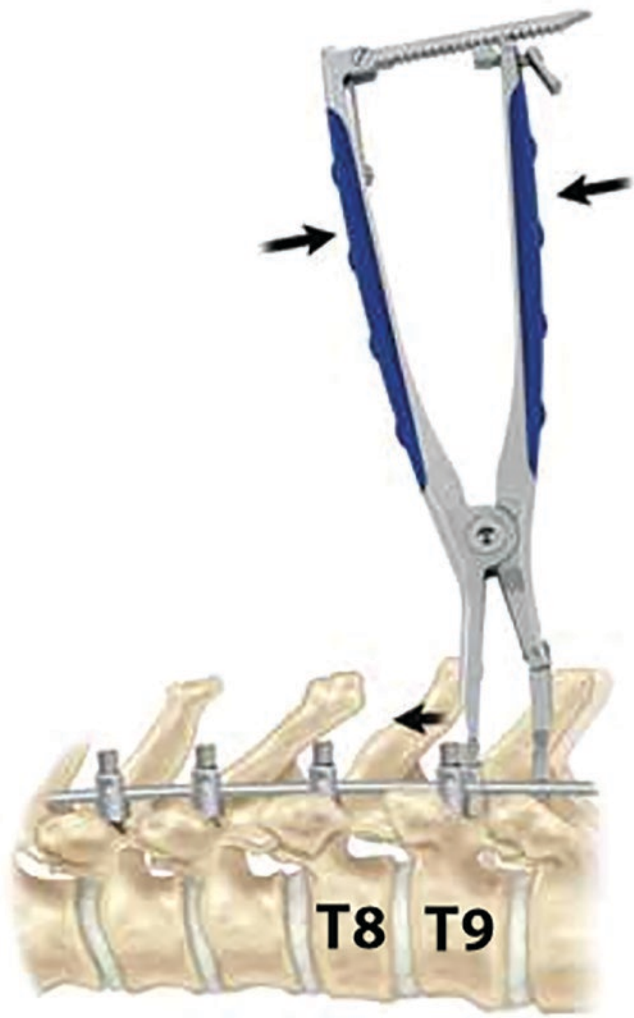

Fig. 9.44 Squeeze the handles

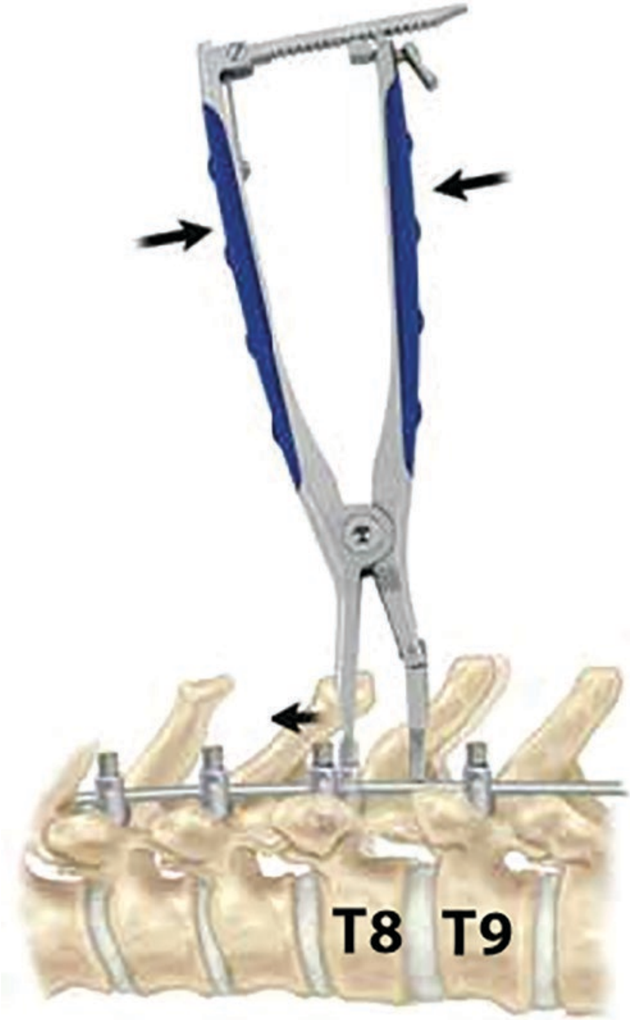

Fig. 9.45 The instrument is placed against the T8 screw

Fig. 9.46 Release the handles

9.2.5.2 Placing the Stabilizing Rod

Following placement of the second rod and set screws (Fig. 9.47), convex compressive forces are placed on the segments by using the compressor to horizontalize the lowest instrumented vertebra and mildly compress the convexity of the deformity (Fig. 9.48). It is preferable that compression be released just prior to the set screw being broken off or with final tightening. This technique will help to ensure that the implant head and rod are normalized to one another and therefore allow for the rod to be fully seated in the implant head during final tightening. To detect any potential neurologic deficits, NMEP and/or SSEP monitoring is performed. Fixation is verified with anteroposterior and lateral X-rays for confirmation of spinal correction and alignment.

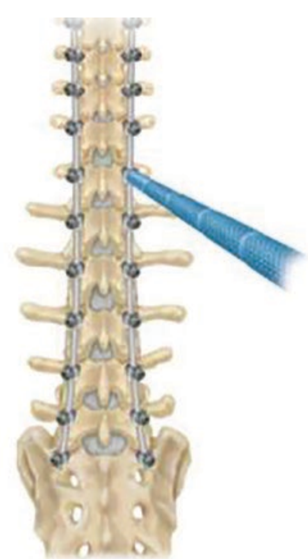

Fig. 9.47 Placement

9.2.5.3 Final Tightening and Decortication

Using the Counter Torque and the Self-Retaining Break-Off Driver, the set screws which lock the rods into place are sheared off (Fig. 9.49). Having the appropriate locking

Fig. 9.48 Compression

torque built into it, the break-off set screw should not require additional tightening. The final tightening torque range is 9–10.5 Nm or 80–93 in-lbs for 4.75-mm implants and 10.50–12.50 Nm or 92–110 in-lbs for 5.5-/6.0-mm implants.

To prevent overtightening of the set screw which could reduce the strength of the connection, the Torque Indicating Driver should be used if additional manipulation of the set screw is desired after the break-off is achieved. To use the 4.75-mm or the 5.5-/6.0-mm Torque Indicating Driver, the Quick Connect T-Handle is attached to the Torque Indicating Driver and passed through the Counter Torque and into the inner portion of the set screw (Fig. 9.49). The handle is turned until the slot reaches the line on the right side of the scale to ensure the correct torque limit has been achieved (Fig. 9.50). The posterior elements are decorticated with a burr and the bone graft is placed.

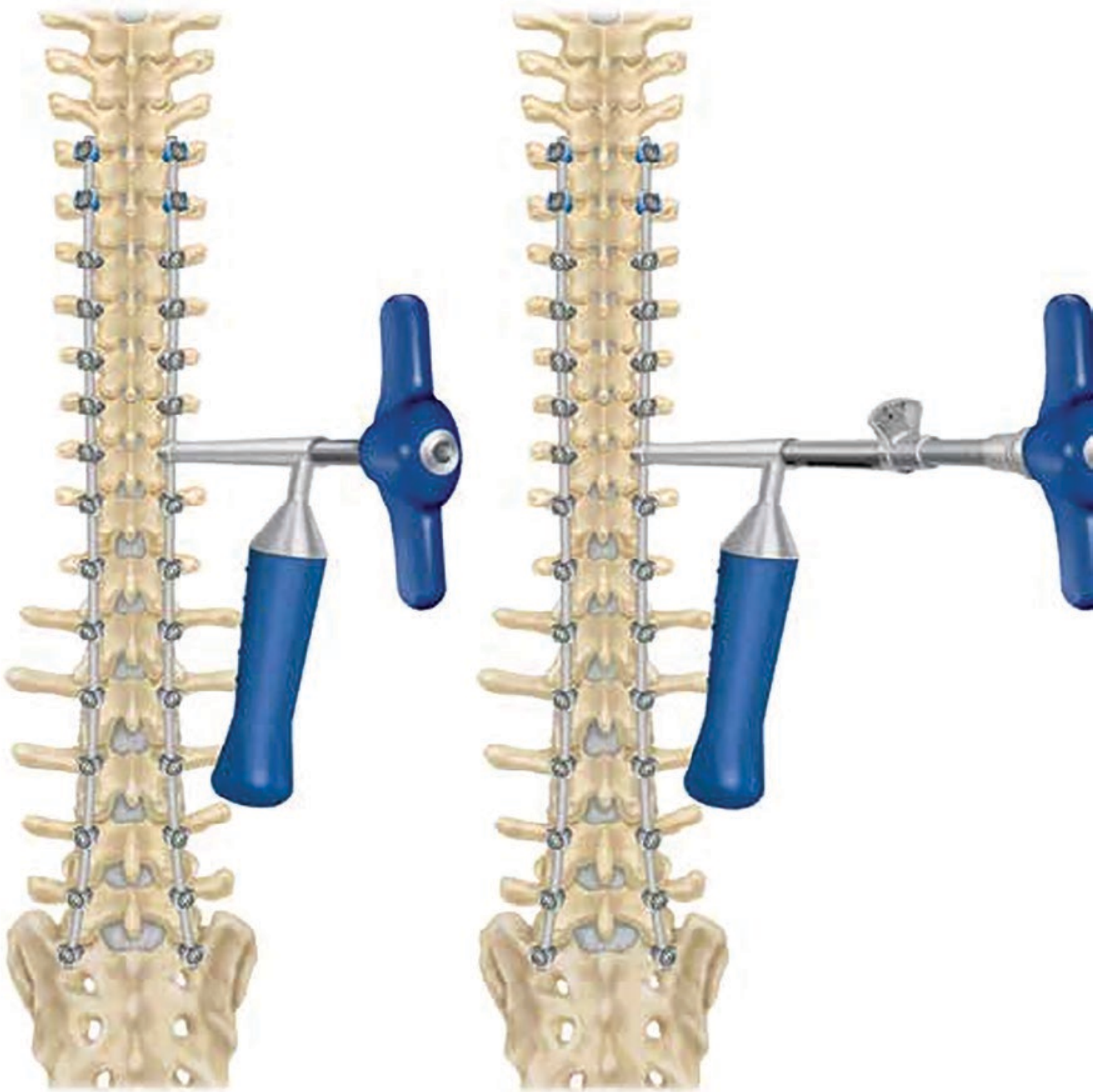

Fig. 9.49 Final tightening

9.2.6 Multi-axial Reduction Screw Techniques

9.2.6.1 Screw/Rod Placement

After the pedicles are prepared, multi-axial screws are placed horizontally at L4 and S1, and Multi-axial Reduction Screws are inserted at L5 (Fig. 9.51a). Multi-axial screws can be used at all segments to facilitate rod placement. The set screws are then inserted into the implants at L_4 and S_1 and provisionally tightened to facilitate seating the rod (Fig. 9.51b).

Fig. 9.50 Torque limit

9.2.6.2 Spondylolisthesis Reduction

1. Screw pulling reduction: The Ring Counter Torque is placed over the implant head throughout the reduction procedure. The reduction set screws are inserted into the reduction implant head using the self-retaining screwdriver. This will pull the implant to the rod, translating the vertebral body of L5 posteriorly and, therefore, reducing spondylolisthesis (Fig. 9.52).
2. Use of Forceps Rocker for reduction: The Forceps Rocker can be used to seat the rod and provide incremental reduction. The head of the implant is grasped with the Forceps Rocker and rocked down, applying pressure to the rod (Fig. 9.53).
3. Use of the Beale Rod Reducer for reduction: The Beale Rod Reducer can be used in conjunction with the Rod

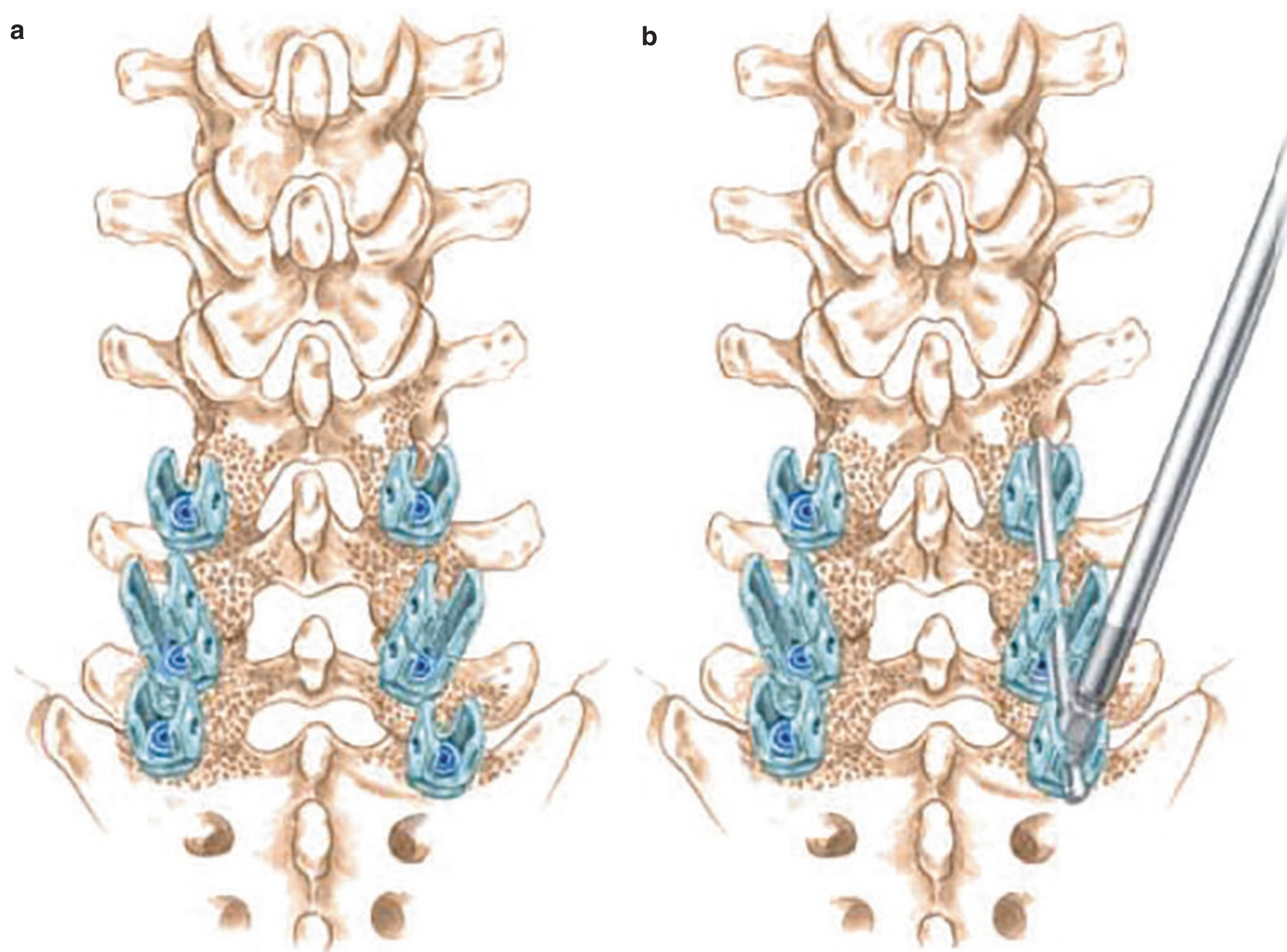

Fig. 9.51 The rod is placed and provisionally tightened. (**a**) Inserting the screw. (**b**) Rod is placed and provisionally tightened

Fig. 9.52 Screw pulling reduction

Fig. 9.53 Reduction by Forceps Rocker

Reducer Sleeves to reduce the rod into the extended implant head. To achieve full reduction with the Beale Rod Reducer, the surgeon incrementally reduces spondylolisthesis by graduating to the 7- and 14-mm sleeves (Fig. 9.54). When the rod is fully seated in the bottom of the implant head, reduction is complete. Bilateral reduction may be attained by simultaneously driving the set screws at L5 on both sides.

9.2.6.3 Final Tightening

Once the rod is secured in the implants, distraction and/or compression is performed to place the screws in their final position. Preferably, compression should be released immediately before the set screws are broken off or finally tightened. This technique helps to ensure that the implant head and rod are normalized to one another, thus allowing for the rod to be fully seated in the implant head during final tightening. Once these maneuvers are performed, the set screws at L4 and S1 should be broken off.

To break off the extended tabs of the Multi-axial Reduction Screw, the Ring Counter Torque is placed over the implant head with the handle of the Ring Counter Torque facing lateral. The Reduction Screw Tab Breaker is slid over the medial tab of the extended portion of the Multi-axial Reduction Screw. Air pressure is applied to break off the tabs medially (Fig. 9.55).

While the Ring Counter Torque remains in place, the tab is broken off (Fig. 9.56), which should be broken off medially (Fig. 9.57a). If the tabs do not bend and break off easily, the surgeon should examine if the set screw is fully advanced. If not, its threads will prevent the tabs from being broken off. The surgery is completed after final tightening (Fig. 9.57b).

9.3 Clinical Cases

Case 1

Patient: A 57-year-old female with back pain and radiating pain of the left lower leg for 1 year and worsening for 3 months.

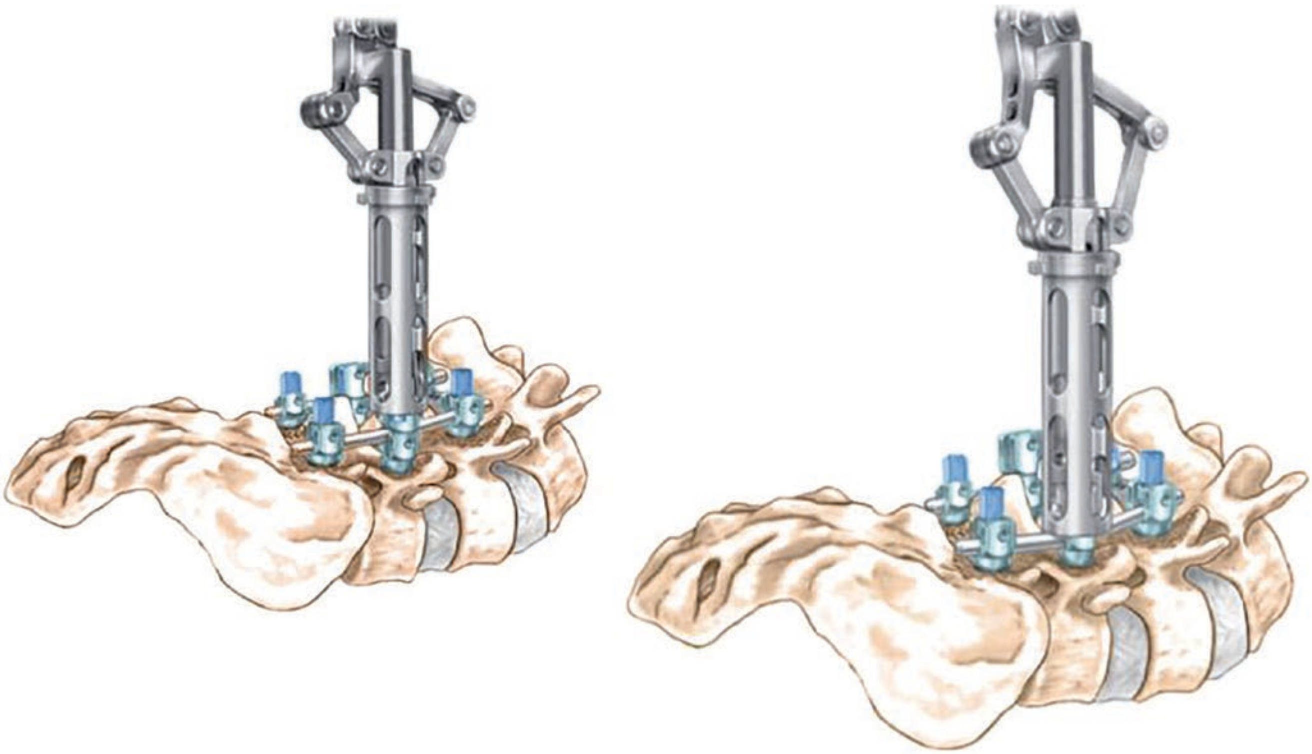

Fig. 9.54 Reduction with two types of sleeves. (**a**) 7-mm sleeve; (**b**) 14-mm sleeve

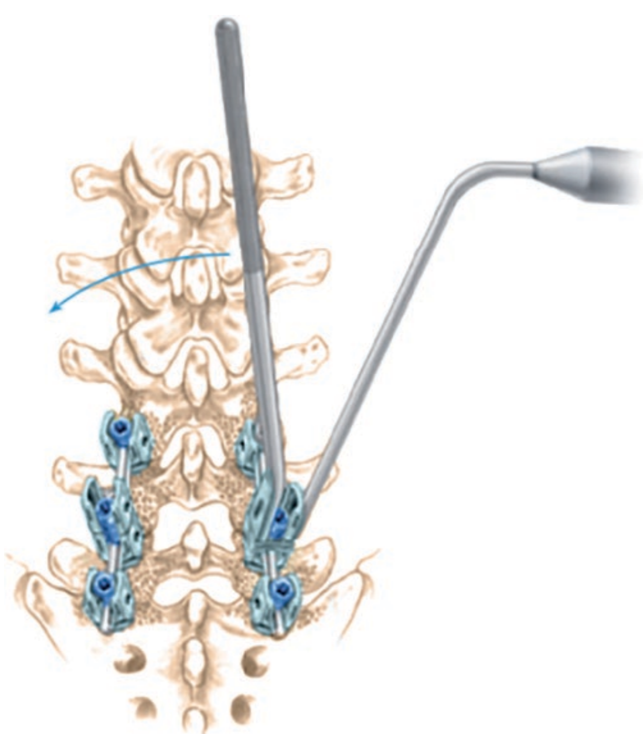

Fig. 9.55 Breaking off the tabs

Fig. 9.56 Breaking off the tab with the Ring Counter Torque

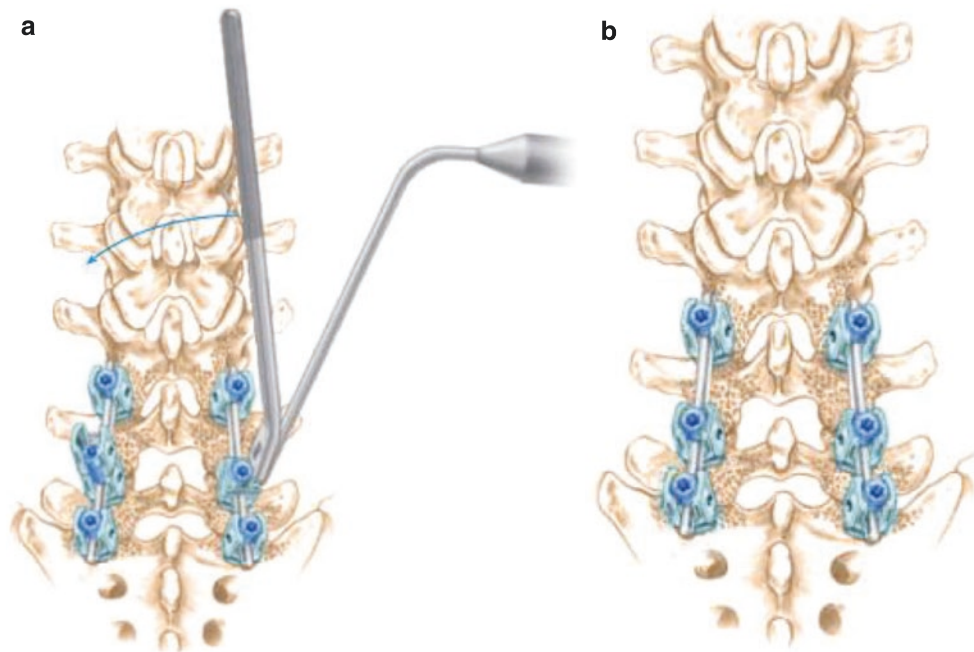

Fig. 9.57 (**a**) The tab is broken off medially. (**b**) Surgery is completed

Diagnosis: L5 isthmic spondylolisthesis.

Surgery: L5–S1 left intervertebral disc fenestration with removal of nucleus pulposus from the intervertebral disc, interbody fusion surgery, CAPSTONE placement, spondylolisthesis reduction, and L5 and S1 pedicle screw internal fixation.

Imaging studies: Preoperative (Fig. 9.58) and postoperative images (Fig. 9.59).

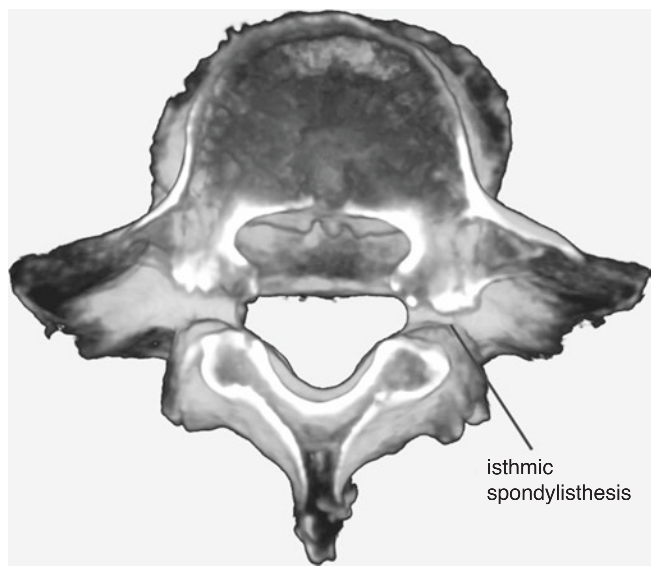

Fig. 9.58 Preoperative imaging studies. CT 3D reconstruction image (*horizontal*)

Case 2

Patient: A 16-year-old boy with back pain for 11 h due to trauma.

Diagnosis: L2–L3 fracture.

Surgery: Open reduction, posterior interbody fusion surgery, L1–L4 pedicle screw internal fixation.

Imaging studies: Preoperative (Fig. 9.60) and postoperative images (Fig. 9.61).

Case 3

Patient: A 35-year-old female complaining of lumbosacral pain due to trauma and defecation dysfunction for 7 days.

Diagnosis: L5 spondylolisthesis (grade V, posterior spondylolisthesis).

Surgery: L5, S1 open reduction, vertebral interbody fusion surgery, L4–L5, S1–S2 pedicle screw internal fixation.

Imaging studies: Preoperative (Fig. 9.62) and postoperative images (Fig. 9.63).

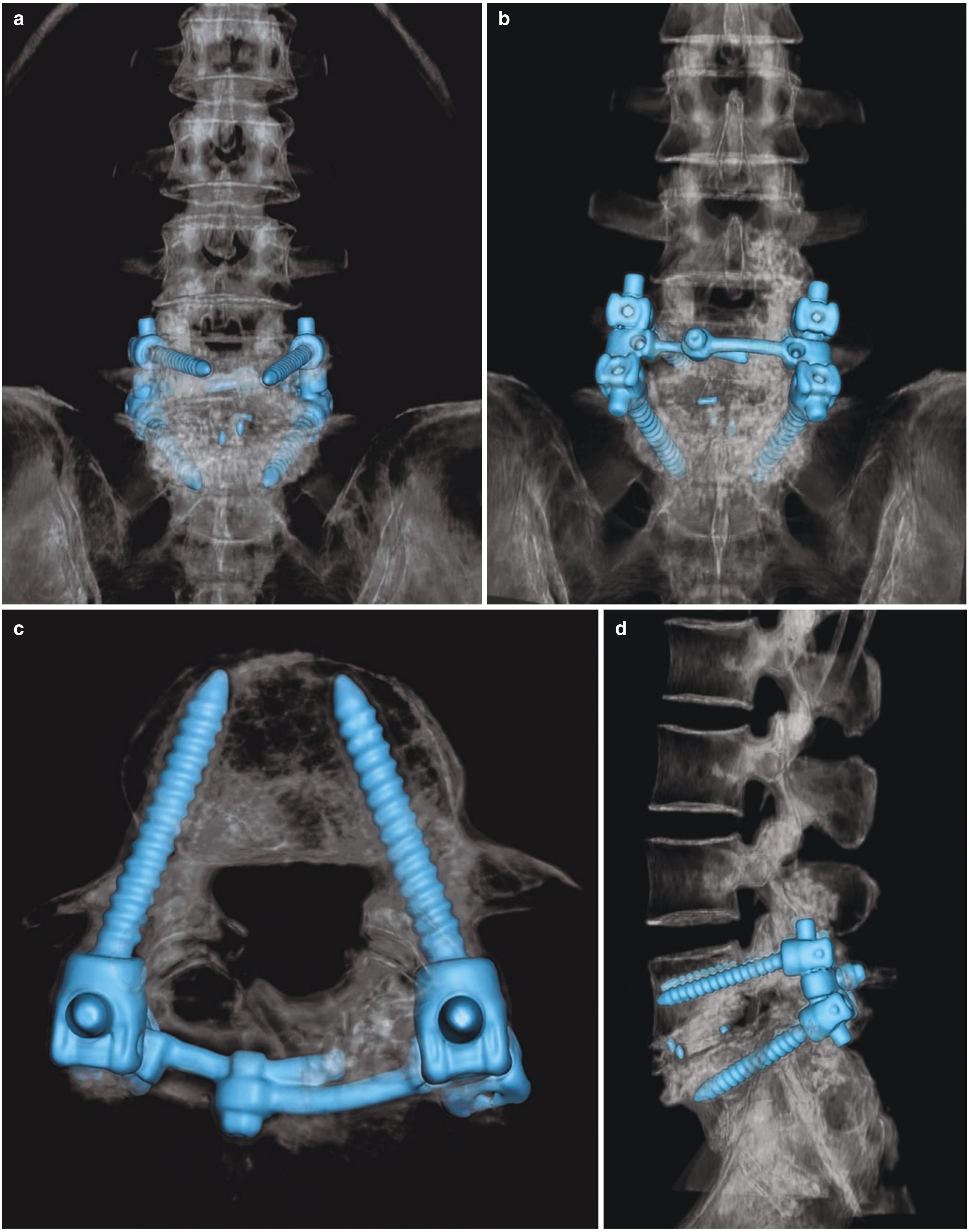

Fig. 9.59 Postoperative images. (**a**) CT 3D reconstruction (*anterior view*); (**b**) CT 3D reconstruction (*posterior view*); (**c**) CT 3D reconstruction (*axial view*); (**d**) CT 3D reconstruction (*lateral view*)

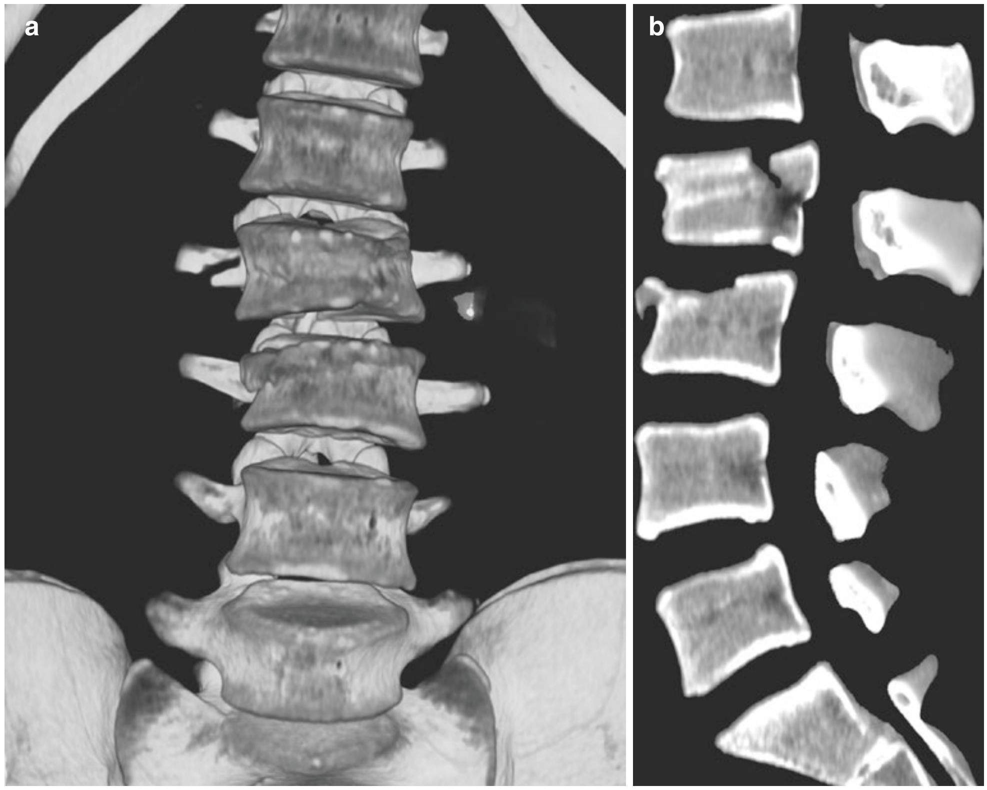

Fig. 9.60 Preoperative imaging studies. (**a**) CT 3D reconstruction (*anterior view*); (**b**) CT 3D reconstruction (*sagittal view*)

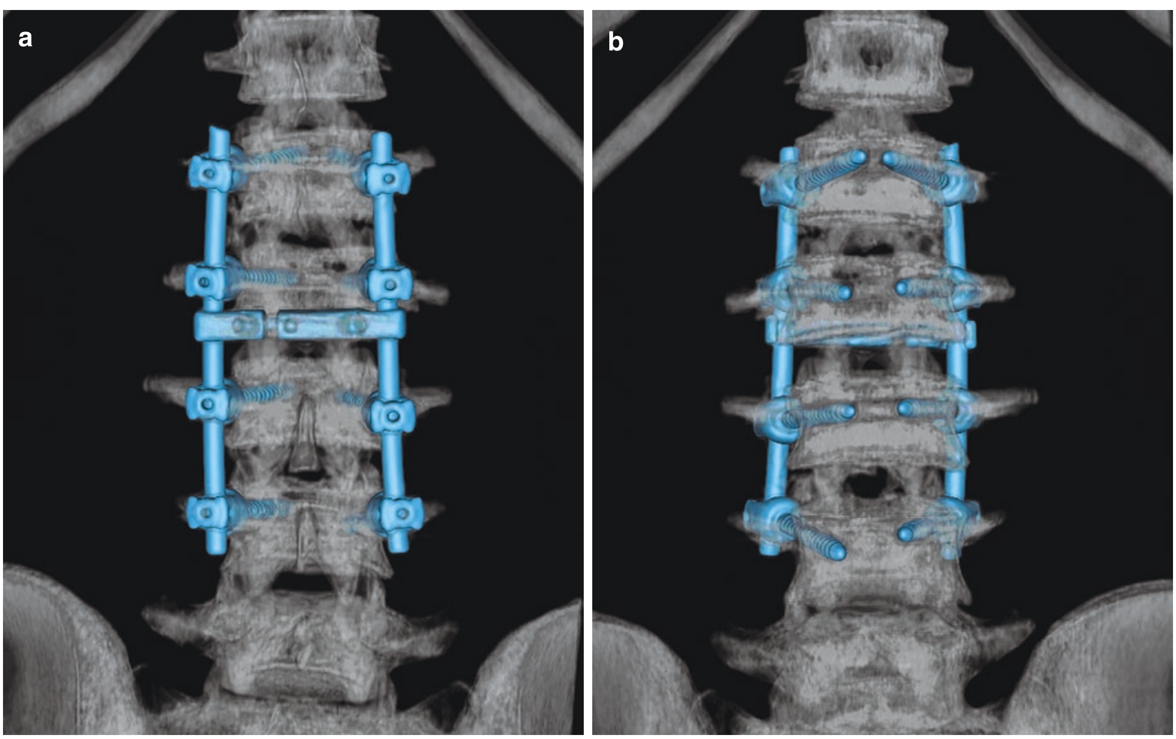

Fig. 9.61 Postoperative images. (**a**) CT 3D reconstruction (*posterior view*); (**b**) CT 3D reconstruction (*anterior view*); (**c**) CT 3D reconstruction (*sagittal view*); (**b**) CT 3D reconstruction (*lateral view*); (**e**) CT 3D reconstruction showing screw positions

Fig. 9.61 (continued)

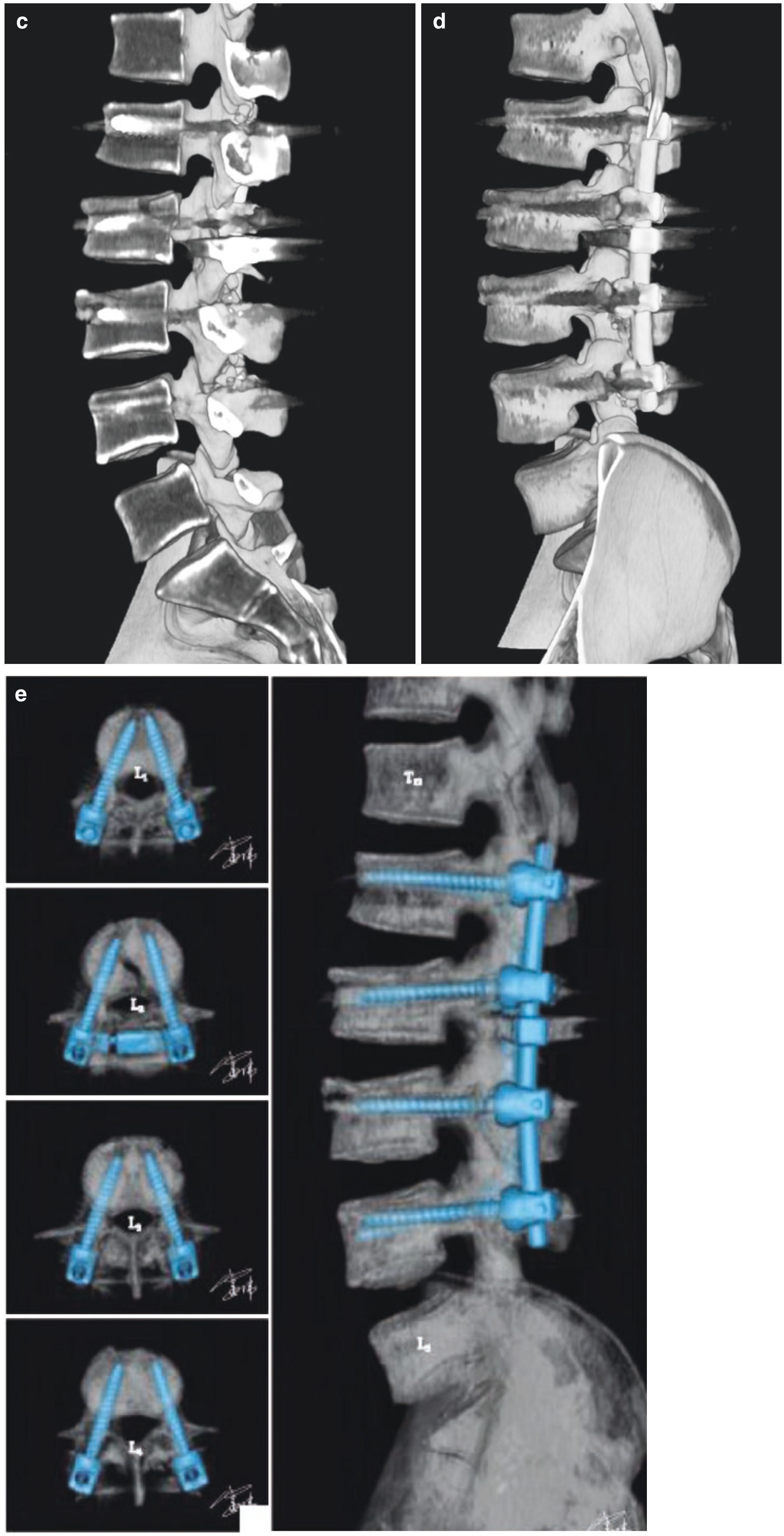

Fig. 9.62 Preoperative imaging studies. (**a**) CT 3D reconstruction (*lateral view*); (**b**) CT 3D reconstruction (*sagittal view*)

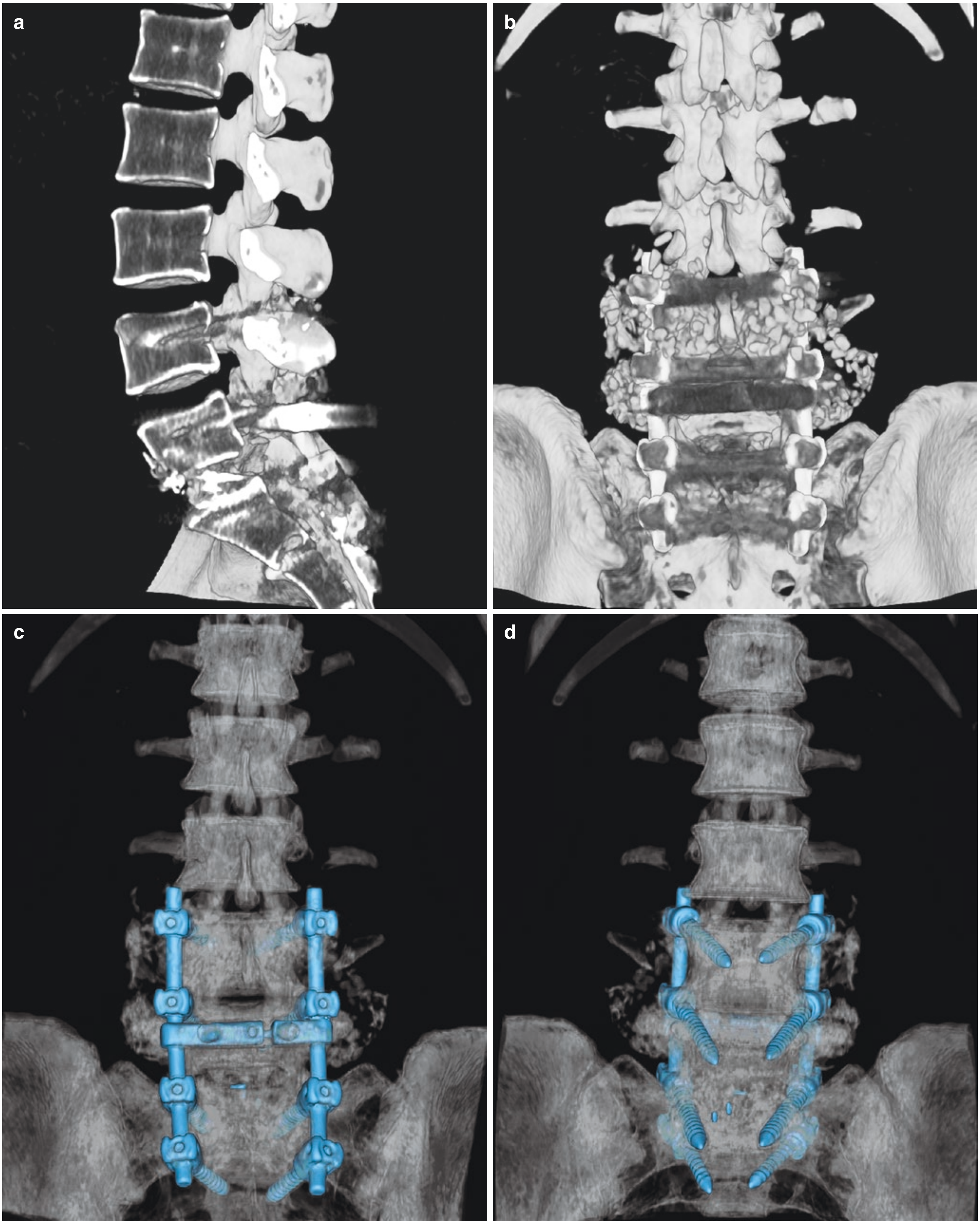

Fig. 9.63 Postoperative images. (**a**) CT 3D reconstruction (*sagittal view*); (**b**) CT 3D reconstruction (*posterior view*); (**c**) CT 3D reconstruction (*posterior view*); (**d**) CT 3D reconstruction (*anterior view*); (**e**) CT 3D reconstruction showing screw positions

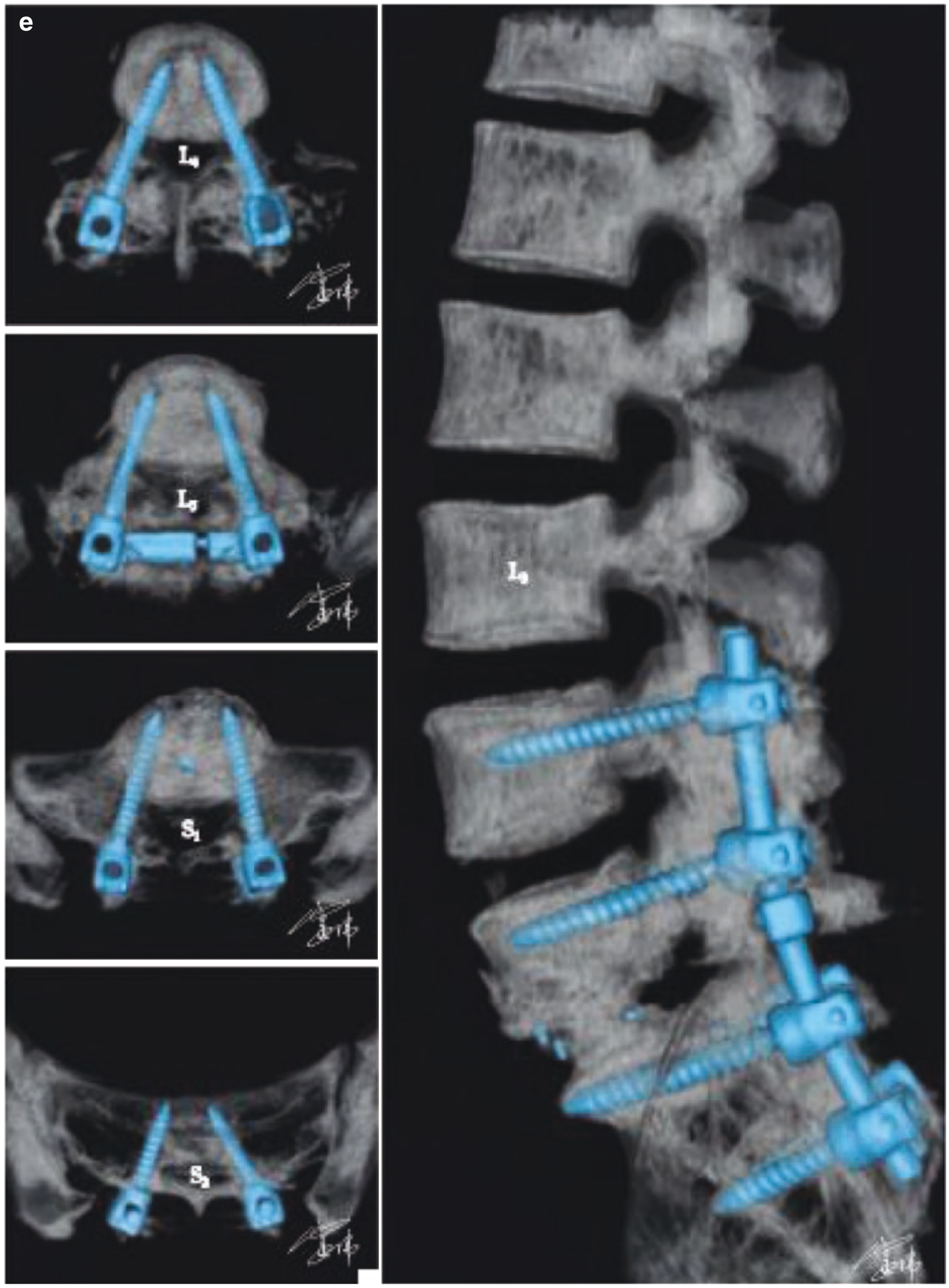

Fig. 9.63 (continued)

Case 4

Patient: A 20-year-old male with vertebral deformity for 3 years.

Diagnosis: Idiopathic vertebral scoliosis.

Surgery: T1–L2 posterior pedicle screw internal fixation and spine correction surgery, interbody fusion surgery.

Imaging studies: Preoperative (Fig. 9.64) and postoperative images (Fig. 9.65).

Case 5

Patient: A 10-year-old boy with vertebral deformity for 5 years.

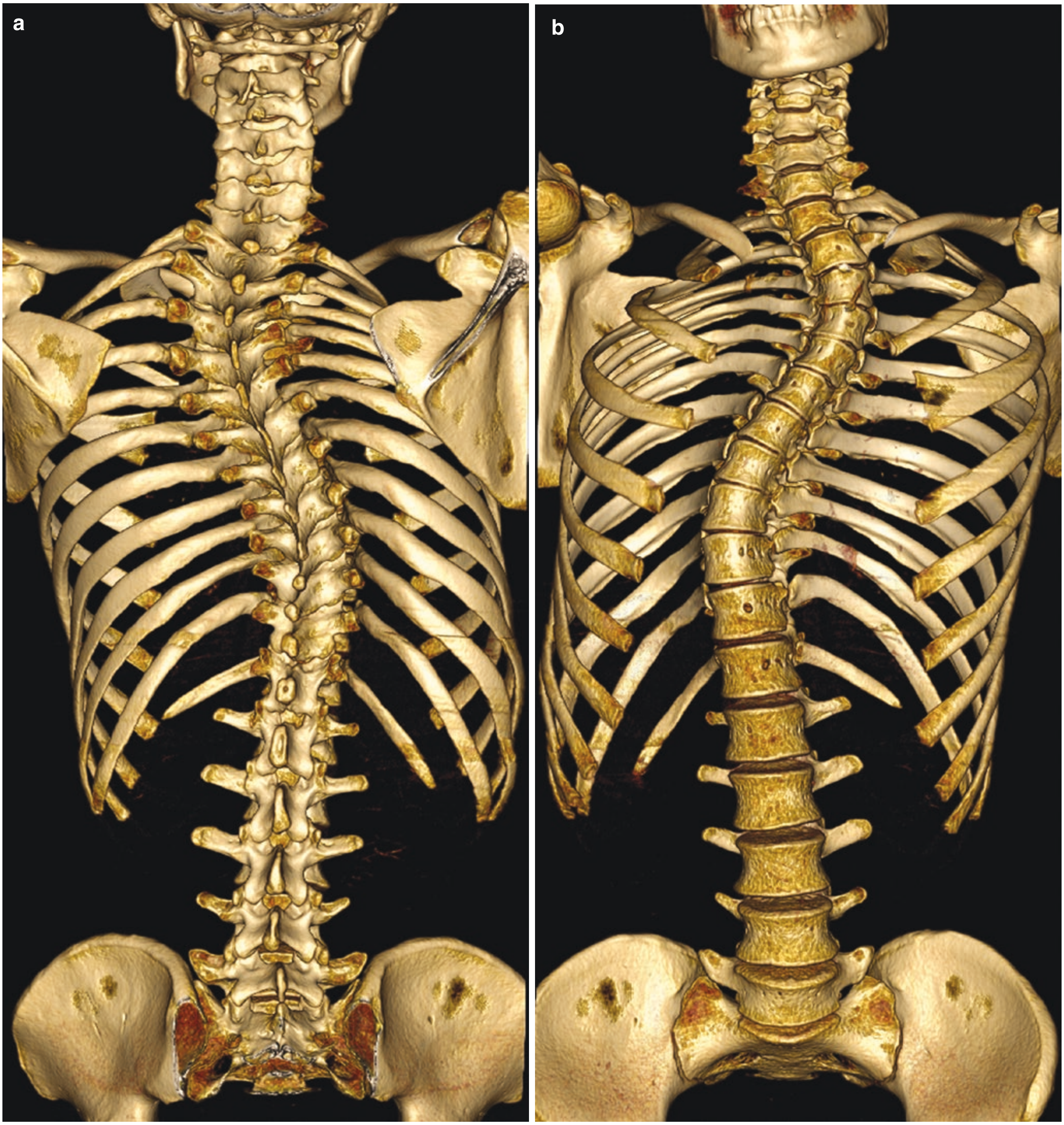

Fig. 9.64 Preoperative imaging studies. (**a**) CT 3D reconstruction (*posterior view*); (**b**) CT 3D reconstruction (*anterior view*)

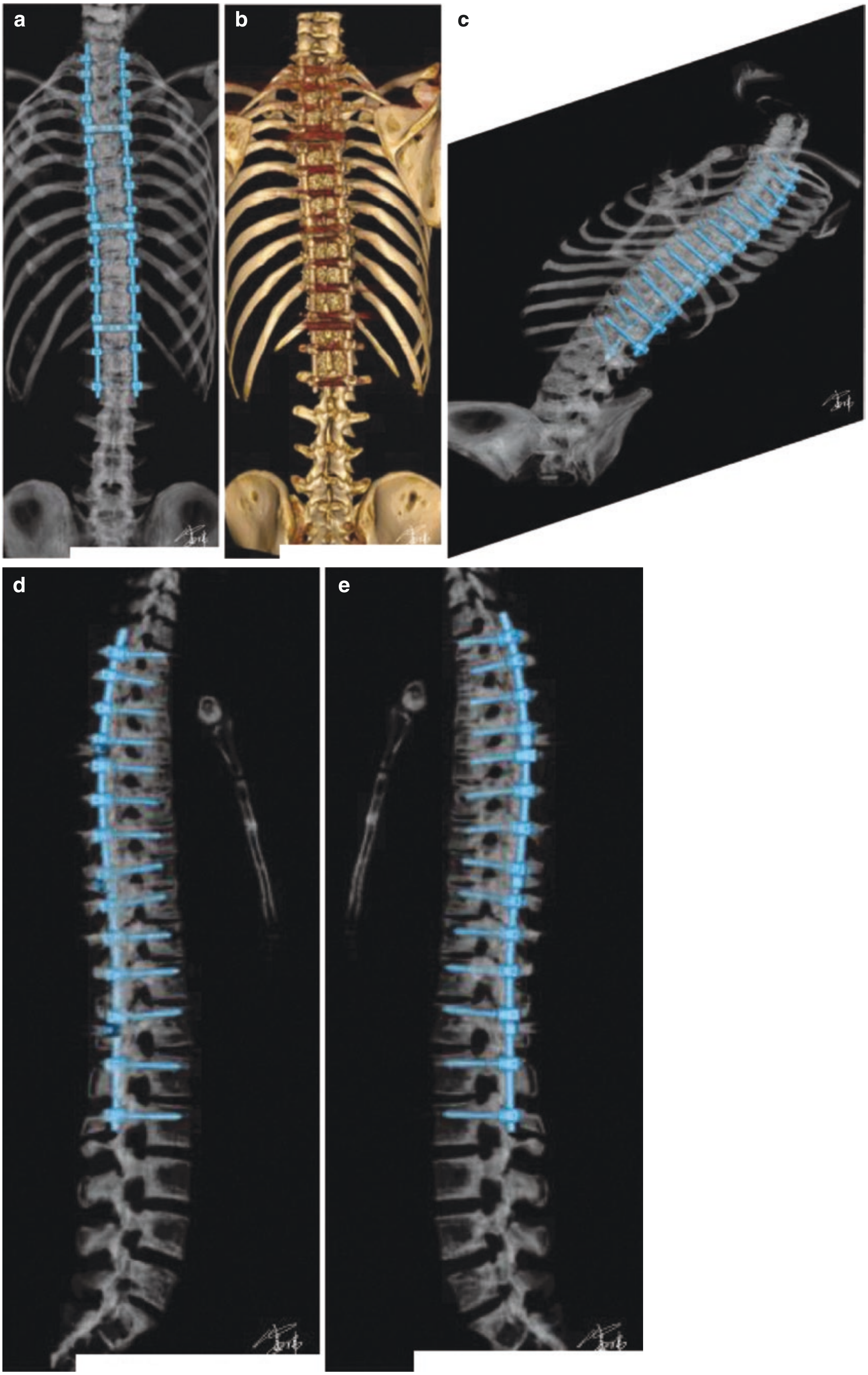

Fig. 9.65 Postoperative images. (**a**) CT 3D reconstruction (*posterior view*); (**b**) CT 3D reconstruction (*posterior view*); (**c**) CT 3D reconstruction showing screw positions; (**d**) CT 3D reconstruction (*right lateral view*); (**e**) CT 3D reconstruction (*left lateral view*)

Diagnosis: Vertebral scoliosis due to neurofibromatosis.

Surgery: Spine correction surgery with transverse process hook and pedicle screw internal fixation, interbody fusion surgery.

Imaging studies: Preoperative (Fig. 9.66) and postoperative images (Fig. 9.67).

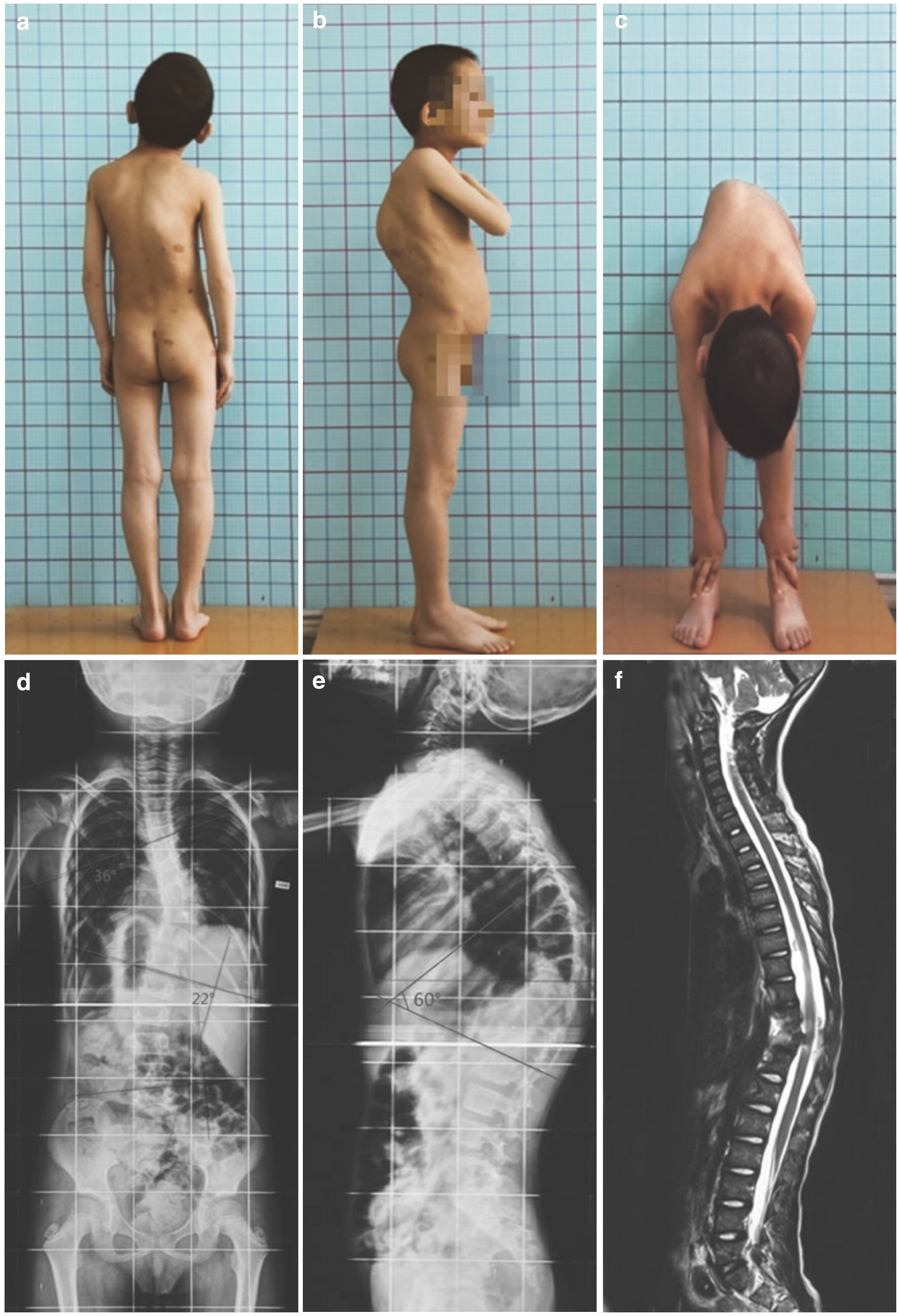

Fig. 9.66 Preoperative imaging studies. (**a**) The posterior view of the patient; (**b**) The lateral view of the patient; (**c**) The patient bending over; (**d**) X-ray image (*anteroposterior view*); (**e**) X-ray image (*lateral view*); (**f**) MRI (*sagittal view*)

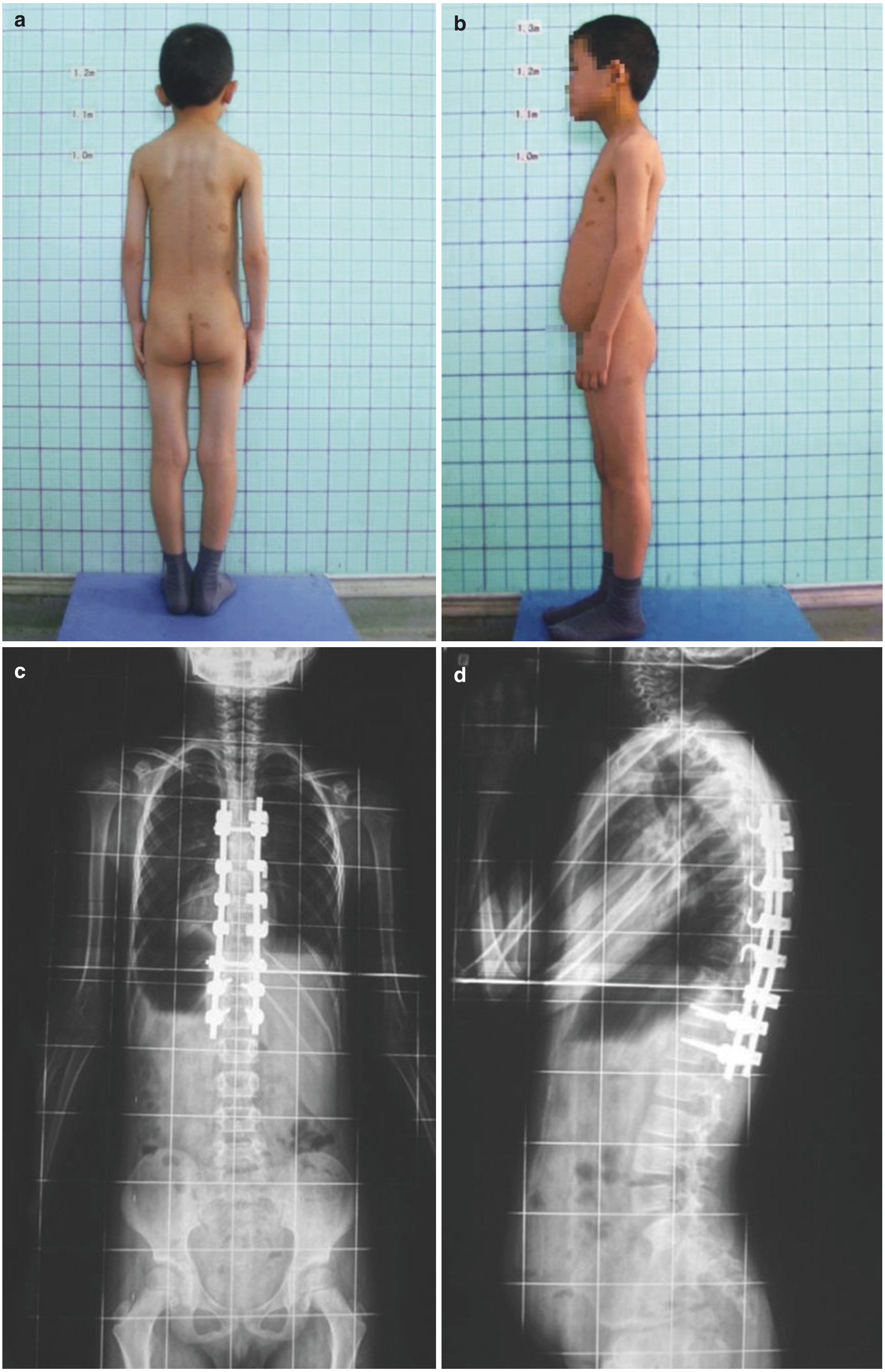

Fig. 9.67 Postoperative images. (**a**) The posterior view of the patient; (**b**) The lateral view of the patient; (**c**) X-ray image (*anteroposterior view*); (**d**) X-ray image (*lateral view*); (**e**) CT 3D reconstruction showing position of implants; (**f**) CT 3D reconstruction (*anterior view*); (**g**) CT 3D reconstruction (*lateral view*); (**h**) CT 3D reconstruction (*anterior view*); (**i**) CT 3D reconstruction (*posterior view*)

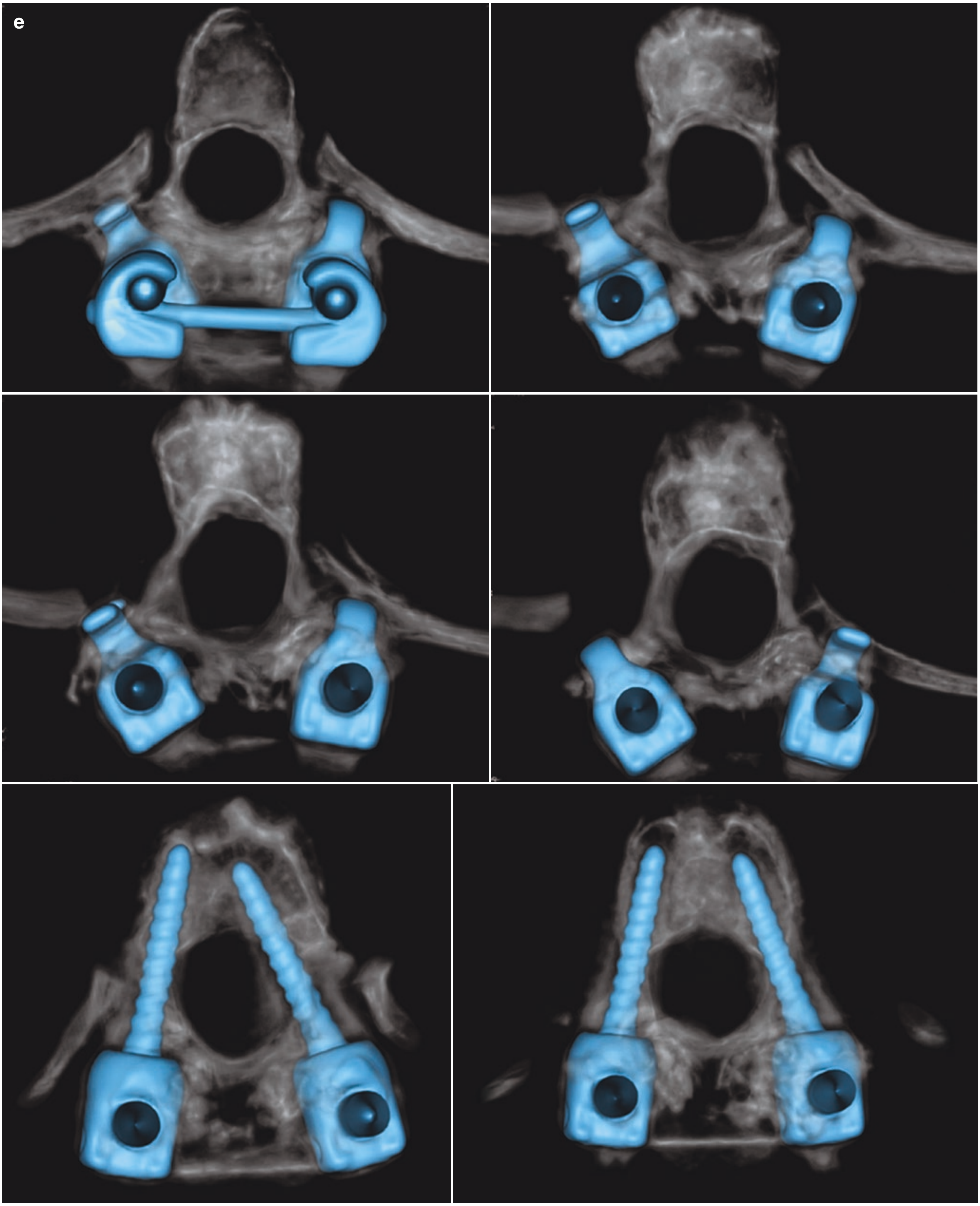

Fig. 9.67 (continued)

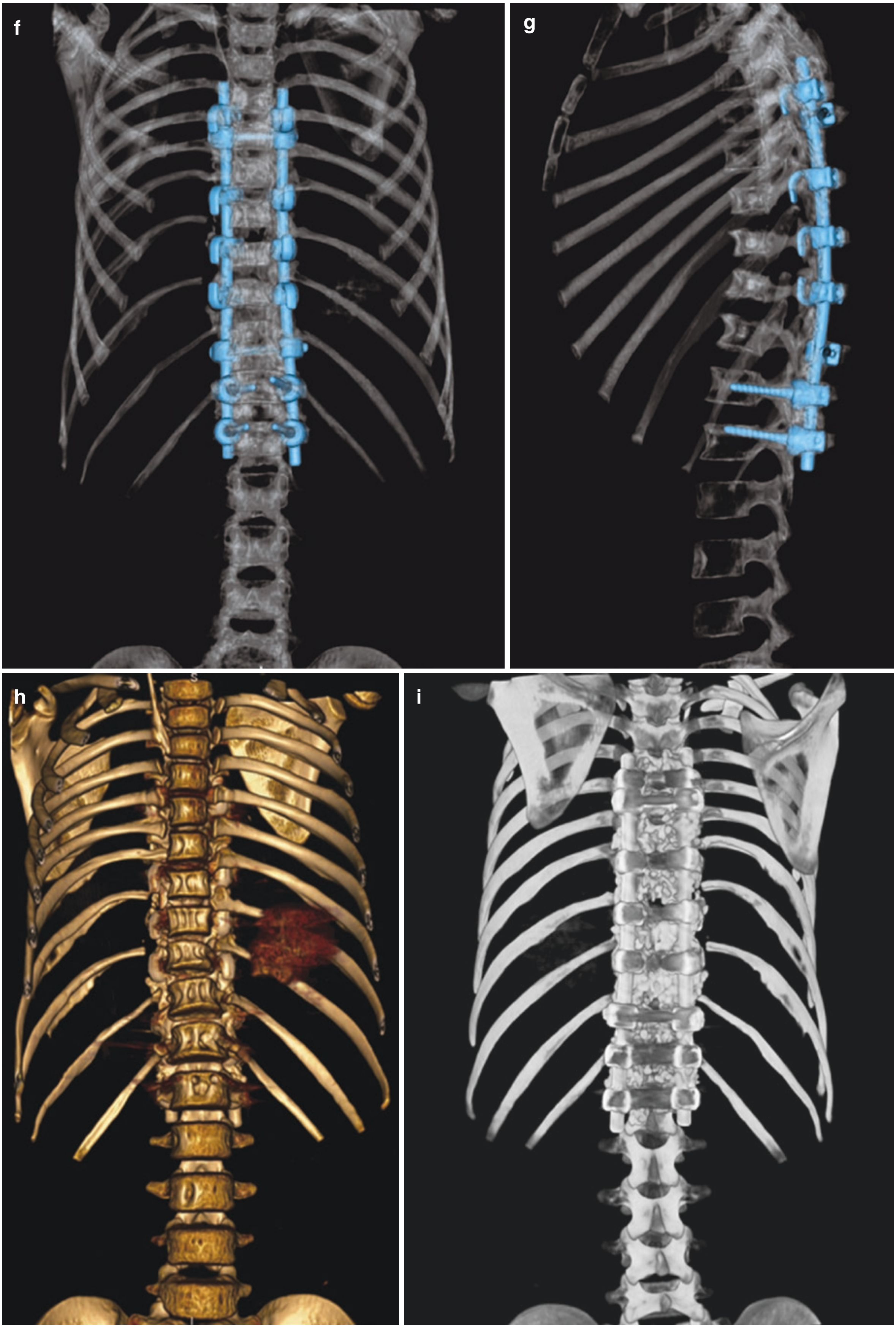

Fig. 9.67 (continued)

9.4 Common Pitfalls in Surgery of Vertebral Scoliosis due to Neurofibromatosis

9.4.1 Pitfall #1

In the presence of invasion by the capitulum costae into the vertebral canal, blind correction surgery may readily lead to paralysis of the patient (Fig. 9.68).

9.4.2 Pitfall #2

The use of screws for small pedicles may lead to multiple injuries (Fig. 9.69).

9.4.3 Pitfall #3

Mishandling of paravertebral soft tissue tumors may inadvertently cause massive bleeding (Fig. 9.70).

Cautions:

1. Preoperative reading of imaging results should focus on capitulum costae dislocation, pedicle diameter, size of the transverse process, and size of the spinal canal and the contents within and paravertebral tumor.
2. Surgery precautions: The capitulum costae invading the spinal canal should be first excised before correction surgery. The use of hook or screw is based on pedicle diameter and size of the transverse process. The likelihood of using hooks is greater. Besides, bone graft volume should be sufficient.

Case 6

Patient: A 13-year-old boy with vertebral deformity for 8 years with worsening for 2 years.

Diagnosis: Congenital vertebral scoliosis, L5 hemivertebra.

Surgery: Posterior L5 hemivertebrectomy, interbody fusion surgery, L1–L4, S1 pedicle screw internal fixation, posterior interbody fusion surgery.

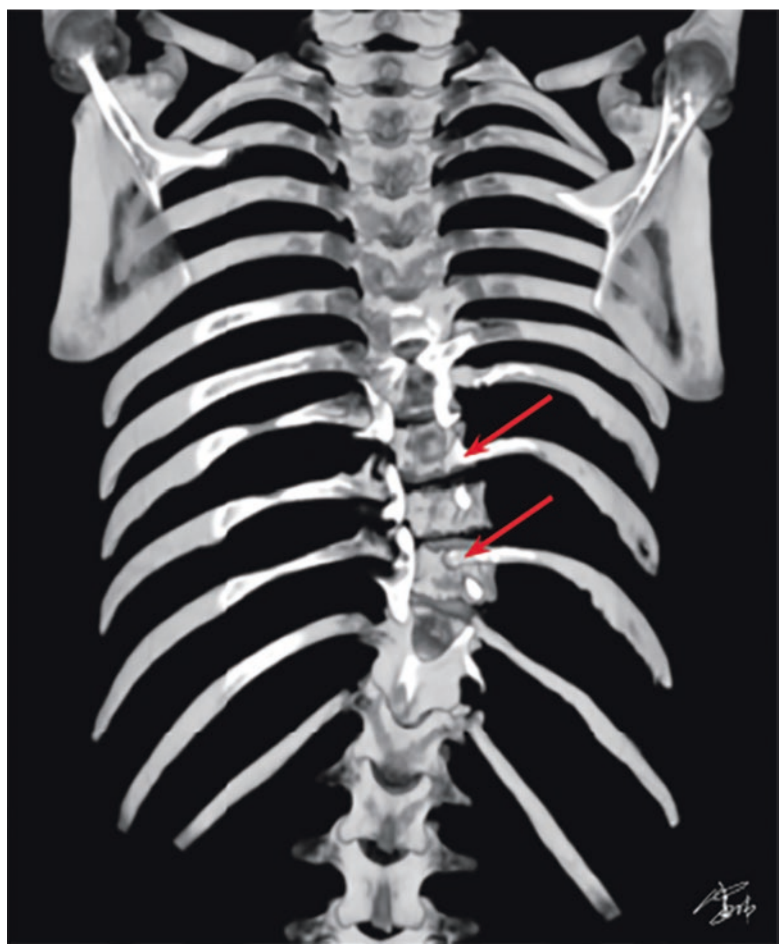

Fig. 9.68 Invasion by the capitulum costae into the vertebral canal

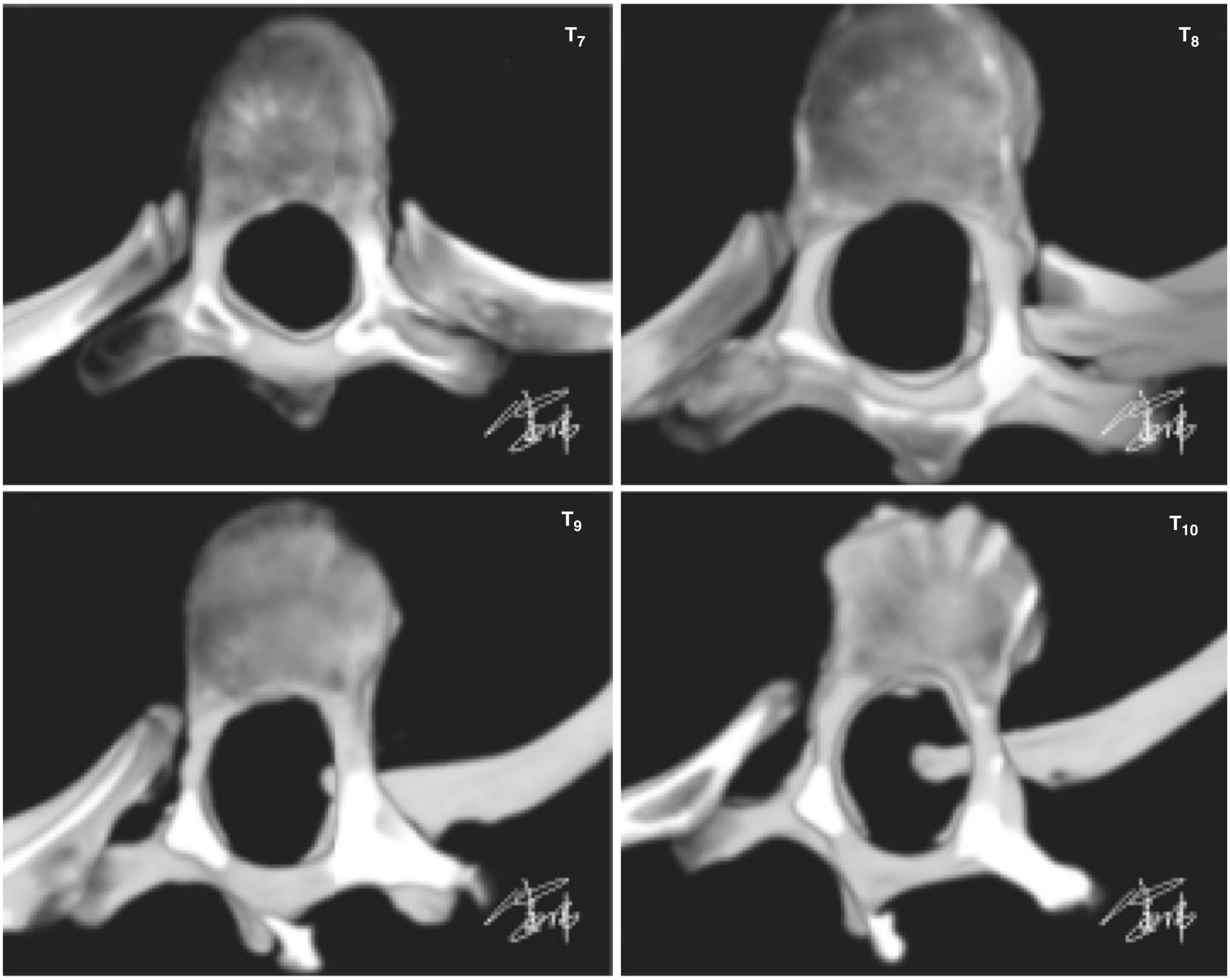

Fig. 9.69 Small pedicles

Imaging studies: Preoperative (Fig. 9.71) and postoperative images (Fig. 9.72).

Case 7
Patient: A 33-year-old female with lumbosacral deformity for 32 years and defecation and urinary dysfunction for 1 year.

Diagnosis: Congenital lumbosacral kyphosis.

Surgery: Correction surgery by posterior lumbosacral osteotomy; L1, L2, S2 pedicle screw internal fixation; sacroiliac screw internal fixation; and interbody fusion surgery.

Imaging studies: Preoperative (Fig. 9.73) and postoperative images (Fig. 9.74).

Case 8
Patient: A 43-year-old male complaining of back pain with right front thigh pain for 1 year.

Diagnosis: L3–L4 intervertebral disc herniation.

Surgery: L3–L4 posterior intervertebral disc fenestration with removal of the nucleus pulposus, CAPSTONE interbody fusion surgery, and L3–L4 pedicle screw internal fixation (PEEK rod).

Imaging studies: Preoperative (Fig. 9.75), intraoperative (Fig. 9.76), and postoperative images (Fig. 9.77).

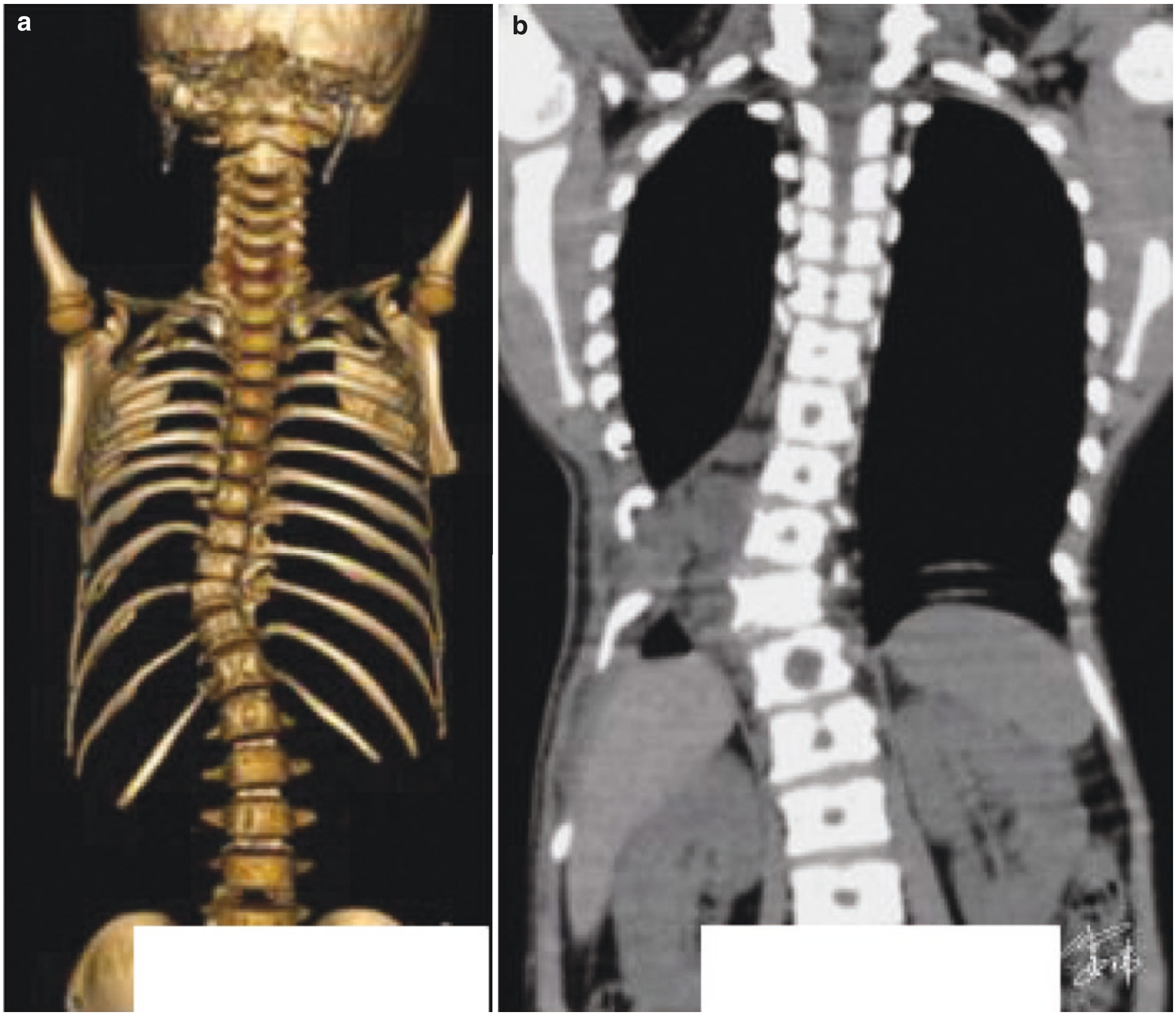

Fig. 9.70 Anatomical relationship of paravertebral tissues. (**a**) CT 3D reconstruction (*anterior view*); (**b**) CT 3D reconstruction (*sagittal view*)

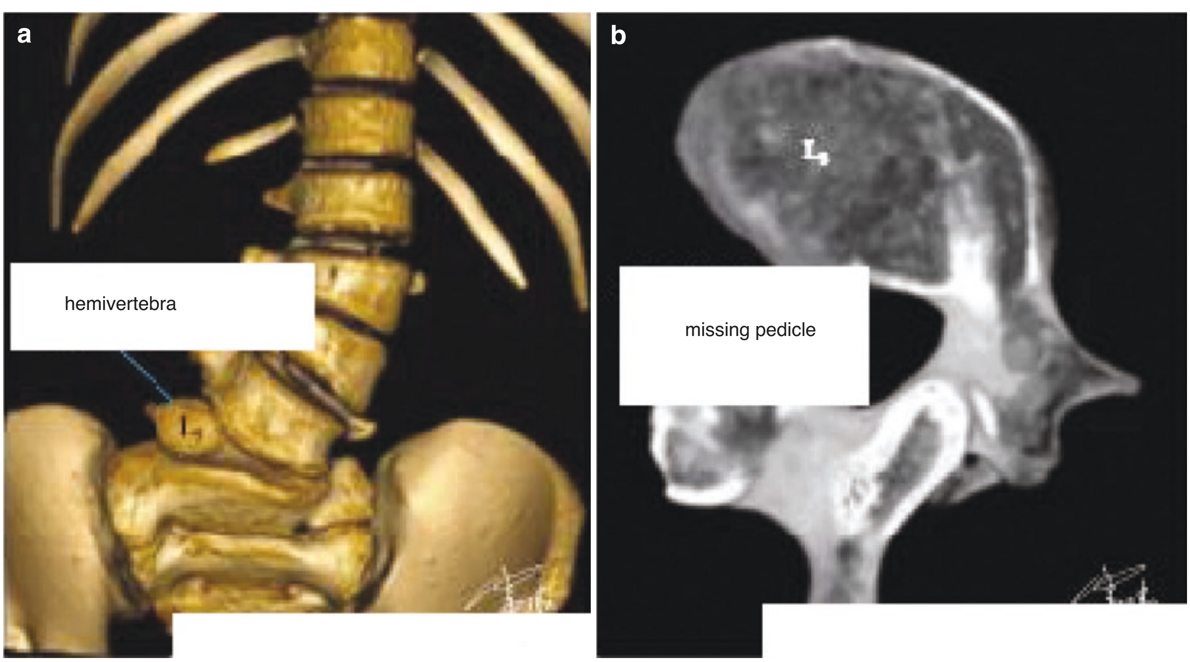

Fig. 9.71 Preoperative imaging studies. (**a**) CT 3D reconstruction (*anterior view*); (**b**) CT 3D reconstruction (*hemivertebra*)

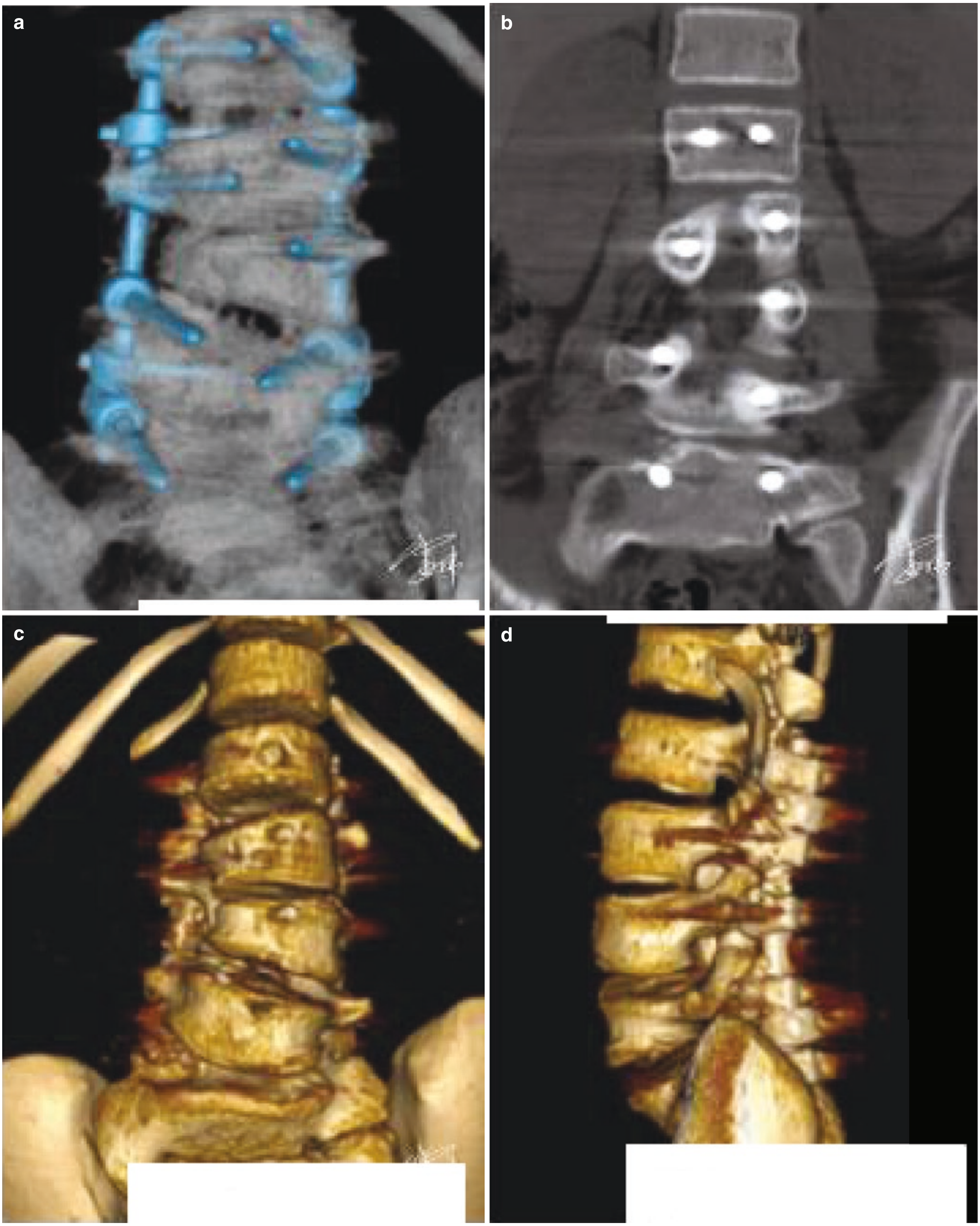

Fig. 9.72 Postoperative images. (**a**) CT 3D reconstruction (*anterior view*); (**b**) CT 3D reconstruction (*coronal view*); (**c**) CT 3D reconstruction (*anterior view*); (**d**) CT 3D reconstruction (*lateral view*); (**e**) CT 3D reconstruction showing screw position

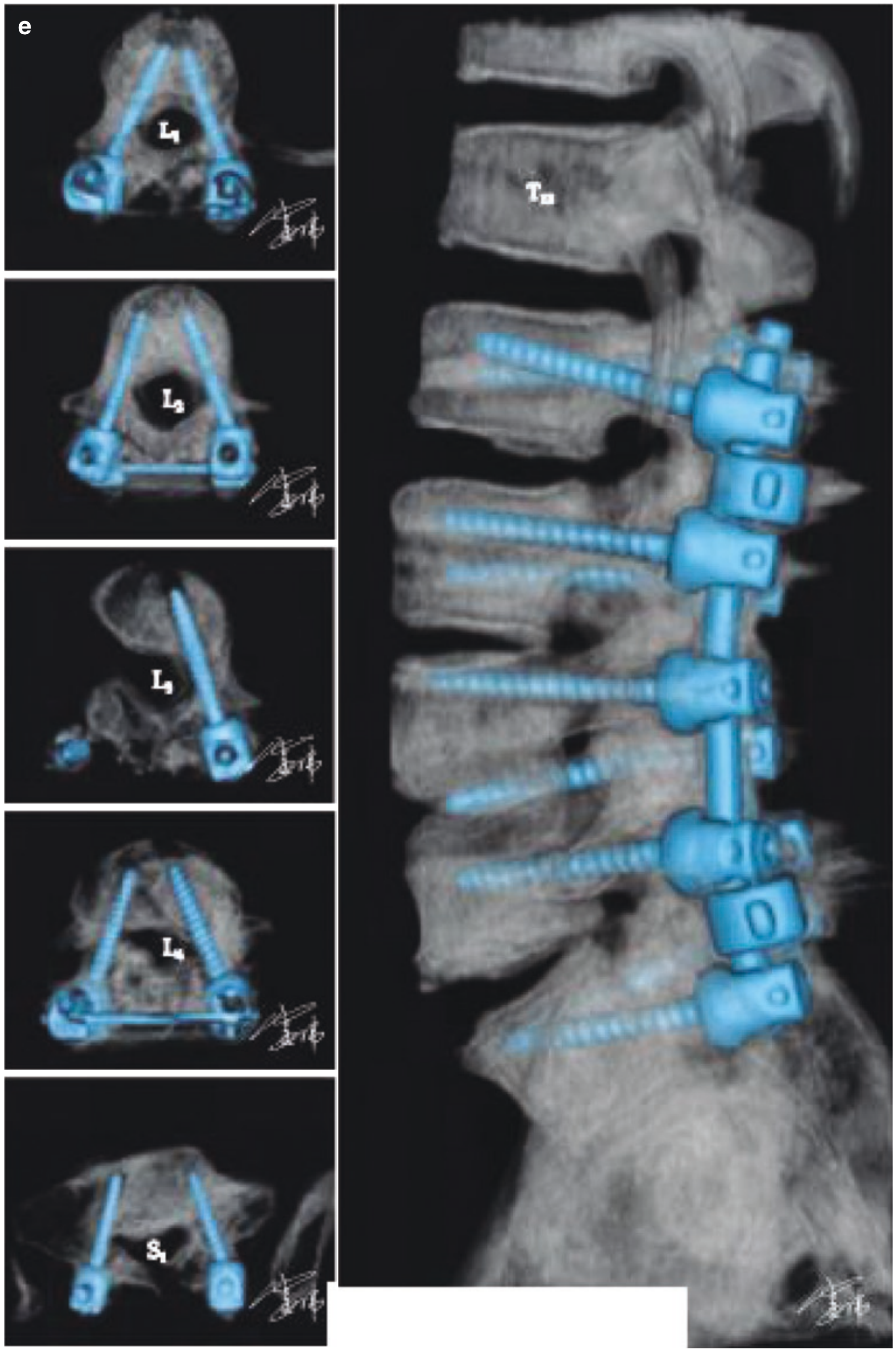

Fig. 9.72 (continued)

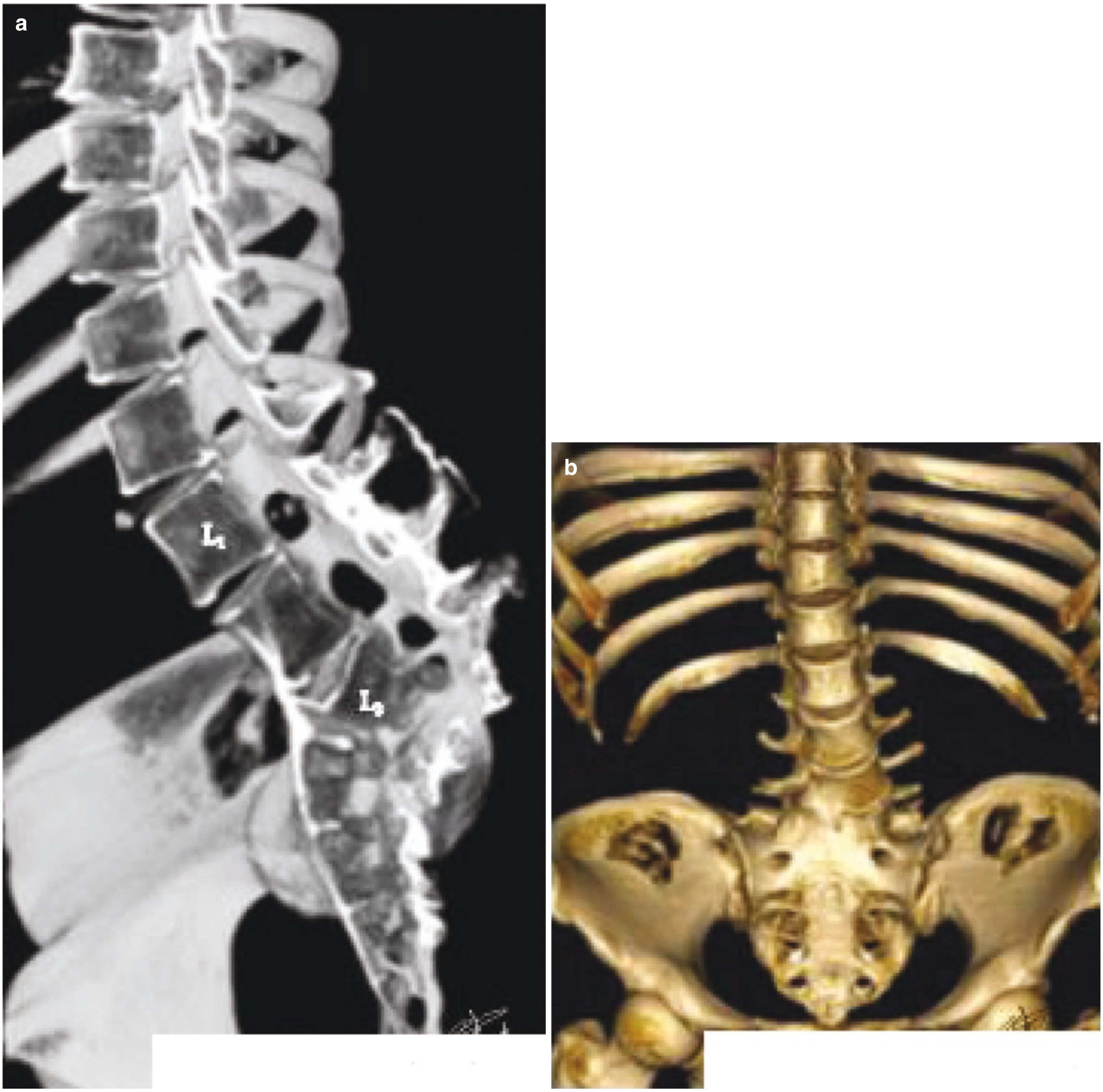

Fig. 9.73 Preoperative imaging studies. (**a**) CT 3D reconstruction (*sagittal view*); (**b**) CT 3D reconstruction (*anterior view*)

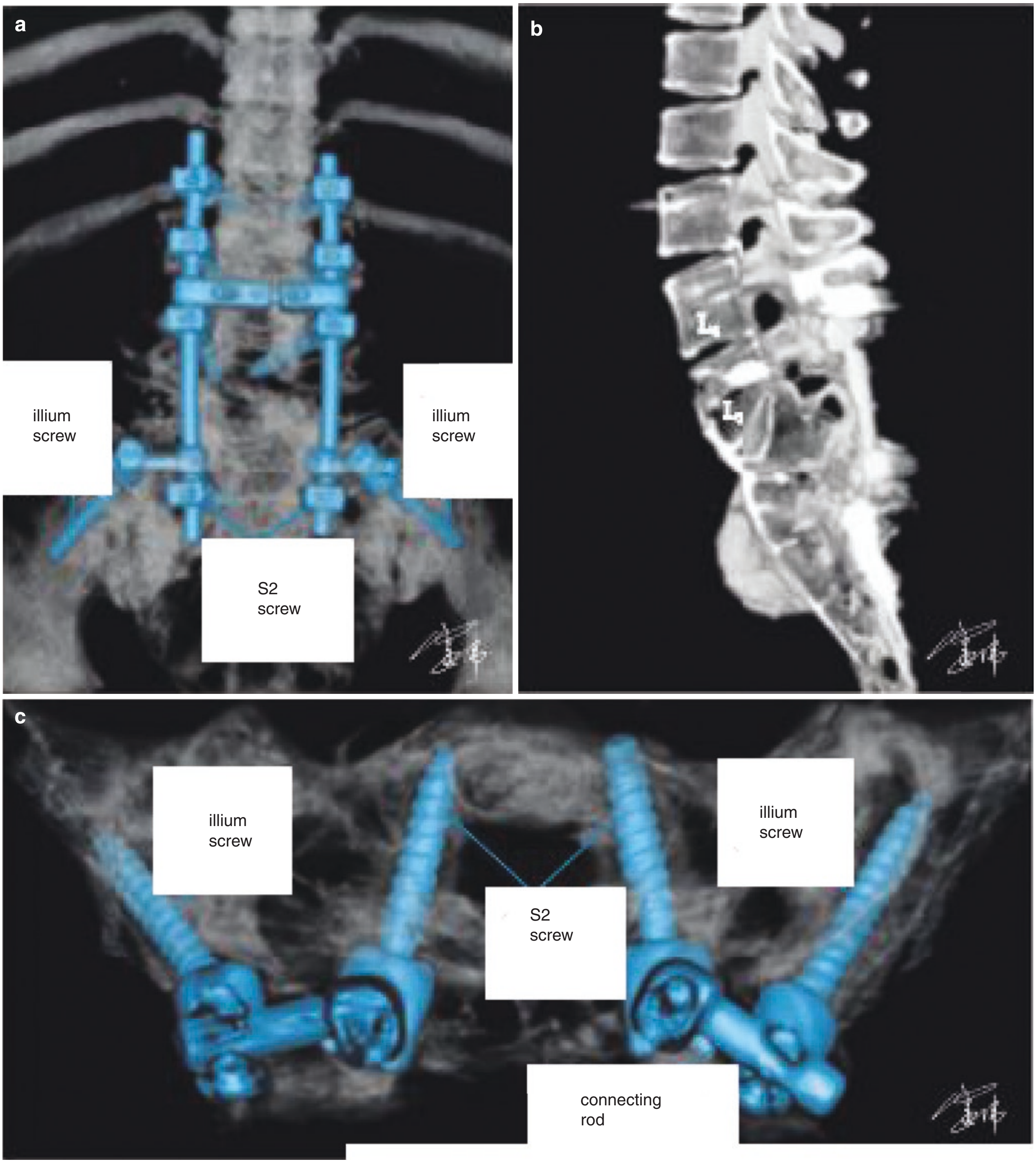

Fig. 9.74 Postoperative images. (**a**) CT 3D reconstruction (*posterior view*); (**b**) CT 3D reconstruction (*sagittal view*); (**c**) CT 3D reconstruction (*sagittal view*); (**d**) CT 3D reconstruction showing screw positions

Fig. 9.75 Preoperative imaging studies. (**a**) X-ray (*lateral view*); (**b**) MRI (*horizontal view*); (**c**) MRI (*sagittal view*)

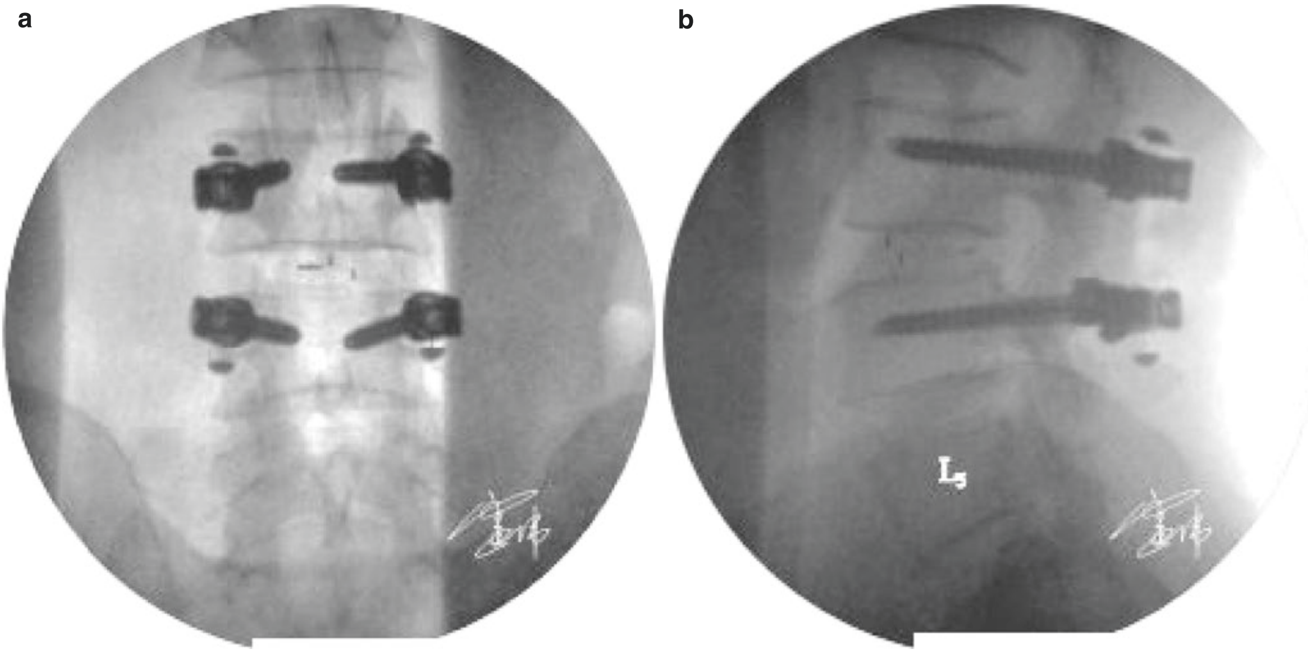

Fig. 9.76 Intraoperative images. (**a**) Fluoroscopy (*anteroposterior view*); (**b**) Fluoroscopy (*lateral view*)

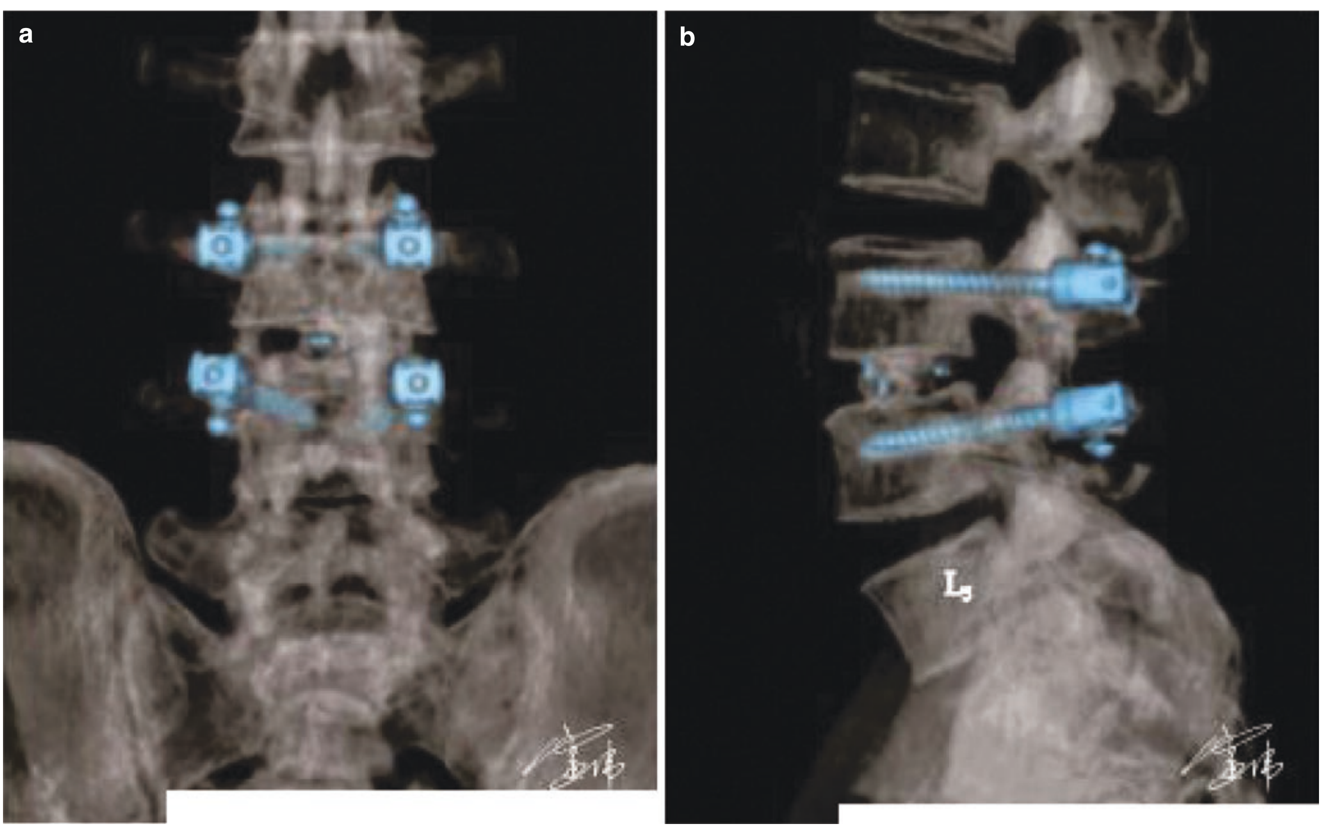

Fig. 9.77 Postoperative images. (**a**) CT 3D reconstruction (*posterior view*); (**b**) CT 3D reconstruction (*lateral view*)

9.5 Pearls and Pitfalls

1. Be cautious about the use of compressors and distractors

During compression and distraction, the feet of either the compressor or the distractor are placed securely against the implant body and not against the screw plug; otherwise, slippage of the implant or premature breaking of the plug may ensue.

2. Change of screw threads

The provisional screwdriver can be used to temporarily secure the rod. Temporary fixations can be done multiple times without damaging the screw plug or implant threads. If the screw plug has been cross-threaded, it should be replaced.

3. Caution in bending horizontally connected devices

The curvature on any plane cannot exceed 20 degrees; otherwise, breakage may occur.

4. The break-off of multi-axial reduction (lifting) screws

If soft tissues prevent the lateral break-off of the lengthened portion of the reduction screw, the medial lengthened proportion of the screw can be first broken off medially. Then, the Counter Torque can be used for break-off of the screw plug, and finally the lateral lengthened proportion of the screw can be broken off medially. If the lengthened portion cannot be easily bent and broken off, the screw plug should be examined to see it is fully seated. If the screw plug is not fully seated, the threads still exert resistance and prevent the break-off of the lengthened portion.

5. Handling of the bone adjacent to the screw

If the superior facet is inappropriately handled, the movements of the screw head are limited, leading to difficulty in inserting the screw plug and uneven force distribution, thus readily damaging the screw plug. If the bone beneath the head of the screw is not smoothened, the head of the screw and the bone beneath will impact on one another.

6. Choice of screw entry angle

For fixation of L5–S1, if the entry angle of the screw is incorrectly chosen, it will cause the heads of the two screws to collide against each other, interfering with the placement of the system. The correct spatial relation between the screw plug and the rod should be known to achieve the optimal fixation results.

The rod should be bent; otherwise, it will result in uneven force distribution between the screw plug and the rod, affecting the outcome of fixation. There should be a gap between the screw and the bone surface; otherwise, the motion of the head of the screw will be limited, leading to uneven force distribution between the screw plug and rod, affecting the outcome of fixation.

7. The fracture is not fully reduced

Based on our clinical experience, for treatment of thoracolumbar fractures, we believe that the superior endplate of the adjacent lower vertebral body and the inferior endplate of the adjacent upper vertebral body of the fractured vertebral body should be kept parallel during reduction or in mild lordosis. Meanwhile, sufficient intervertebral disc height should be maintained, and if, with sufficient intervertebral disc height, the anterior vertebral body is still collapsed, indicating severe injury of the anterior longitudinal ligament and the intervertebral disc, no traction of the fractured end should be undertaken for reduction. This is the reason for unsatisfactory vertebral fracture reduction despite sufficient posterior and anterior distraction. In such cases, there is no need for multiple adjustments of the reduction devices so as to avoid screw loosening and pedicle fracture. To solve this problem, vertebroplasty can perform fracture reduction, that is, a balloon is advanced from the pedicle of the fractured vertebral body to achieve fracture reduction by dilatation, followed by placement of bone cement or cancellous bone, or a pedicle drill can enter the collapsed region of the fractured vertebral body to achieve reduction by prying, followed by filling of the cavity with cancellous bone via the pedicle trajectory. However, the effectiveness of the two methods is not definite.

8. The two extension rods cross each other after placement

For treatment of lumbar spondylolisthesis, if the two extension rods cross each other after their placement, reduction by the distractor will be affected. In this situation, the caudal nut is tightened first after screw placement so that there is enough space for the rostral offset holder to lift the screws for extension rod placement. Thus, distractor placement is not affected. After the intervertebral disc space is distracted, the screw nut is gradually lifted, reduction is done, and the screw is tightened. If lumbar lordosis is to be increased, the extension rod can be pushed caudally in the course of tightening.

9. Failure to achieve full reduction in spondylolisthesis

Full reduction can generally be achieved in the treatment of lumbar spondylolisthesis. Two steps are crucial for full reduction. First, the surgeon should accurately determine the severity of spondylolisthesis preoperatively and correctly estimate the lifting distance with appropriate lifting room preserved intraoperatively. Second, scar tissues, osteophytes, and entangled cords affecting reduction should be loosened completely intraoperatively.

The slip distance in the spondylolisthesis patient should be measured on lateral X-ray films before surgery. The patient is placed in the prone position during surgery for fluoroscopy to examine whether marked changes in the slip distance have occurred. If there are no apparent changes, the preoperative slip distance is used as the lifting distance. A lifting space for reduction that corresponds to the measured slip distance is preserved when a rod is used to lift the screws. Then, the caudal screw head is tightened to set the reduction space, followed by final tightening. As long as sufficient space is preserved for reduction, and the caudal screw head is firmly tightened without loosening, the reduction screws will not slip inside the bone. If the principle of caudal fixation and rostral lifting is followed, reduction can generally be achieved in spondylolisthesis patients.

In addition, the curvature of the rod should be appropriate. If the rod is bent at an excessive curvature, no sufficient lifting space is left. If the rod is bent at too small an angle, lumbar lordosis will decrease, even leading to flat back syndrome.

The presence of bony bridges in the anterior edge of the vertebral body affects reduction. A periosteum elevator can be inserted into the intervertebral disc space for prying and cutting off the bony bridge and loosening the vertebral bodies. Then, lifting reduction is done. If the bony bridge is not disrupted, reduction cannot be done, and the lifting screws will also be pulled out from the vertebral body.

10. Evaluation criteria for lumbar spondylolisthesis reduction

Radiological parameters for evaluation of spondylolisthesis reduction include the Taillard index, intervertebral disc space height, curvature of the lumbosacral spine, and height and width of the intervertebral foramen.

11. The use of offset holder

When more than three sets of pedicle screws are used for posterior fixation, pedicle screws should be best placed in a straight line. Otherwise, it will increase difficulty for rod placement. If the screws are not in a straight line, an offset can be used.

12. Management of crossed L5 and S1 pedicle screws

The two pedicle screws in L5 and S1 should be kept at an appropriate angle and distance. Otherwise, the two pedicle screws will cross each other and make it difficult for placing the offset holder. In such cases, the parallel distractor can be placed between the two sets of pedicle screws for gentle distraction. The lower blade of the parallel distractor is inserted, then the rod is placed, and finally the upper blade is inserted, and the screw is tightened.

13. Advantages of fixation of the injured spine

Fixation of the injured spine is consistent with bone biomechanical requirements, facilitates reduction of the injured spine, and reduces the breaking of internal fixation implants.

14. Indications of fixation of the injured spine fixation

The pedicle integrity of the injured spine should be determined via CT or CT 3D reconstruction (Fig. 9.78).

15. Length and angle of screws for the injured spine

The use of short screws is recommended for fixation, and the screw length is 2/3–3/4 of the length of a regular screw. The fixation angle is aimed in the direction of the solid portion of the bone. If the screw is advanced into the fractured portion of the bone, fixation strength will be markedly reduced (Fig. 9.79).

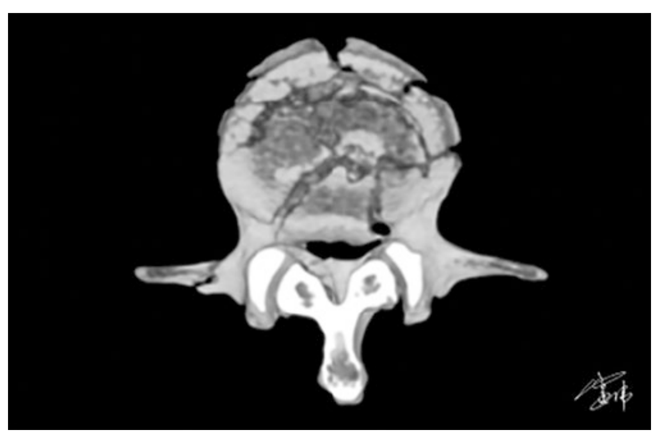

Fig. 9.78 The injured spine

Fig. 9.79 Screw fixation of the injured spine

16. The diseased spine should not undergo pedicle screw fixation

Pedicle screws should be best avoided for diseased vertebral bodies such as with tuberculosis or tumor. On the one hand, the diseased bone has poor holding power for the screw. On the other hand, screw entry into the diseased bone region may facilitate spread of the disease.

17. Prevention of screw loosening in osteoporosis

Expansion pedicle screw fixation can be undertaken in cases of mild or moderate osteoporosis (Fig. 9.80). Partial reinforcement of the screw trajectory plus expansion screw fixation (Fig. 9.81) can be done in cases of severe osteoporosis (Fig. 9.82).

18. Implant fixation failure and principles of management

Common implant fixation failures include breaking of screws or rods, loosening of screws, and improper positioning of screws resulting in pedicle injury and screw entry into the spinal canal or intervertebral disc space. Late complications are mainly bone fusion failures, leading to pseudoarthrosis and breaking of screws or rods (Fig. 9.83).

Fig. 9.80 Expansion pedicle screw fixation

For early postoperative complications, revision surgery should be undertaken as early as possible. For late (>3 months) postoperative complications, if bone fusion has been achieved, and the patient is asymptomatic, revision surgery can be postponed, and watchful observation can be undertaken. If the patient has implant-related clinical manifestations, revision surgery is carried out and the internal fixation can be removed. If bone fusion has not been achieved and pseudoarthrosis is formed, revision surgery can be postponed if the patient is asymptomatic and the patient can be closely watched. If symptoms occur, revision surgery is undertaken, and the implant is adjusted, or bone graft surgery is done.

Revision surgery should be immediately undertaken if implant-related neurologic symptoms have developed, regardless of whether they occur in the early or late stage (Fig. 9.84).

9.6 Postoperative Management

Patients should be cautioned to avoid any activities that may exert a pulling or shearing action on the implant or bone graft, thus impairing bone healing and leading to complications. When the spine is sufficiently stable and under support by external fixation, patients are encouraged to carry out appropriate, regular, and incrementally increasing activities to facilitate bone growth. Wearing durable external fixation devices until bone healing has been achieved by patients. Patients should receive proper guidance on activities from sitting to moving into and out of bed.

Fig. 9.81 Partial reinforcement of the screw trajectory plus expansion screw fixation

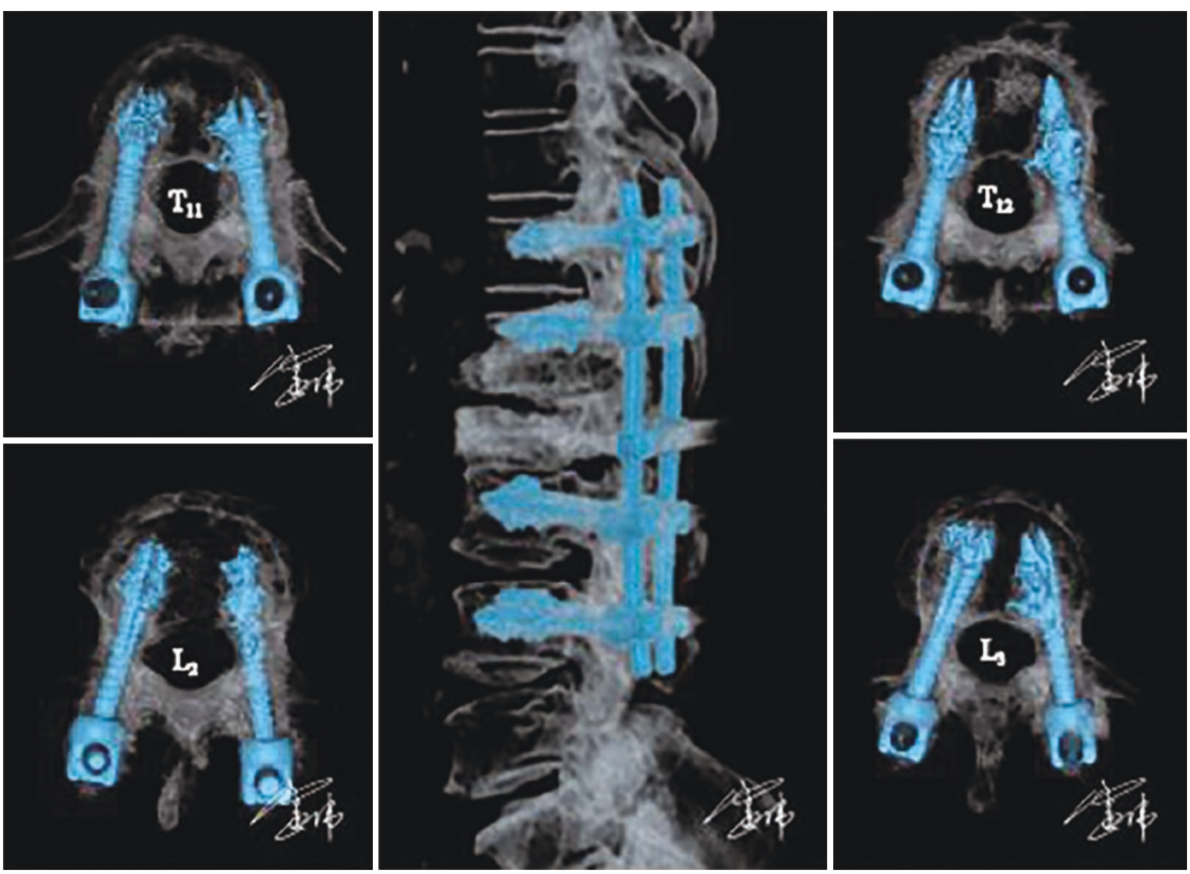

Fig. 9.82 L1 vertebral compression fracture (severe osteoporosis)

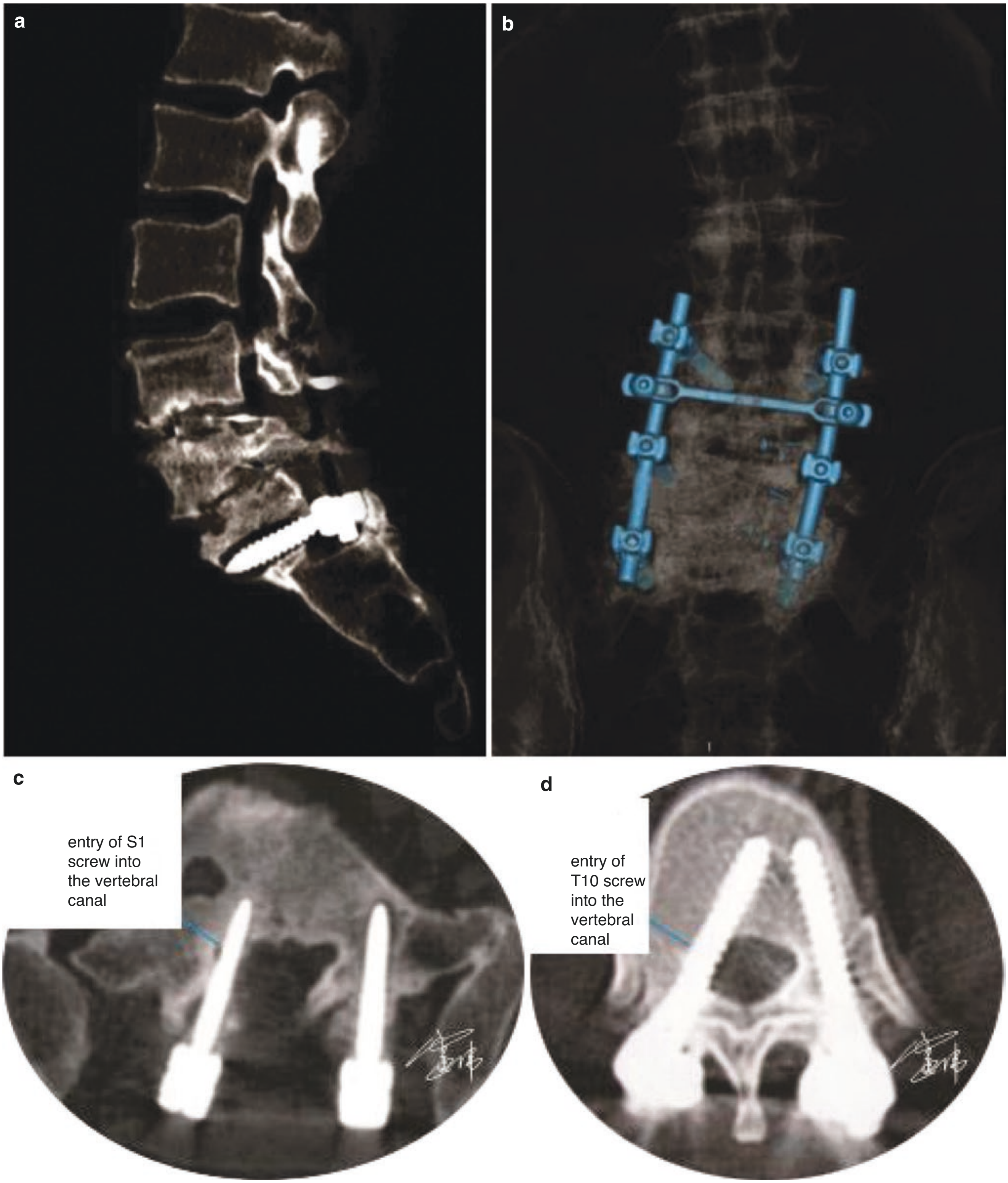

Fig. 9.83 Implant fixation failure. (**a**) CT 3D reconstruction (*sagittal view*); (**b**) CT 3D reconstruction (*posterior view*); (**c**) CT (*horizontal view*); (**d**) CT (*horizontal view*)

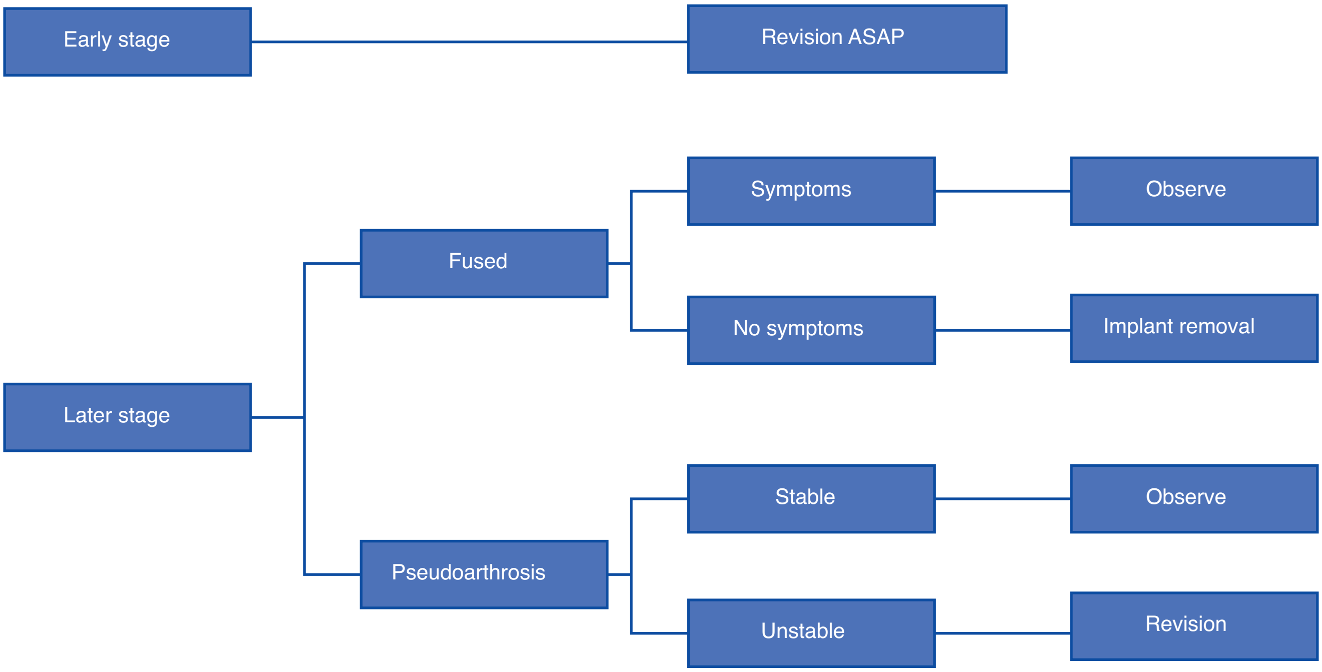

Fig. 9.84 Principles of management for failed implant fixations

Recommendation: Under the protection of external support, patients may start ambulation 1 week postoperatively, and the support can be removed 3–6 months postoperatively depending on bone healing.

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