1 Cervical Spine Fractures and Dislocations

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1.1 Basic Theory and Concepts

1.1.1 Overview

- Cervical spine injuries refer to fractures and dislocations of the section from the atlanto-occipital joint to C7, including the upper (C1–2) and lower (C3–7) cervical spine.
- The major causes of cervical spine injuries are high-energy violence, mostly consisting of transportation accidents (45%) and falls from a high place (20%) (Koval and Zuckerman 2006).
- Fractures of the atlas, axis, and lower cervical spine account for 7%, 12%, and 75% of all cervical spine fractures, respectively (Zhang 2012).
- Approximately 40% of cervical spine fractures are associated with nerve injury. Lower cervical spine injuries are more likely associated with spinal cord damage than upper cervical spine injuries (Koval and Zuckerman 2006).

1.1.2 Applied Anatomy

- The cervical spine has a natural lordosis of 25° (Fig. 1.1), and the perpendicular line of C7 passes S1.
- The upper cervical spine consists of the atlas and the axis with unique shapes, and the lower cervical spine consists of C3–7, which have similar structures.
- The range of motion of the upper and lower cervical spine in neck movements:
  – The vertebral segments constituting the cervical spine vary in range of motion on the three planes during neck movements; correspondingly, arthrodesis of different segments leads to varying degrees of loss of range of motion (Table 1.1).
  – Arthrodesis involving fewer segments retains a larger motion range.
- The atlas (C1; Fig. 1.2):
  – The atlas has a unique shape as its vertebral body has evolved into the odontoid process.
  – Lateral mass:
    It is one of the major contributors to head movements.

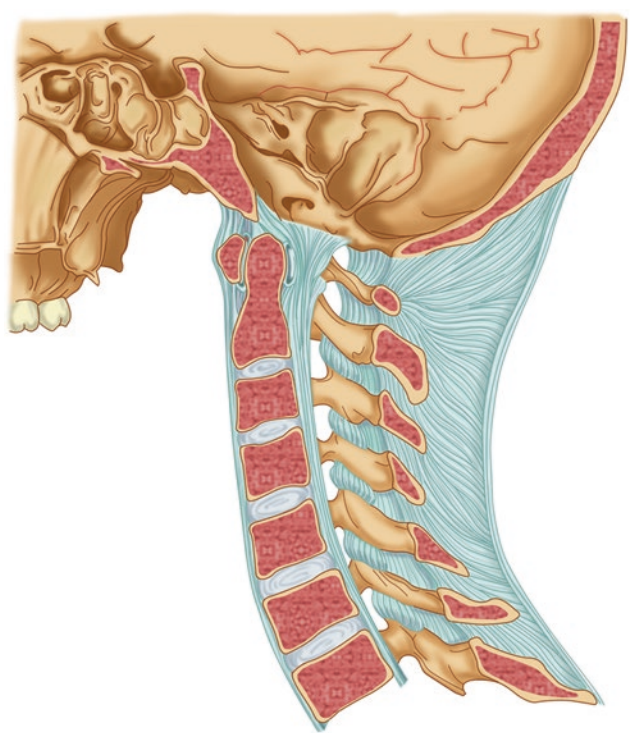

Fig. 1.1 The cervical spine has a physiological lordosis of approximately 25°

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P. Tang, H. Chen (eds.), *Orthopaedic Trauma Surgery*, https://doi.org/10.1007/978-981-16-0219-1_1

Table 1.1 Ranges of motions of different joints and regions of the cervical spine in three planes

Joint or Region	Flexion and Extension (Sagittal Plane, Degrees)	Axial Rotation (Horizontal Plane, Degrees)	Lateral Flexion (Frontal Plane, Degrees)
Atlanto-occipital joint	Flexion: 5 Extension: 10 Total: 15	Negligible	About 5
Atlanto-axial joint complex	Flexion: 5 Extension: 10 Total: 15	35-40	Negligible
Intracervical region (C2-C7)	Flexion: 35-40 Extension: 55-60 Total: 90-100	30-35	30-35
Total across craniocervical region	Flexion: 35-40 Extension: 55-60 Total: 90-100	65-75	35-40

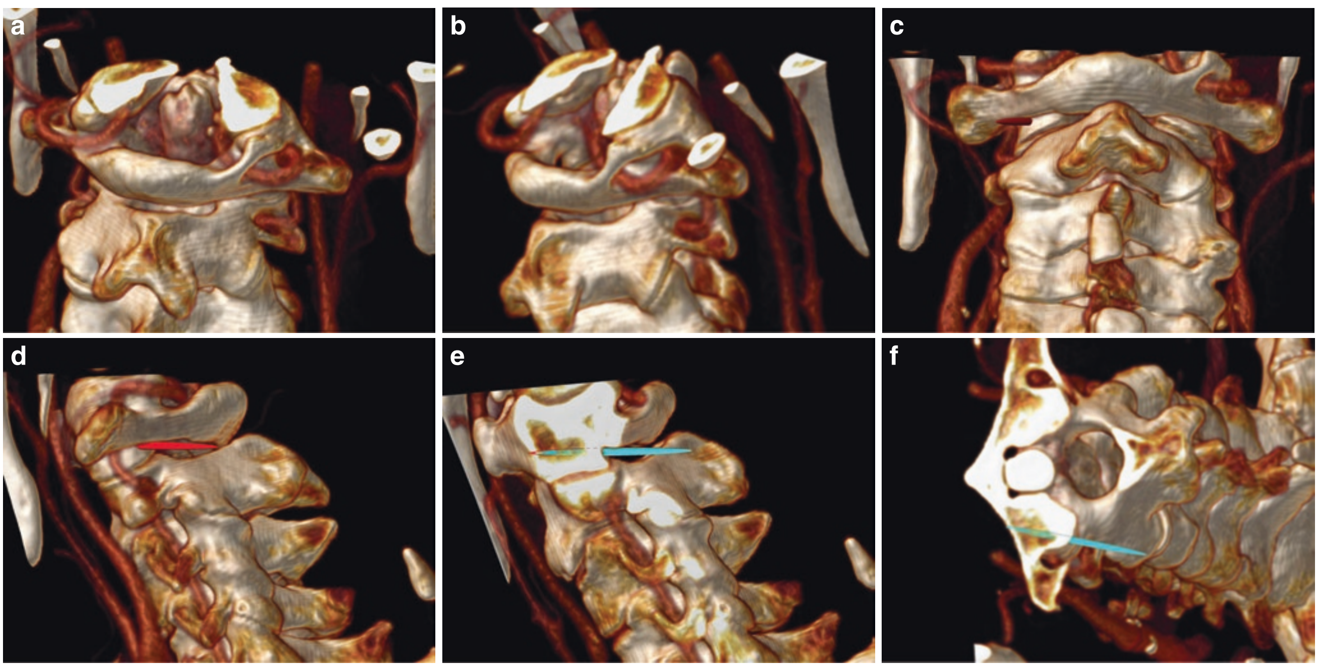

Fig. 1.2 (**a**, **b**) The vertebral artery runs through a bony arch structure in the vertebral artery groove of C1 in a portion of patients. Under such a circumstance, it is important to identify anatomical structures carefully, and non-vigilant screw placement might damage the vertebral artery. (**c**, **d**) The entry point of the C1 lateral mass screw (red bar) is located below the posterior vertebral lamina and on the perpendicular line passing the center of the C1/2 joint. (**e**) The near-sagittal plane of the C1 lateral mass along the direction of the guide wire: the screw placement should be inclined 10° to 20° towards the head side and parallel to the C1 ring. (**f**) The near-cross-section of the C1 lateral mass along the direction of the guide wire: Both sides of the screw converge at an angle of 10° to avoid the lateral vertebral artery

It is located between the anterior and posterior arches, with both the top and bottom surface being articular facets, the spinal canal at its medial side, and the vertebral artery at its lateral side.

The entry point of the lateral mass screw is located below the posterior vertebral lamina and on the perpendicular line passing the center of the C1/2 joint.

The lateral mass screw is placed along the direction inclining to the head by 10–20°, which positions the screw parallel to the ring of C1, and a convergence angle of 10° to avoid damaging the vertebral artery.

– The vertebral artery groove is at the junction of the posterior arch and lateral mass. However, the vertebral artery runs through a bony arch structure in the vertebral artery groove of C1 in a portion of patients. Under such a circumstance, it is important to identify anatomical structures and properly determine the screw entry point; otherwise, non-vigilant screw placement might damage the vertebral artery (Young et al. 2005).
– The atlantoaxial intervertebral venous plexus:

The venous plexus is behind the atlantoaxial joint, and as a result, the venous wall might be easily damaged during tissue separation.

The entry point of the C1 lateral mass screw should be at a higher rather than lower level. The venous plexus and C2 dorsal root ganglion are gently pulled aside using a nerve stripper for screw placement (Goel and Laheri 1994; Harms and Melcher 2001).

- The axis (C2):
  - The odontoid process is the vestige of the vertebral body of the atlas.
  - Vertebral pedicle:

    The upper and lower edges of the vertebral pedicle of the axis are the superior and inferior articular processes, respectively; the spinal canal and the vertebral artery are located on the medial and lateral sides of vertebral pedicle, respectively.

    The entry point of the pedicle screw is at the midpoint of the perpendicular bisector of the superior articular process of C2.

    The pedicle screw is placed along a direction inclining to the head by 25° and has a convergence angle of 25–35° to avoid damaging the vertebral artery (Borne et al. 1984) (Fig. 1.3).
- Distinct structure of the atlantoaxial ligaments (Fig. 1.4):
  - The surrounding ligaments and other soft-tissue structures play a pivotal role in stabilizing the occipital bone, atlas, and axis, as the bony interconnection among the latter three lacks internal stability.
  - Anteriorly, the anterior atlanto-occipital membrane, which is an extension of the anterior longitudinal ligament, connects the anterior rim of the foramen magnum and the anterior arch of the atlas.
  - Posteriorly, the posterior atlanto-occipital membrane, which shares the same origin as the ligamentum flavum, connects the posterior rim of the foramen magnum and the posterior arch of the atlas.
  - The atlantoaxial ligament consists of three layers:

    The superficial layer is the tectorial membrane, which originates from the ventral side of the foramen magnum and ends at the dorsal side of the odontoid process, is the major ligament stabilizing the atlanto-occipital joint.

    The middle layer includes the cruciate ligament (the transverse ligament of the atlas), which originates from the two inner tubercles of the anterior arch of the atlas, pulls the odontoid process towards the anterior arch of the atlas to prevent the odontoid process from moving backward, and enhances the ability of the cervical spine to rotate.

    The deep layer includes the alar ligament and the apical odontoid ligament. The alar ligament is attached to the tubercles on the two sides of the foramen magnum, additionally stabilizing the atlanto-occipital joint, whereas the apical odontoid ligament contributes little to the stability of the joint.
- C3–C7 vertebrae have a similar structure (Fig. 1.5).
  - The transverse foramen:

    The transverse foramen, which is a unique structure in the cervical vertebrae, includes the ventral and dorsal parts. The ventral part has the same origin as the corresponding rib and is therefore called the costal process. The round blunt end of the costal

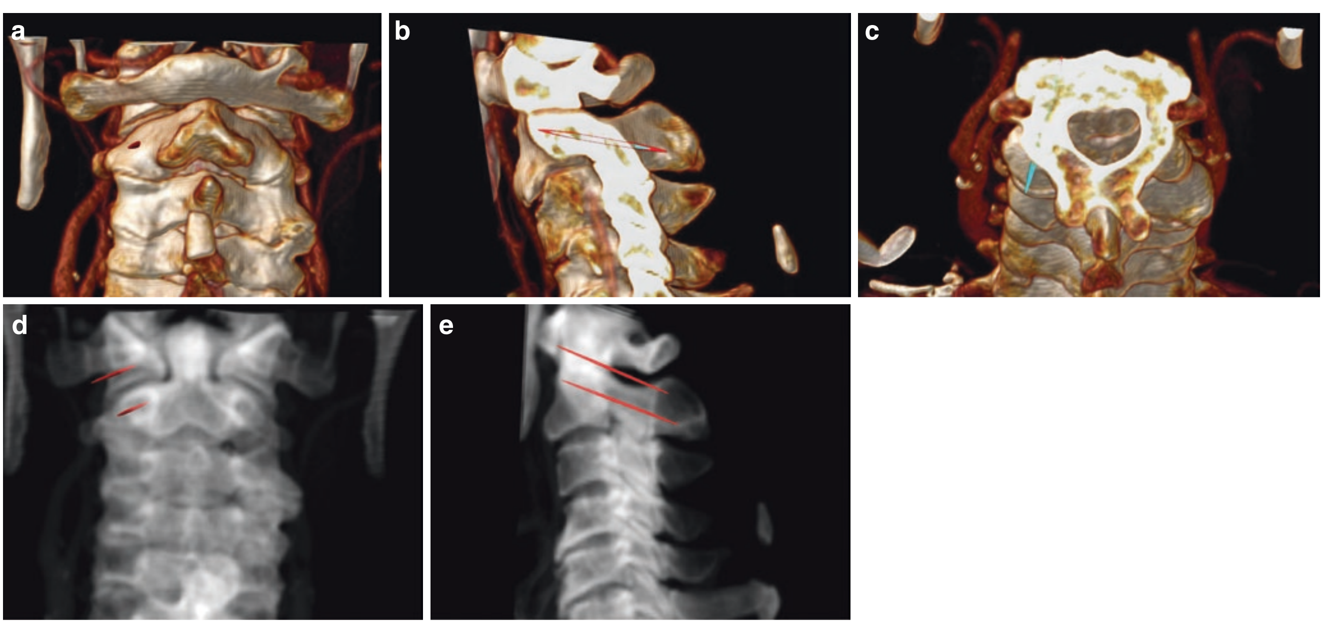

Fig. 1.3 (**a**) The entry point of the pedicle screw is located at the midpoint of the perpendicular bisector of the superior articular process of C2. (**b**) The near-sagittal plane of the C2 pedicle along the direction of the guide wire: The pedicle screw should be tilted towards the head side by 25°. (**c**) The near-cross-section of C2 along the direction of the guide wire: The screws at both sides converge at an angle of 25–35° to avoid damaging the vertebral artery. (**d**, **e**) Reconstructed X-ray CT image showing the guide wire positions

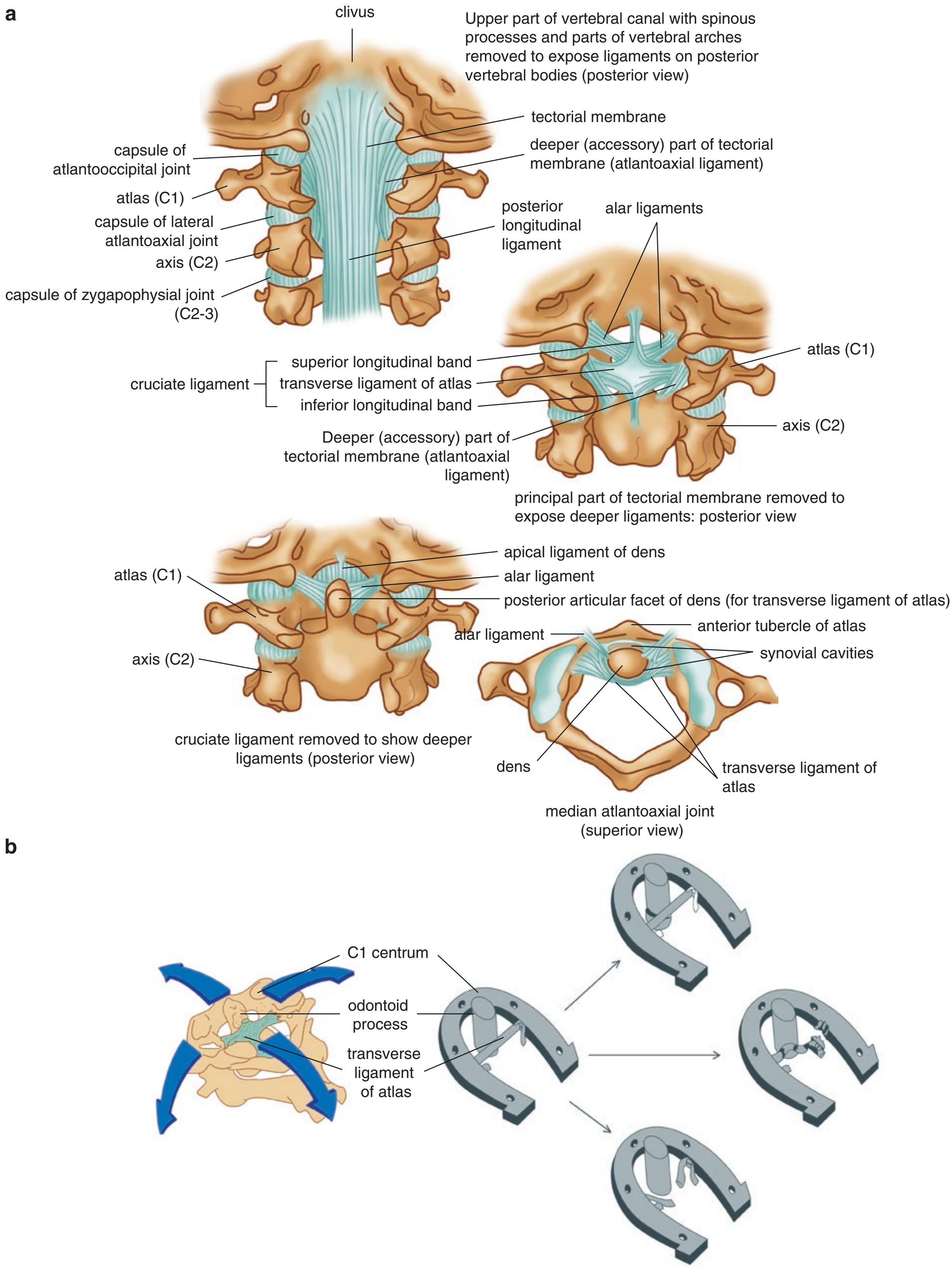

Fig. 1.4 (**a**) The atlantoaxial ligament: The superficial layer is the tectorial membrane, which originates from the ventral side of the foramen magnum and ends at the dorsal side of the odontoid process. The middle layer includes the cruciate ligament (the transverse ligament of the atlas), which originates from the two inner tubercles on the dorsal side of the anterior arch of the atlas. The deep layer includes the alar ligament and the apical odontoid ligament. (**b**) The relationship between the atlas and the axis can be simplified in the following model: the atlas is the horseshoe, the odontoid process is the wooden pole, and the transverse ligament is the cloth belt. There are three basic types of damage, a break of the wood pole (i.e., an odontoid process fracture), a break at the junction of the cloth belt and the horseshoe (i.e., the avulsion of the transverse ligament), and a break of the cloth belt (i.e., a transverse ligament rupture)

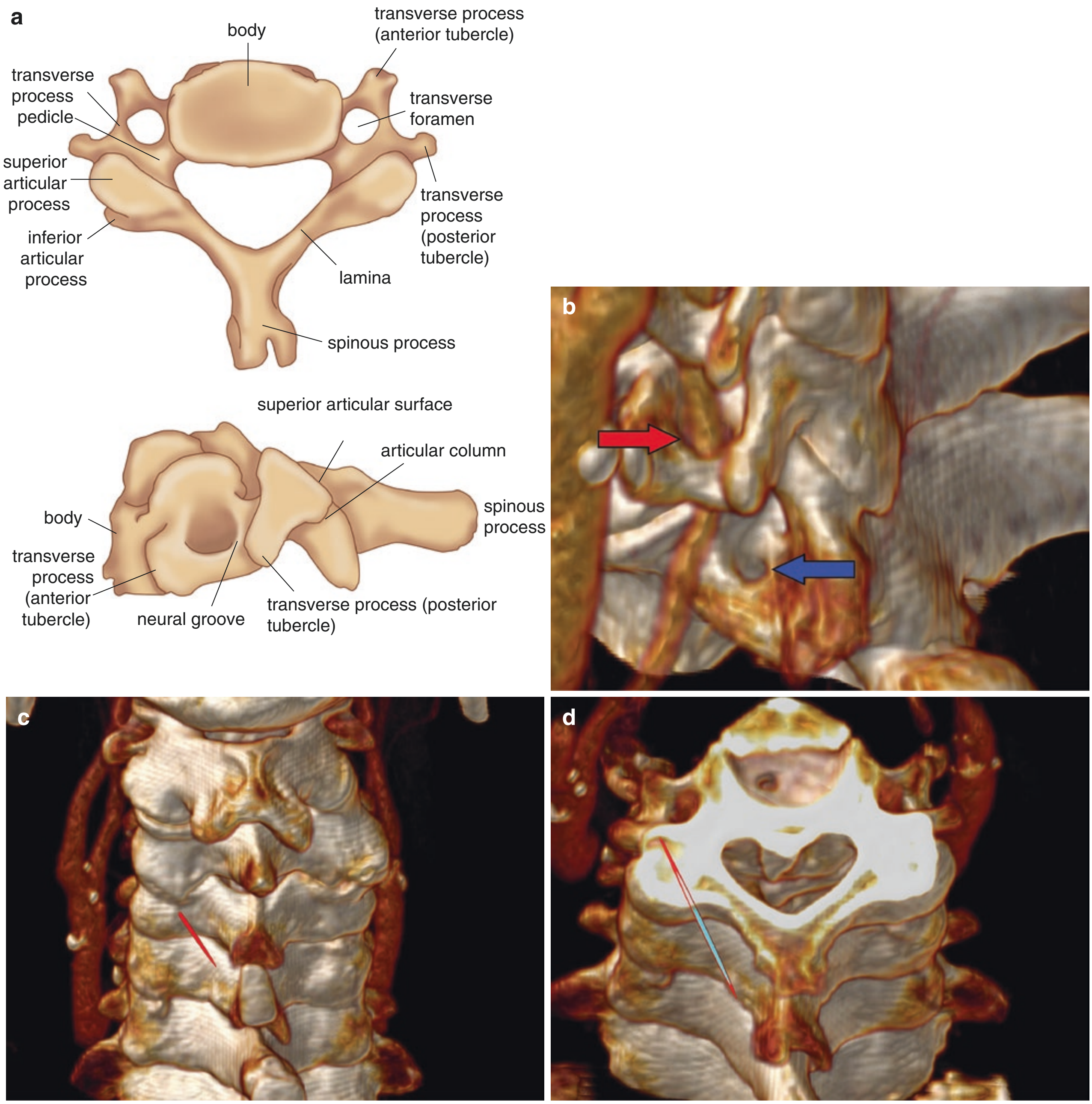

Fig. 1.5 (**a**) Schematic diagrams of AP and lateral views of a lower cervical vertebra, showing the structure of the transverse foramen. (**b**) The transverse foramina of the sixth and seventh cervical vertebra: The red arrow indicates the vertebral artery passing through the transverse foramen of the sixth cervical vertebra; the blue arrow indicates the transverse foramen of the seventh cervical vertebra without any vertebral artery passage. (**c–g**): The fourth cervical vertebra is used as an example to display the method for lateral mass screw placement in the lower cervical spine: (**c**) The entry point of the lateral mass screw is 2 mm medial to the center of the rectangular area that is lateral to the junction of the vertebral lamina and lateral mass and between the superior and inferior articular facets. (**d**) The near-cross-section of C2 along the direction of the guide wire: The screw is inclined laterally 20°–25° to avoid damaging the vertebral artery. (**e**) The near-sagittal plane of the C4 lateral mass along the direction of the guide wire: The screw is inclined to the head side 30–40°. (**f**, **g**) Reconstructed X-ray CT image showing the guide wire positions. (**h–j**) The seventh cervical vertebra is used as an example to show the method for pedicle screw placement of the lower cervical spine: (**h**) The entry point of the pedicle screw is lateral to the midpoint of the lateral mass and close to the lower edge of the inferior articular process of the above vertebral body. (**i**) The cross-section of the C7 vertebral body along the direction of the guide wire showing that the pedicle screw should be placed at a convergence angle from 25° to 45°. (**j**) Reconstructed X-ray CT image showing the guide wire positions

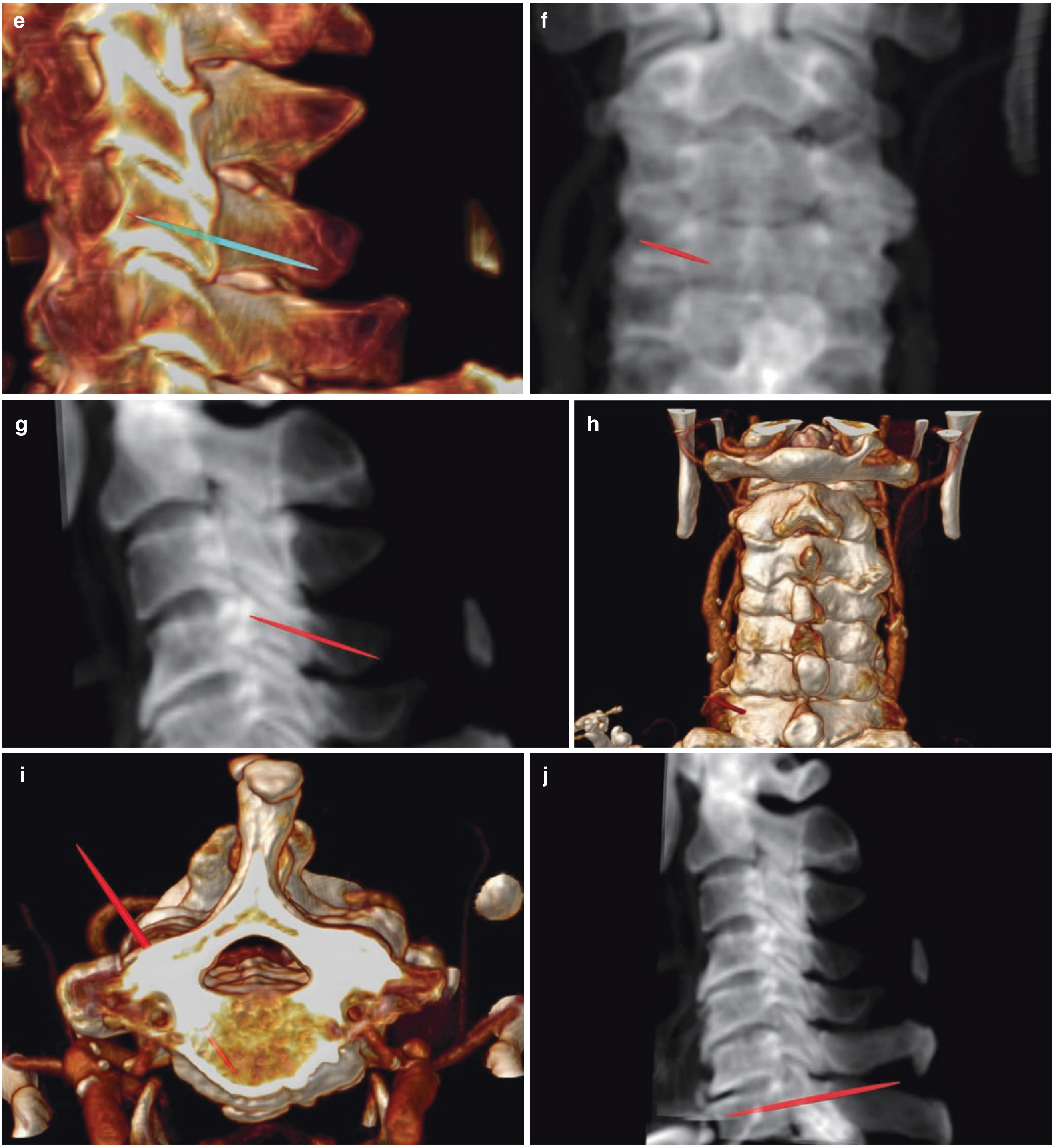

Fig. 1.5 (continued)

process is the anterior tubercle of the transverse process.

The dorsal part is the actual transverse process, and its relatively flat end forms the posterior tubercle of the transverse process.

The vertebral artery travels between the anterior and posterior tubercles, and the costotransverse bar is located at its lateral aspect.

Generally, no vertebral artery travels in the transverse foramen of C7.

– The lateral mass:

The lateral mass is an enlarged bony structure between the superior and inferior articular processes. Because the vertebral artery travels in the transverse foramen, it is difficult to place a pedicle screw; instead, the lateral mass screw technique is safer and thus often used to secure the lower cervical spine.

The Magerl technique is often used for lateral mass screw placement (Heller et al. 1991; Xu et al. 1998), which is briefly described as follows:

- The entry point of the lateral mass screw is 2 mm medial to the center of the rectangular area that is lateral to the junction of the vertebral lamina and lateral mass and between the superior and inferior articular facets.
- The lateral mass screw should be placed in the direction pointing to the head side at a 30–40° angle and biased laterally by 20–25°.

– The vertebral pedicle:

Because no vertebral artery travels in the transverse foramen of C7, it is safer to place a pedicle screw via the vertebral pedicle of C7 than via that of C3–6.

The pedicle screw entry point is slightly lateral to the center of the lateral mass and close to the lower rim of the inferior articular process of the above vertebra.

The pedicle screw should be placed at a convergence angle of 25–45°.

1.1.3 Mechanism of Injury

- Direct violent force: Cervical spine fractures are rarely caused by direct violence.
- Indirect violent force: This is relatively common. The violent force applied on the head, foot, and hip is longitudinally transmitted to a particular cervical spinal segment and causes a vertebral fracture and dislocation. There are five types of forces according to the direction acted on by the force:
  – Vertical compressive forces: An axial violent force parallel to the spine acts on the vertebra. A representative is the C1 Jefferson fracture (Bozkus et al. 2001; Jefferson 1920).
  – Compressive hyperflexion forces: The violence acts on the flexed spine and causes a compression of the vertebra, which might even be associated with dislocation or interlocking of the facet joints.
  – Compressive hyperextension forces: The violence acts on the backward extended spine and damages the anterior longitudinal ligament and posterior osteoligamentous complexes.
  – Compressive lateral shear forces: A force acting on the side of the vertebra causes unilateral injuries of the vertebra and facet joints.
  – Compressive rotary forces: A violence acting on the rotated spine causes a spine fracture, which is often accompanied by other types of injuries, as described above.

1.1.4 Fracture Classification

- Classification of upper cervical spine injuries
  – Levine classification of atlas fractures (Levine and Edwards 1985) (Fig. 1.6).

    Type I: Isolated fractures of the protuberant components of the atlas.

    Type II: A single fracture of the posterior arch, which is stable and usually a compressive hyperextension injury.

    Type III: A single fracture of the anterior arch, which is stable and usually a compressive hyperflexion injury.

    Type IV: A lateral mass fracture of the atlas. The fracture line often crosses the lateral mass joint from anterior to posterior. The open-mouth view can demonstrate whether the bilateral atlantoaxial complexes are separated and asymmetric.

    Type V: Atlas burst fractures. Typically, the patients have two fracture sites in the anterior arch, two in the posterior arch, and probably a lateral mass facture. A finding of bilateral lateral displacements larger than 6.9 mm might suggest that the transverse ligament is ruptured and that both the atlas and axis are unstable.
  – Classification of axis fractures: The Anderson classification is the most commonly used method for odontoid fractures (Grauer et al. 2005) (Fig. 1.7).

    Type I: Avulsion fractures of the odontoid tip, which is the attachment point of the alar ligament.

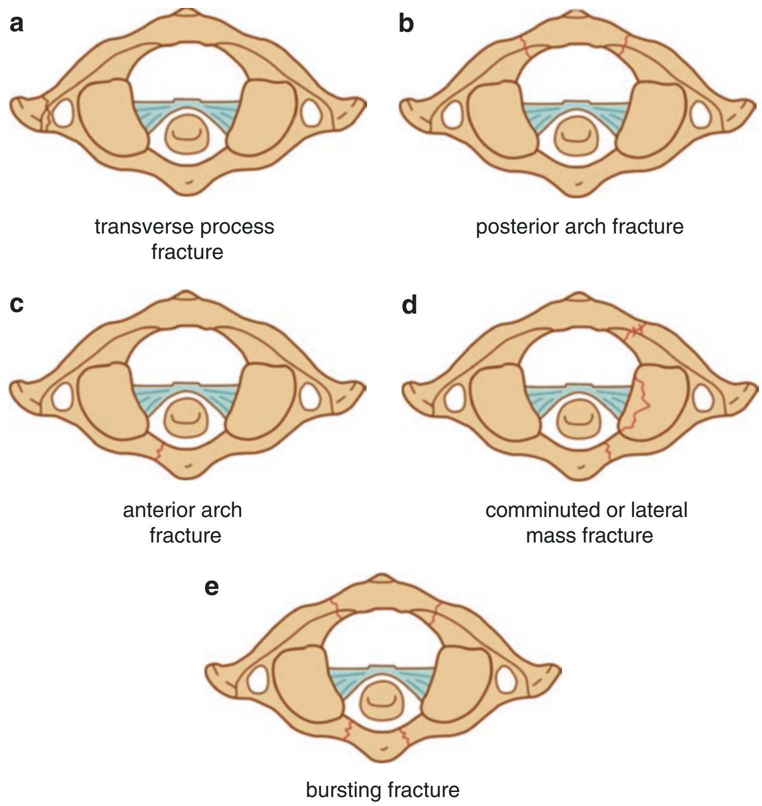

Fig. 1.6 Levine classification of atlas fractures. (**a**) Transverse process fracture. (**b**) Posterior arch fracture. (**c**) Anterior arch fracture. (**d**) Comminuted or lateral mass fracture. (**e**) Burst fracture

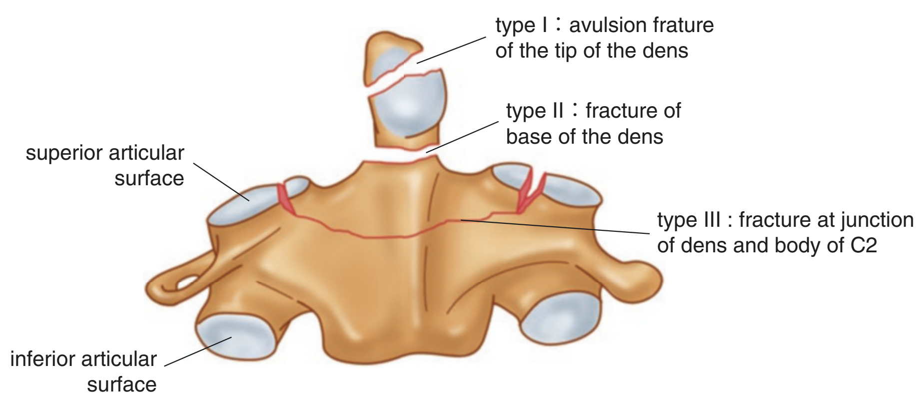

Fig. 1.7 Anderson classification of odontoid fractures

Type II: Fractures of the base of the odontoid process, which has a poor blood supply and little cancellous bone in the cross-section. This type of fracture is difficult to heal, and the healing rate further declines when there is an angulation deformity or a displacement larger than 4 mm.

Type III: Fractures with a fracture line extending to the vertebral body of the axis. Oblique fractures have a high healing rate.

– Traumatic spondylolisthesis of the axis (hangman's fracture): A hangman's fracture refers to a fracture occurring in the junction area of the superior and inferior articular processes of the axis, which is primarily classified using the classification system proposed by Levine and Edwards (Levine and Edwards 1985) (Fig. 1.8).

Type I: Fractures without angulation and with forward slippage <3 mm

Type II: The anterior displacement of the axis is >3 mm or with angulation

Subtype IIa: Hyperflexion traction injuries, in which the axis has severe angulation with the intact anterior longitudinal ligament as a hinge and relatively slight displacement. For this type of fracture, traction is contraindicated because it might lead to displacement deterioration.

Type III: Bilateral vertebral pedicle fractures associated with articular process displacement or inter-

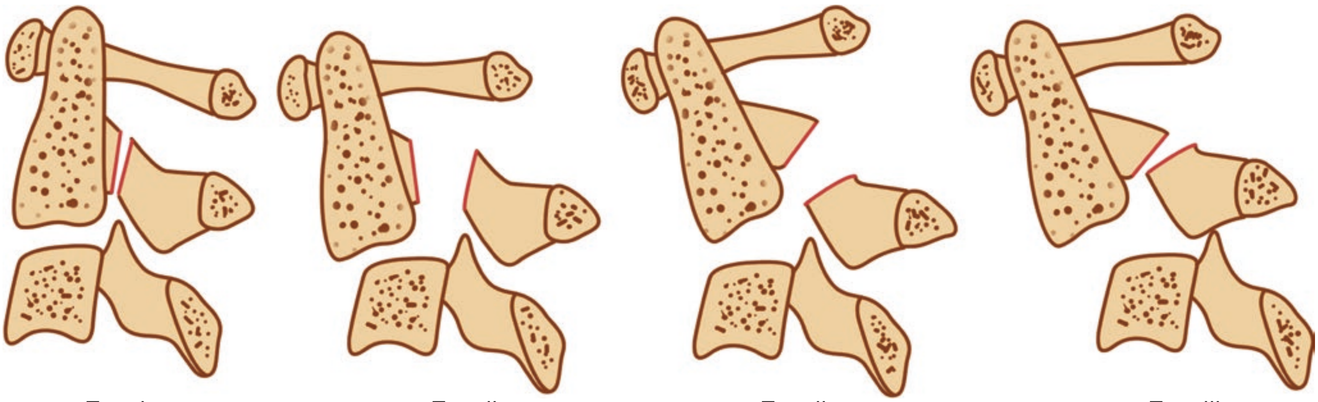

Fig. 1.8 Classification of traumatic spondylolisthesis of the axis

Table 1.2 Classification and severity score of lower cervical spine injury

Characteristics	Points
Injury morphology	
No abnormality	0
Compression	1
Burst	2
Distraction	3
Translation	4
Integrity of the disco-ligamentous complex	
Intact	0
Indeterminate	1
Disrupted	2
Neurological status	
Intact	0
Nerve root injury	1
Complete	2
Incomplete	3
Persistent cord compression	+1

SLIC Subaxial Injury Classification

locking. This type of fracture is highly unstable and often associated with spinal cord damage.

- Classification of lower cervical spine injuries: Lower cervical spine injuries are scored using the SLIC system (Vaccaro et al. 2007) based on the injury severity (Table 1.2).
  - For fractures with an SLIC score < 4, non-surgical treatment is recommended.
  - For fractures with an SLIC score ≥ 5, surgical treatment is recommended.
  - Fractures with an SLIC score of 4 (the cut-off level) can be treated either surgically or non-surgically.

1.1.5 Preoperative Assessment

- Clinical assessment:
  - Spine injuries are often caused by high-energy violence.
  - It is critical to first address the accompanying injuries that might be more life-threatening.
  - It is crucial to ensure airway patency and stability of the circulation system.
  - The consciousness state of the patient is evaluated (usually using the Glasgow scoring scale) (Table 1.3).
- Neurologic injury
  - The force-bearing of the spinal cord at the time of injury and its displacement determine the neurologic outcomes.
  - Neurologic deficits are correlated to but not completely consistent with the decrease in the cross-section area of the spinal canal.
  - Complete spinal cord injury:

    The sensory and motor functions and reflexes below the injured spinal segment are completely lost.

    Patients surviving a complete spinal cord injury of C3 or a higher level also lose most autonomous respiration function and rely on respirators.
  - Classification of incomplete spinal cord injuries (Fig. 1.9).

    Anterior cord syndrome: Patients have motor paralysis but normal deep and proprioceptive sensations.

    Posterior cord syndrome: Opposite to anterior spinal cord syndrome, the patients have normal motor function but lose deep and proprioceptive sensation.

    Central cord syndrome: It usually results from damage to the central gray matter and adjacent white matter of the spinal cord and affects the arms more than the legs.

Table 1.3 Glasgow Coma Scale score

Feature	Response
Best eye response	
Open spontaneously	4
Open to verbal communication	3
Open to pain	2
No eye opening	1
Best verbal response	
Orientated	5
Confused	4
Inappropriate words	3
Incomprehensible sounds	2
No verbal response	1
Best motor response	
Obeys commands	6
Localising pain	5
Withdrawal from pain	4
Flexion to pain	3
Extension to pain	2
No motor response	1

Glasgow score criteria is used to evaluate the state of consciousness of patients. Coma caused by severe brain injury is considered when GSC ≤ 8; moderate brain injury is considered when GSC is 9–12; mild brain injury is considered when GSC is 13–15

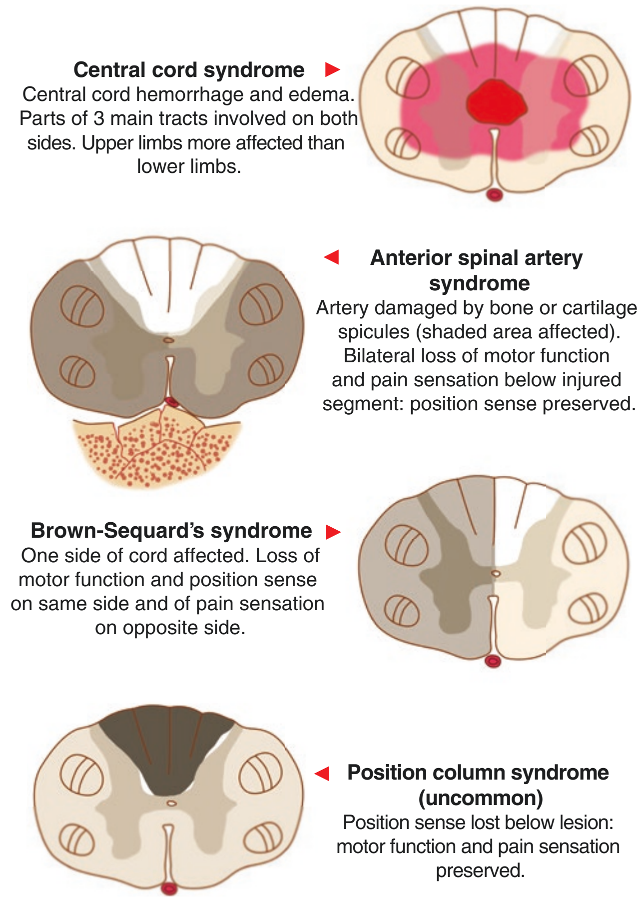

Fig. 1.9 Types of incomplete spinal cord injury: central cord syndrome, anterior spinal artery syndrome, Brown-Sequard syndrome, and posterior cord syndrome

Brown-Sequard syndrome: Movement and position sensation are lost below the level of injury on the injured side. Pain and temperature sensation are lost on the side of the body opposite the injury.

Anterior spinal artery syndrome: Movement and pain sensation are lost while the position sensation is preserved below the level of the injury.

- Neurologic examination:
  - Sensory function:

    Temperature and touch sensations are examined according to the segmental distribution of the cutaneous nerves.

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

    A sensory dermatome body map corresponding to the spinal segments is presented in Fig. 1.10.
  - Motor function:

    The motor function of both the upper and lower extremities is examined, including testing the strength of the muscle groups and comparing the left and right sides.

    The corresponding relationship between the common movements of the upper and lower extremities and the spinal segments is demonstrated in Fig. 1.11.
  - Reflex tests (Fig. 1.12).
- The American Spinal Injury Association (ASIA) scoring scale (Maynard Jr et al. 1997): Imaging assessment
- Radiographs:
  - Cervical AP and lateral radiography.
  - Lateral radiography:

    A sufficient lateral radiograph includes the area from the basis cranii to the T1 vertebra. For patients who have a short neck, the lower cervical spine can be included in the film by pulling the upper arm downwards. Complete overlapping of the joints and mandibular condyles between the left and right sides indicates that the lateral film is taken from an appropriate angle.

    The alignment of all cervical vertebrae is observed to determine whether the following lines are smooth: anterior vertebral body line, posterior vertebral body line, spinous process-vertebral lamina line, and spinous process line. The continuity loss

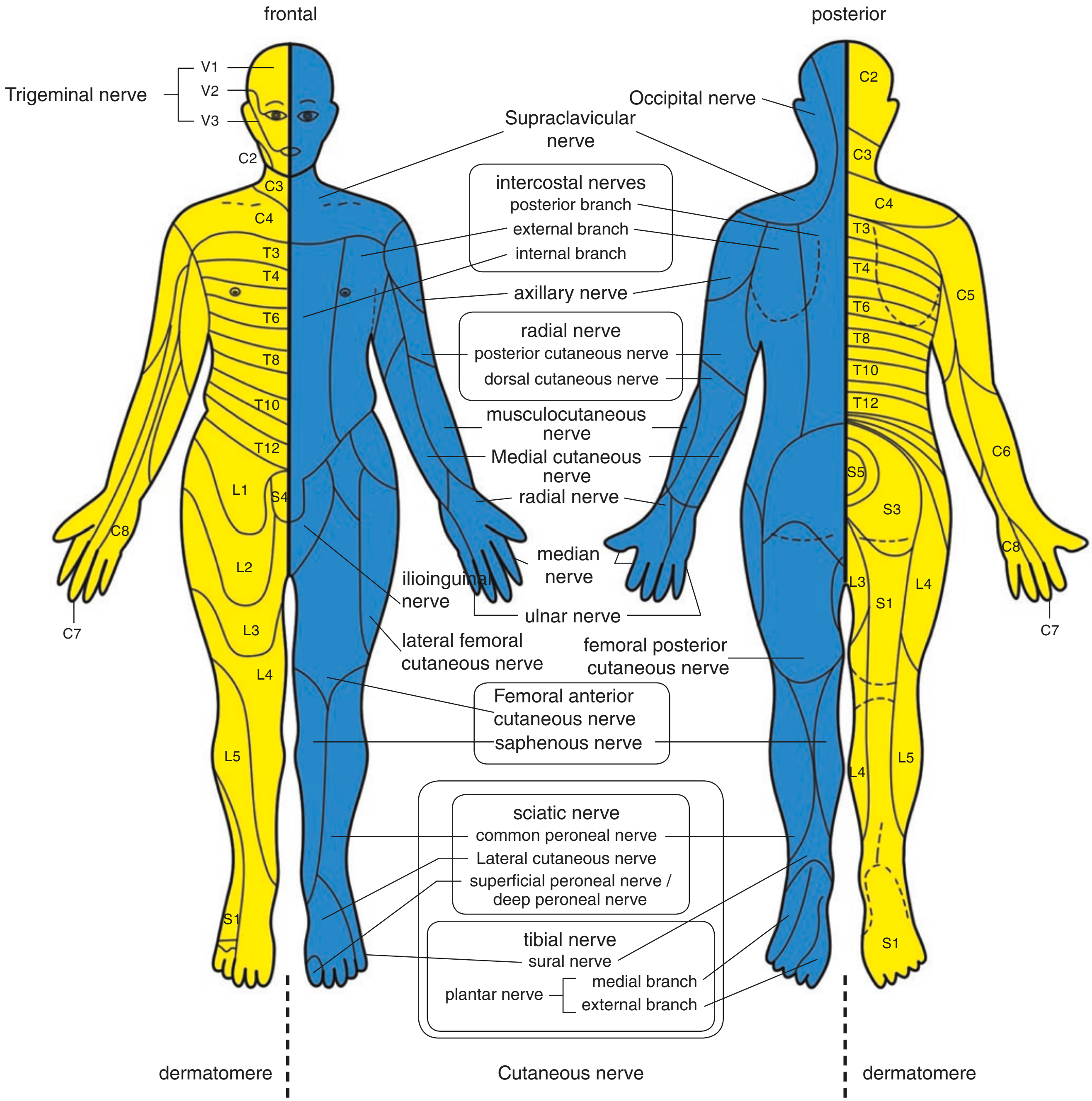

Fig. 1.10 A sensory dermatome body map corresponding to the spinal segments: The commonly used levels include the T4-nipple, T6-the xiphoid process, T10-navel, and T12-the pubic symphysis

of any of these lines indicates a bone fracture or ligament damage (Bucholz and Court-Brown 2010).

Assessment of the occipito-atlantal joint: In the lateral view, normally the odontoid process should not posteriorly pass the extending line of the slope of the occipito-atlantal joint, i.e., the Wackenheim line. The normal Power's ratio, which is the ratio of the distance between the anterior edge of the foramen magnum and the posterior arch of the atlas relative to the distance between the anterior arch of the atlas and the posterior edge of the foramen magnum, should be <1 (Bono et al. 2007).

Assessment of the atlantoaxial joint: An important parameter is the space between the atlas and the odontoid process, which is measured as the distance between the posterior edge of the anterior arch of the atlas and the ventral surface of the odontoid pro-

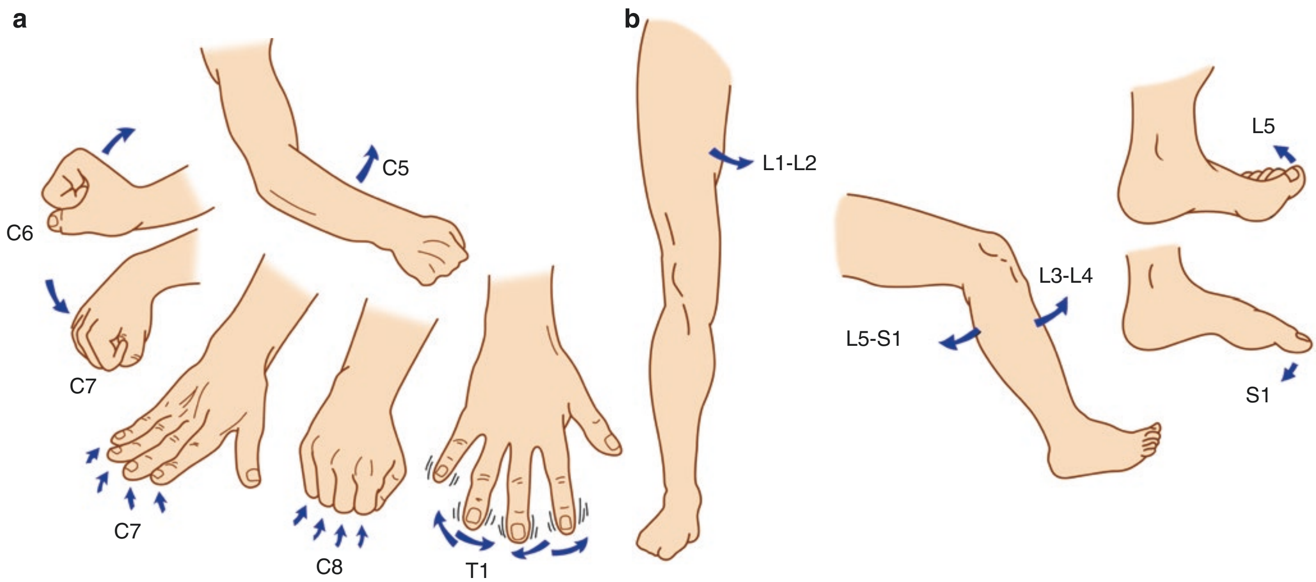

Fig. 1.11 (**a**) The segmental relationship of the spinal cord to the muscle groups for motor function of the upper extremity: C5 for elbow flexion, C6 for wrist extension, C7 for finger extension, C8 for finger flexion, and T1 for finger abduction. (**b**) The segmental relationship of the spinal cord to the muscle groups for motor function of the upper extremity: L1–L2 for hip abduction, L3–4 for knee extension, L5–S1 for knee flexion, L5 for hallux dorsiflexion, and S1 for hallux plantar flexion

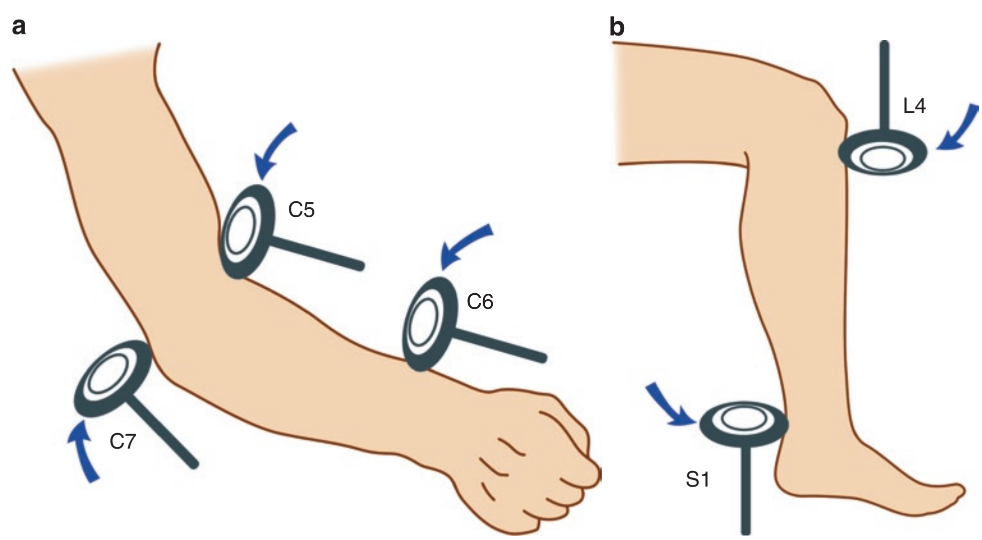

Fig. 1.12 (**a**) The segmental relationship of the spinal cord to the reflexes of the upper extremity: C5 for the biceps reflex, C7 for the triceps reflex, and C6 for the radioperiosteal reflex. (**b**) The segmental relationship of the spinal cord to the reflexes of the lower extremity: L4 for the knee-jerk and S1 for the Achilles tendon reflex

cess. This parameter is normally <3 mm in adults and < 5 mm in adolescents (Bono et al. 2007).

Assessment of the lower cervical spine: The below changes suggest instability of the cervical spine:

- In radiographs obtained in the flexion-extension position, the medial rotation angle is >20° in the sagittal plane.
- In radiographs obtained in the flexion-extension position or neutral position, the displacement of the vertebra is >3.5 mm or 20% of the width of the vertebra in the sagittal plane (White and Panjabi 1990).
- In radiographs obtained in the neutral position, the angle difference (White and Panjabi 1990), which represents the difference in angulation of the vertebral laminae between two adjacent vertebral segments, is >11°.
- In the sagittal plane, the diameter of the spinal canal is <13 mm or the Pavlov ratio (the ratio of the spinal canal diameter to the width of the vertebral body) is <0.8.

An anterior wedge-shaped vertebral compression deformity can cause local kyphosis.

The widening of the inter-spinous-process space suggests a hyperflexion traction injury.

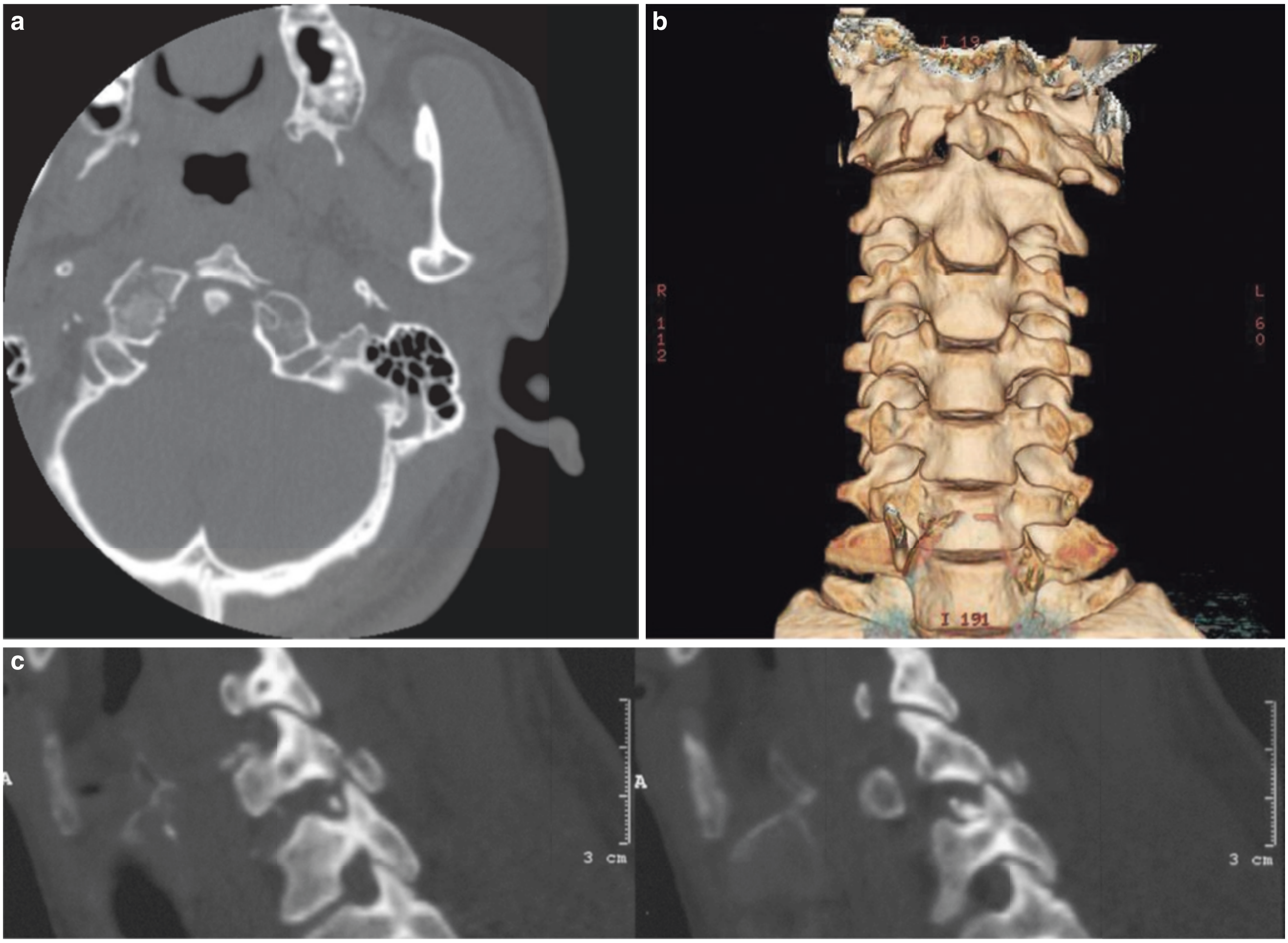

Fig. 1.13 (**a**) Preoperative CT plain scan of a patient with an atlas fracture: The anterior arch of the atlas was fractured at two locations, and the right lateral mass was fractured. (**b**) The 3D reconstructed CT image of the same patient demonstrating the fracture dislocation stereoscopically and comprehensively. (**c**) The CT plain scan and 3D reconstructed image on the joint sagittal plane of another patient with cervical spine fracture and dislocation: joint interlocking can be displayed in detail

Attention should be paid to observing whether the soft-tissue shadows in the pharyngeal wall are thickened.

– AP radiography:

The question of whether the cervical vertebrae have any lateral displacement is addressed.

The asymmetric shadows of the vertebral pedicles between two sides suggest a rotational dislocation.

The widening of the shadow of a vertebral pedicle suggests burst of the vertebral body.

Attention should be paid to observing whether there is a transverse process fracture.

– Open-mouth radiography:

It helps examine fractures of the atlas and axis.

- CT (Daffner 2001) (Fig. 1.13):
  – It can be used to evaluate the bone mass damage in detail in multiple planes and sections.
  – The structure at the junction of cervical and thoracic spine can be more clearly demonstrated.
  – Axial CT scans can be used to evaluate the severity of the space-occupying effect of intra-canal fragments in a burst fracture.
  – The sagittal reconstruction helps evaluate the damage to neural elements within the spinal canal caused by a vertebral dislocation.
  – It serves as the best technique for evaluating the vertebral pedicle, vertebral lamina, articular process, and transverse process.
- Magnetic resonance imaging (Katzberg et al. 1999) (MRI):
  – It can be used to precisely evaluate soft-tissue damage.
  – In the acute stage, the increased signal intensity of the spinal cord on T2-weighted images suggests spinal cord edema and hemorrhage.

– The ligaments are presented by low-intensity signals on T2-weighted images, and a disruption of the signals suggests ligament rupture.
– Acute intervertebral disc herniation is indicated by an increased signal intensity on T2-weighted images.

1.2 Surgical Treatment

1.2.1 Treatment Goals

- In patients with nerve compression, spinal cord decompression is performed to facilitate recovery of the damaged nerve.
- The displaced vertebra is returned to the normal position, and its alignment is well maintained.
- The spine is well secured, which allows the patient to stand up or sit up as early as possible and avoid being bedridden for a long duration.
- The severity of the deformity at the late stage can be reduced.
- Fewer vertebral segments need to be fused.
- Adverse events can be avoided as much as possible.

1.2.2 Surgical Indications

1.2.2.1 Atlas Fractures

- Patients with Type I, Type II, and Type III fractures primarily undergo conservative treatments of wearing a rigid neck support or external brace such as a halo vest.
- Type IV Jefferson fractures (Verheggen and Jansen 1998)
  – A fracture displaced <6.9 mm is fixed with a halo-vest brace for 3–4 months until it heals.
  – A fracture displaced >6.9 mm should first be reduced by cranial traction until it primarily heals and then immobilized by wearing a halo-vest brace.
  – For a fracture accompanied by spinal cord compression or an atlas-dens interval (ADI) >3.5 mm after healing, the C1 lateral mass screw technique via the posterior approach can be used, or even occipitocervical arthrodesis can be considered if necessary.

1.2.2.2 Odontoid Fractures (Greene et al. 1997; Kontautas et al. 2005)

- Type I fractures are stable and require only fixation with a neck support.
- Type II fractures are difficult to heal.
  – In elderly patients who can tolerant surgery, atlantoaxial arthrodesis via a posterior approach is performed at the early stage.
  – For young patients:

    A non-displaced fracture is fixed with a halo-vest brace for 6–12 weeks.

    Surgical treatment is recommended for displaced fractures.
    - Except for patients with a short neck, kyphosis of the upper thoracic spine, or barrel chest, the fracture can be fixed with odontoid screws via an anterior neck approach.
    - The fracture can be fixed with Magerl screws via a posterior approach, followed by posterior atlantoaxial arthrodesis.
- Type III fractures have a high healing rate, which can be reduced through traction and then immobilized by wearing a halo-vest brace or rigid neck support.

Traumatic Spondylolisthesis of the Axis (Hangman's Fracture) (Vaccaro et al. 2002; Coric et al. 1996)

- For most patients, the fracture can be treated with immobilization by wearing a halo-vest brace or rigid neck support for 6–12 weeks.
- Type II fractures associated with severe angulation and type III fractures associated with C2–3 intervertebral disc rupture or facet joint dislocation can be treated with anterior C2–3 arthrodesis, posterior C1–3 arthrodesis, or C2 pedicle screw fixation.

Lower Cervical Spine Injuries

- The severity of a lower cervical spine injury is scored using the SLIC system (Dvorak et al. 2007; Patel et al. 2010).
  – An injury score < 4 can be treated with immobilization by wearing a halo-vest brace or rigid neck support for 6–12 weeks.
  – For an injury score ≥ 5, surgical treatment is recommended.
  – For an injury score of 4 (a cutoff score), either surgical or non-surgical treatment can be considered.
  – Compression/burst injuries are usually treated via a simple anterior approach.
  – Injuries with a lateral/rotational displacement are usually treated via the posterior or combined anterior and posterior approach.

1.2.3 Surgical Techniques

1.2.3.1 Halo Brace Fixation (Boullosa et al. 2004; Mihara et al. 2001)

- Installation of the halo ring:
  – A halo brace should be installed under the condition that the neck support is well secured.
  – The size of the halo ring is selected to allow a 1-cm distance between the ring and skin of the patient.

- The safe zone for anterior skull pin placement is 1 cm above and at the junction between the lateral and middle thirds of the ridge of the orbit, which is below the level of the maximal circumference of the skull and higher than the ears. The positions for of two posterior skull pins are roughly opposite to the two anterior pins. After the local skin is disinfected, the pins are placed under local anesthesia.
- The patient is instructed to close his or her eyes and relax the facial muscles.
- After all four pins are installed, they are gradually tightened in sequence until the ring is secured onto the skull.

- Vest installation:
  - The neck must be stabilized during installation of the vest.
  - The vest and connecting rods are installed.
- Adjustment of the rods:
  - The four rods are adjusted to ensure that the left and right sides are symmetric and the flexion and extension angles of the neck are appropriate.
  - The purpose of adjustment is to restore the normal alignment of cervical vertebrae and make the patient more comfortable without affecting the visual field and swallowing function.
  - After adjustment, all nuts are tightened, and then the neck support is removed.
- Follow-up and examination:
  - After the halo brace is installed, radiographs are obtained in the sitting position to ensure the positioning of the cervical spine.
  - Radiography and CT scanning should subsequently be regularly performed to monitor the healing of the fracture (Fig. 1.14).

1.2.3.2 Anterior Screw Fixation for Odontoid Fractures

- Body position and preoperative preparation:
  - The patient receives general anesthesia through nasotracheal intubation.
  - The patient lies supine and undergoes Mayfield head holder or halo traction for reduction of the displaced fracture.
  - Anatomical reduction must be achieved prior to internal fixation with a cannulated screw system.
  - The vertical distance between the lower mandible and sternum should be adequate. Before surgery, a Kirschner wire is placed on the side of the neck to test whether the manubrium would obstruct the screw placement. The position of the patient is adjusted to meet the requirement.
  - Screw placement should be performed under C-arm-aided AP and lateral radiography (Fig. 1.15).
- Operative incision according to the projection on the body surface: The Cloward incision at the C5 level (Fig. 1.16).
- Surgical approaches (Fig. 1.17):
  - After the subcutaneous tissue is fully dissociated, the platysma muscle is cut in the muscular fiber direction along the anteromedial edge of the sternocleidomastoid muscle.
  - The sternocleidomastoid muscle is pulled aside laterally, and then the thyroid is pulled medially along with the midline structure. After the carotid artery is identified by palpation, the pretracheal fascia is incised from the medial side of the carotid sheath. If necessary, the superior and inferior thyroid arteries can be ligated on one side.
  - After the tissue is further separated towards the pretracheal fascia until a white shiny structure is observed, the anterior longitudinal ligament, on the midline structure is exposed. An 8-mm-wide Hohmann hook is placed along the C2 lateral mass, and then the anterior longitudinal ligament is cut along the midline at the level of the C2–3 intervertebral disc. Through subperiosteal dissection, the anterior longitudinal ligament and longus colli muscle are dissociated and pulled aside, followed by tissue separation along the front surface of the spine up to the inferoanterior edge of the C2 vertebral body.
- Fracture reduction and fixation:
  - The entry point at the inferoanterior C2 vertebra is determined radiographically. Subsequently, under protection of the sleeve, two 1.25-mm Kirschner wires with the length of 200 mm are placed towards the posterior side of the odontoid tip on the sagittal plane inclining medially by 5° towards the midline on the coronal plane (Fig. 1.18).
  - Both AP and lateral radiographs are obtained to confirm that the Kirschner wires penetrate the cortex of the odontoid process along the correct direction.
  - After the depth measurements, a countersink drill is used to open the bone cortex at the lower edge of the C2 vertebra. The bone mass of the upper edge of the C3 vertebra is filed or nibbled out to an appropriate extent to avoid obstruction of the screw placement.
  - Under radiographic monitoring, two 3.5-mm self-tapping cannulated lag screws are screwed in place along the guide wires until they reach the cortex on the opposite side (Fig. 1.19). It is important to ensure that the guide wires are not bent and that the cannulated screwdriver is not obstructed. In addition, the guide wires must not be screwed in along with the cannulated

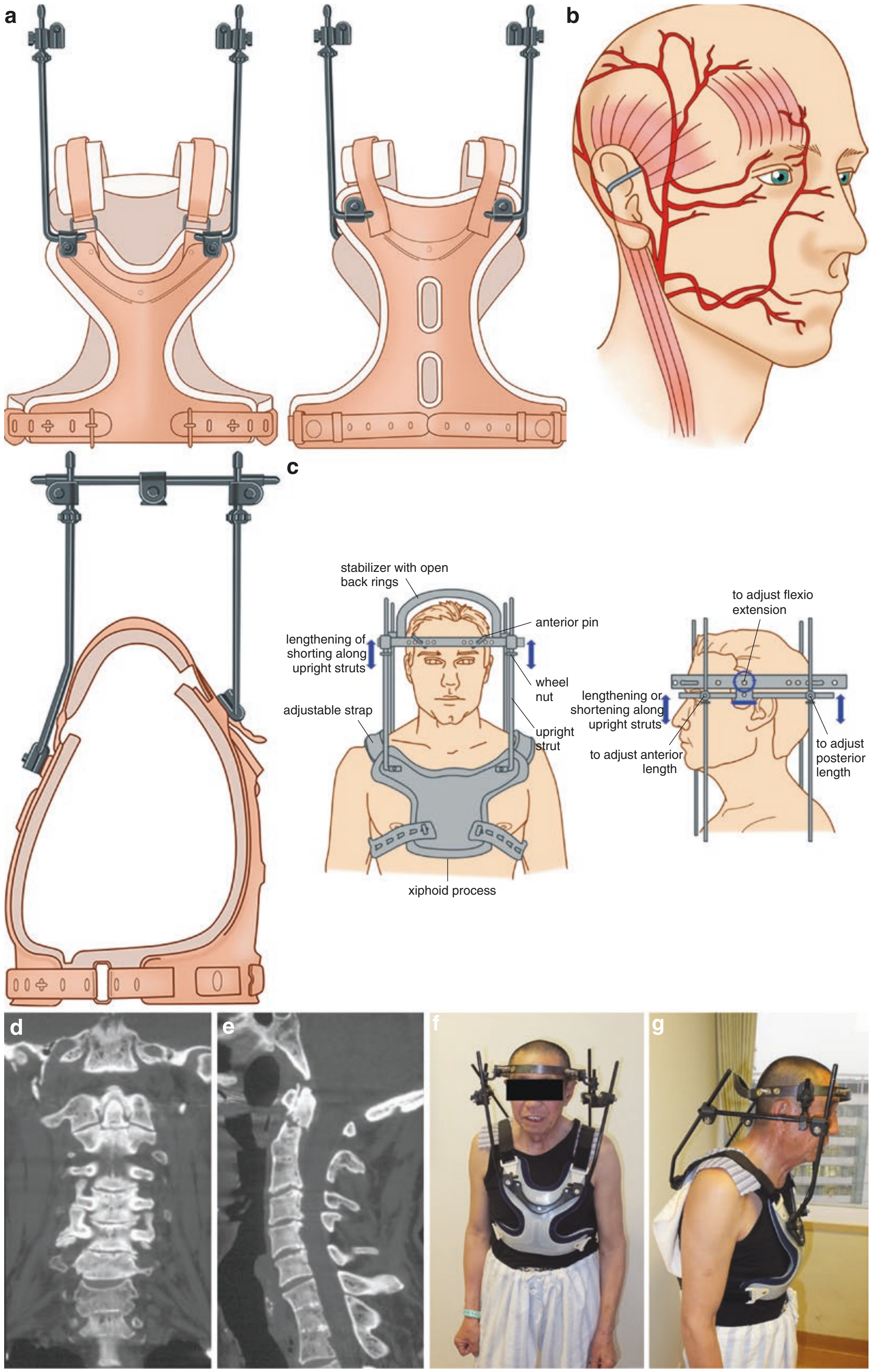

Fig. 1.14 (**a**) Structure of a halo brace: The halo brace consists of three parts: the vest, halo ring, and connecting rod. (**b**) The safe zone for anterior skull pin placement is 1 cm above and at the junction between the lateral and middle thirds of the ridge of the orbit, which is below the level of the maximal circumference of the skull and higher than the ears. (**c**) Schematic diagrams showing how to wear a halo brace: Neck flexion and extension can be controlled by adjusting the positions of the halo ring and connecting rods. (**d**–**g**) A patient with an Anderson type II odontoid fracture of the axis: (**d**, **e**) Coronally and sagittally reconstructed CT plain scans: The base of the odontoid process was fractured without obvious displacement. (**f**, **g**) AP and lateral photos of the patient wearing a halo brace

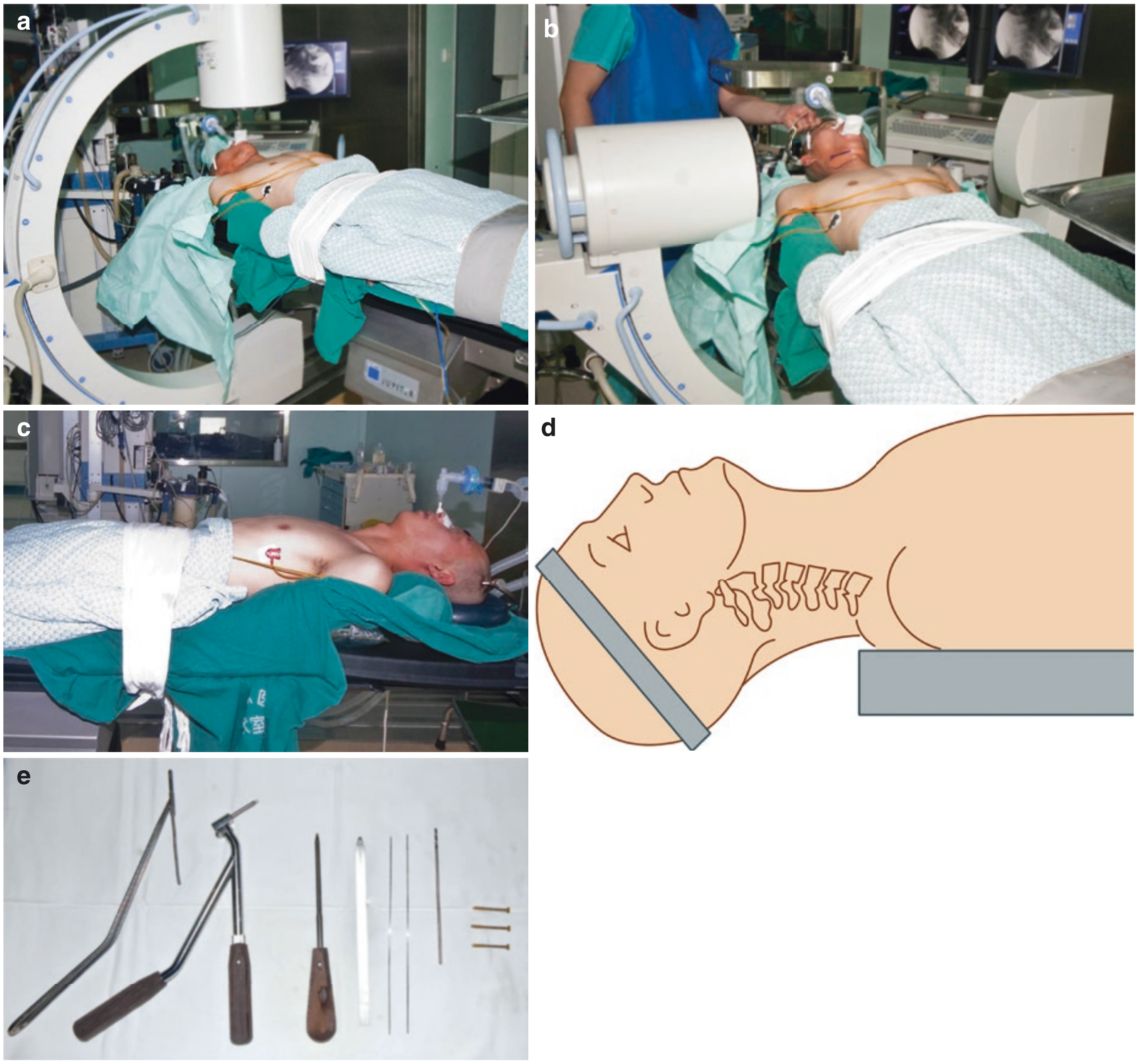

Fig. 1.15 (**a**, **b**) Body position of the patient and positioning of the C-arm device for AP and lateral fluoroscopy during surgery. (**c**, **d**) The patient lies supine with the head tilted backward. Before surgery, a Kirschner wire placed beside the neck is used as a reference for body position adjustment to ensure sufficient posterior extension of the neck under fluoroscopic monitoring, which would prevent the sternal manubrium from obstructing the guide wire placement. (**e**) Special tools and materials used for surgery (the guide wires have been trimmed)

Fig. 1.16 At the C5 level, an incision with a length of 6–7 cm is created along the direction of the dermatoglyphic pattern on one side (usually the right side if the surgeon is right-handed)

screws; otherwise, the damage to the medulla oblongata may cause sudden cardiac and respiratory arrest.

- Incision closure: The surgical field is cleansed, and the incision is sutured layer by layer after placing a drainage tube.
- Postoperative management:
  - The patient is kept in the ICU for 24 h after surgery. Special attention is paid to the presence of difficult breathing caused by hematoma formation and laryngeal edema in the acute stage.
  - The patient wears a neck support for 6 weeks after surgery, particularly those with a superoposterior-to-inferoanterior fracture or osteoporotic patients.
  - Follow-up examinations are performed, and radiographs are obtained to monitor the healing progress (Fig. 1.20).

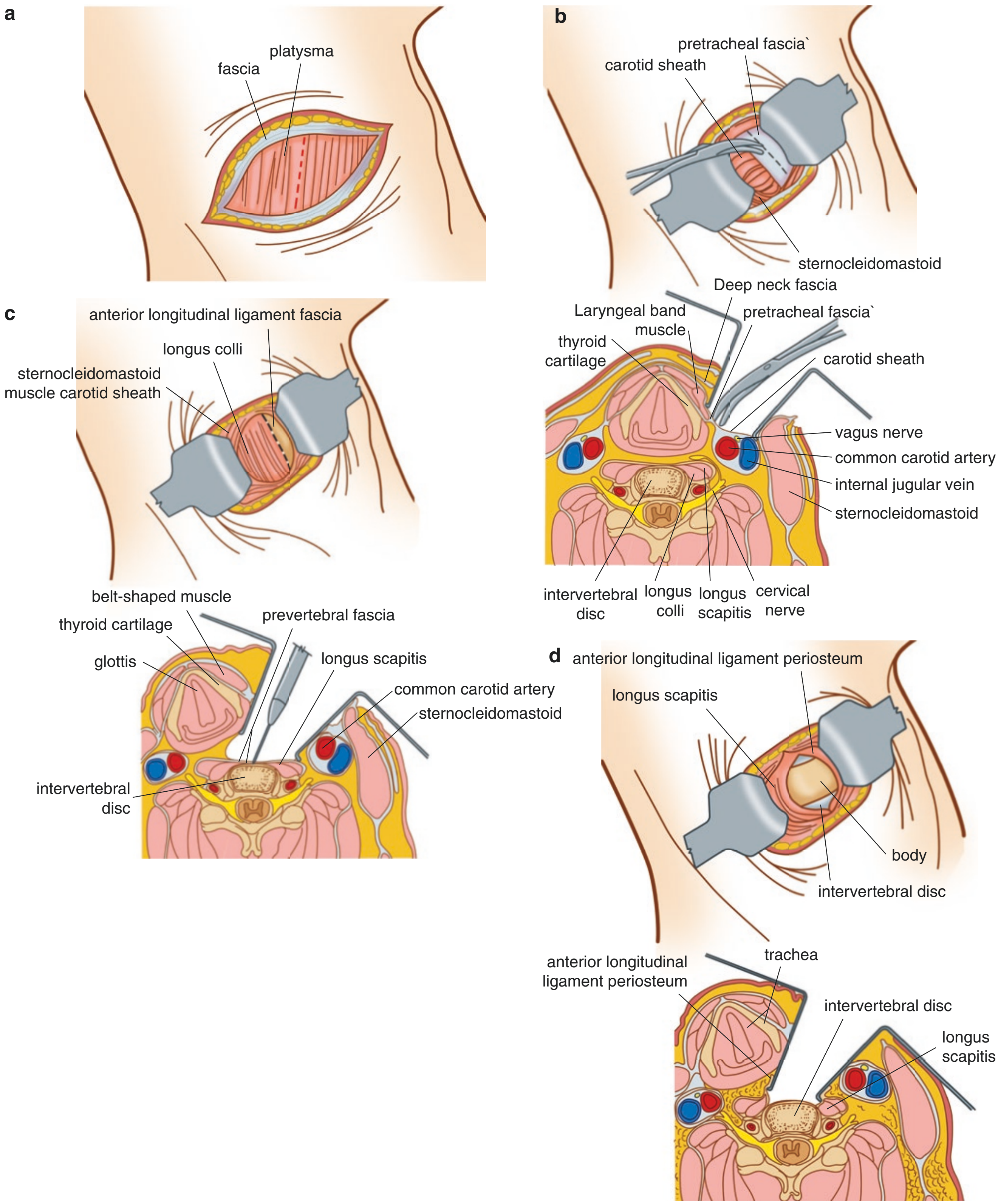

Fig. 1.17 (**a**) The skin, subcutaneous tissue, and platysma muscle are incised. The dotted line denotes the incision direction along the muscle fibers in the platysma. (**b**) The pretracheal fascia is incised from the medial side of the carotid sheath. (**c**) After the anterior longitudinal ligament and the cervical longus muscle of the anterior vertebral body are exposed, the anterior longitudinal ligament is incised horizontally at the level of the C2–3 intervertebral discs. (**d**) The anterior longitudinal ligament and the cervical longus muscle are incised to expose the inferoanterior edge of the C2 vertebral body. The superoanterior edge of C3 vertebral body should be nibbled out with a rongeur to avoid obstruction of the screw placement

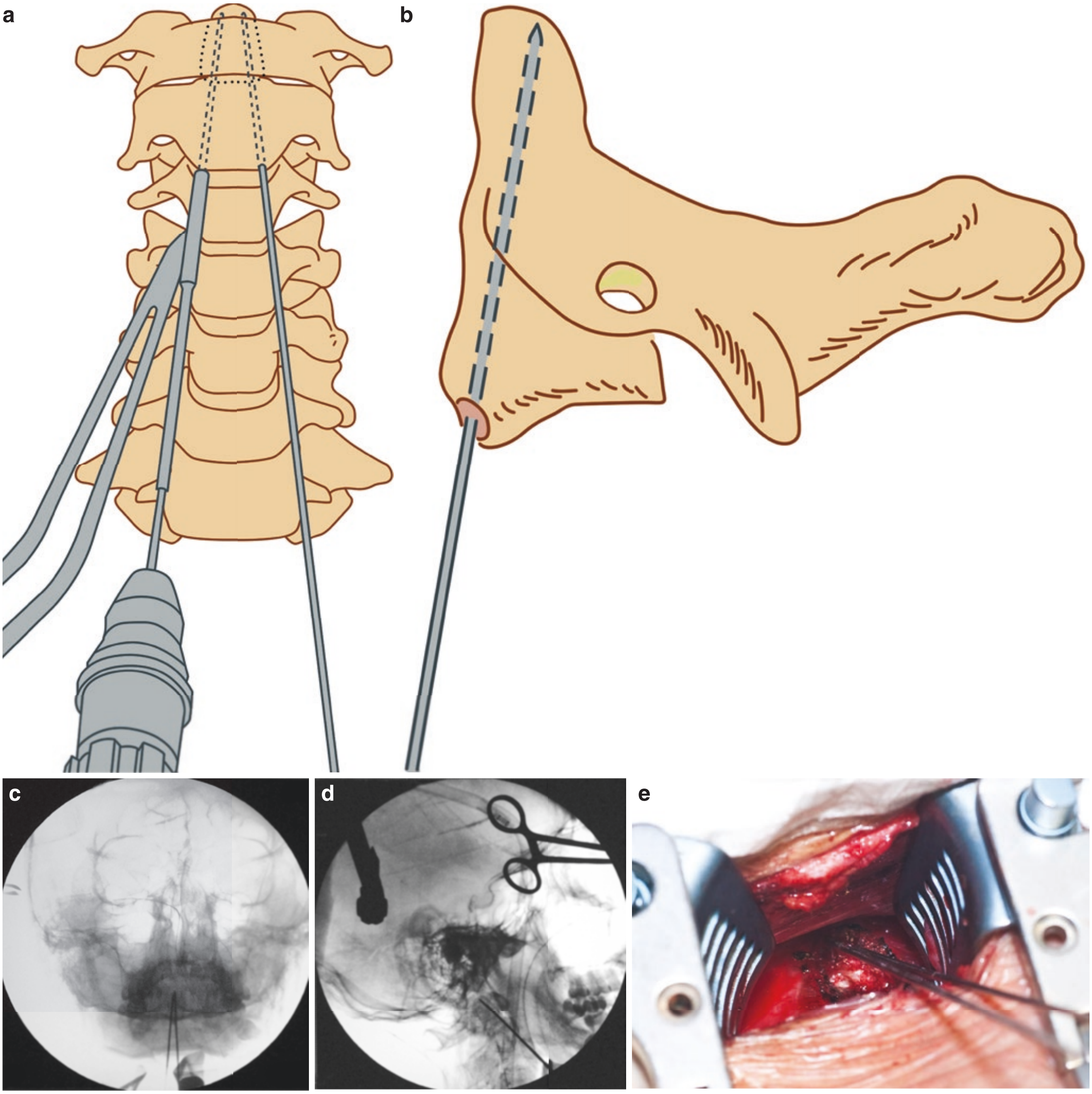

Fig. 1.18 Placement of guide wires for cannulated screw insertion. (**a**) AP view: Two guide wires are placed at a convergence angle of 5°. (**b**) Lateral view: The two guide wires should be placed from the inferoanterior edge of the C2 vertebral body to the superoposterior edge of the odontoid process. (**c**, **d**) Intraoperative fluoroscopy for examination of the guide wire positions. (**e**) An intraoperative photo showing the entry points and convergence angle of the two guide wires

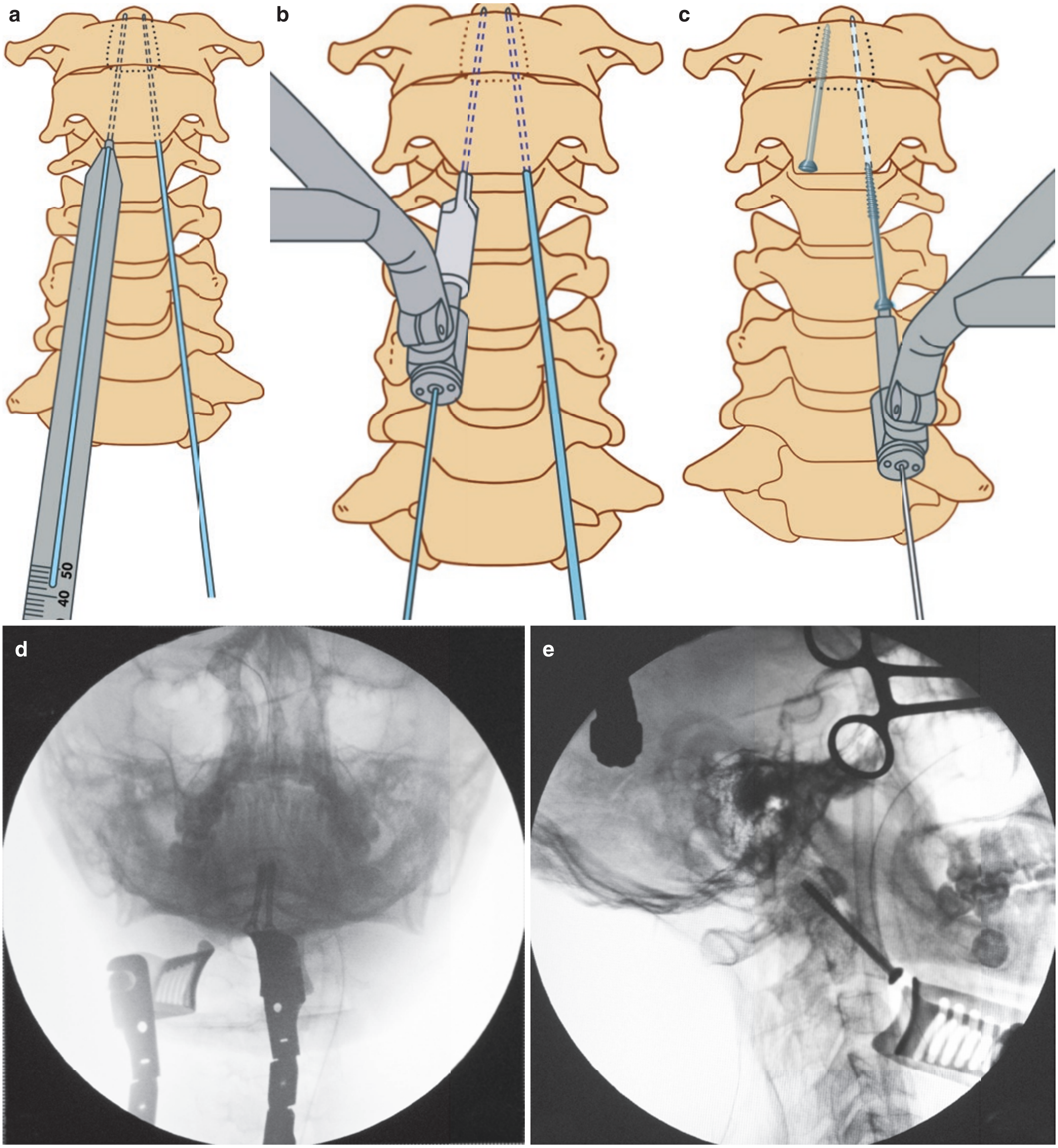

Fig. 1.19 (**a**) Depth measurement with a caliper. (**b**) The lower edge of the C2 vertebral body is opened using a countersunk drill. (**c**) The cannulated screws are screwed along the guide wire sequentially. (**d**, **e**) Under AP and lateral radiographic monitoring, two 3.5 mm self-tapping cannulated screws are screwed in place along the guide wires

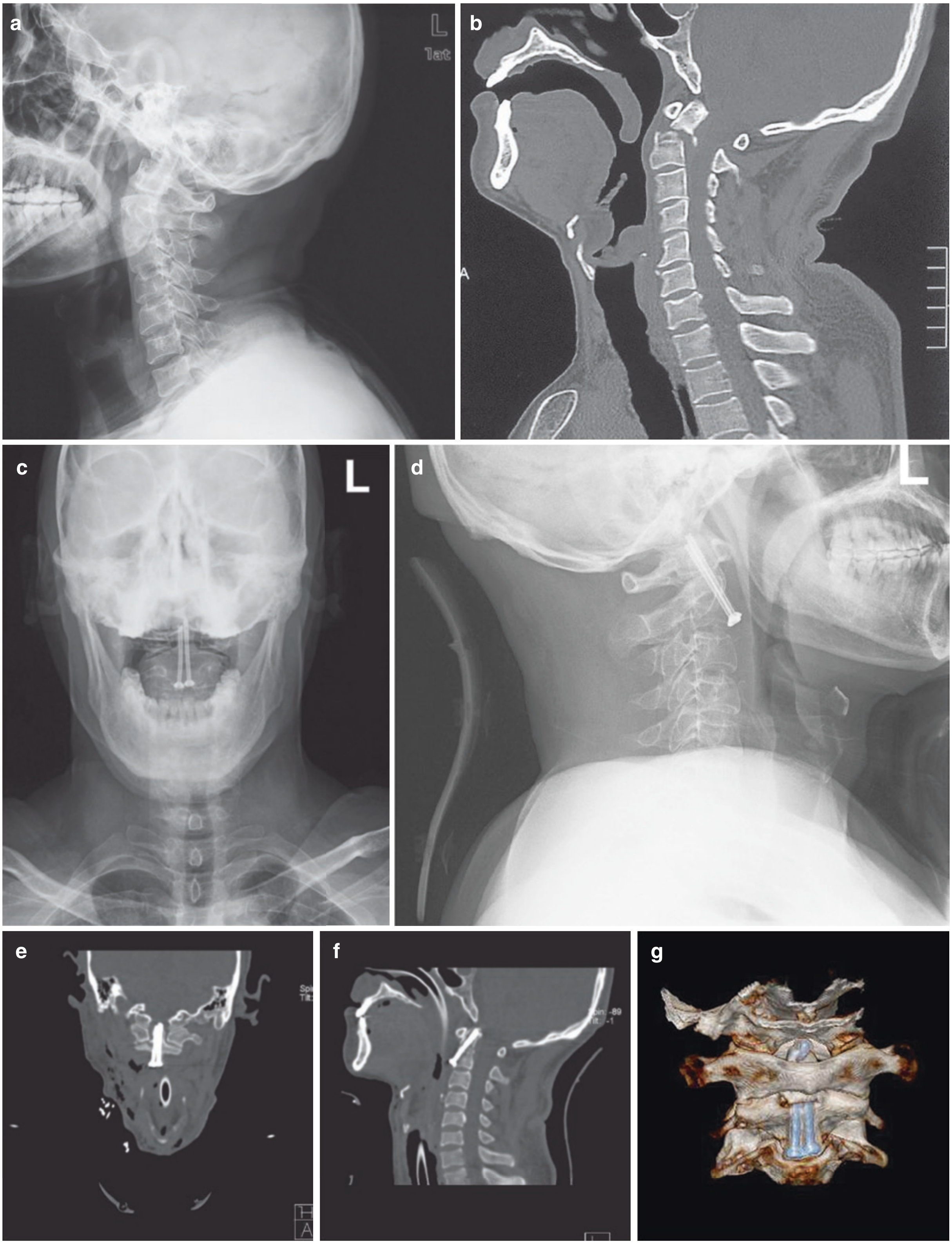

Fig. 1.20 Internal fixation with a cannulated screw for an odontoid process fracture (**a**) A preoperative lateral radiograph: The odontoid process was fractured, and the atlas was dislocated posteriorly. (**b**) Preoperative sagittally reconstructed CT plain scans: There was a transverse fracture at the base of the odontoid process, which belonged to an Anderson type II fracture. (**c**, **d**) Radiographs at the open-mouth and lateral positions after anterior screw fixation of the odontoid process fracture. (**e**) Postoperative reconstructed CT plain scan at the coronal plane of the screws: The screws in the odontoid process had a convergence angle of approximately 5° and reached the cortex on the opposite side. (**f**) Postoperative sagittally reconstructed CT plain scan: The screws were placed along the inferoanterior edge of the second vertebrae body and pointed to the edge of the superoposterior cortex of the odontoid process. (**g**) Postoperative 3D reconstructed CT image: The positional relationship between the reduced fracture and screws was stereoscopically displayed

1.2.3.3 Posterior C1 Lateral Mass Screw and C2 Pedicle Screw Fixation (Bransford et al. 2011)

- Body position and preoperative preparation:
  - Nasotracheal intubation is performed for general anesthesia.
  - The patient lies prone, with the head secured by a Mayfield skull clamp, and the clamp is attached to a Mayfield holder that is connected to the operating table.
  - The C-arm system and/or adjuvant CT scanning system are prepared for reduction quality examination of C1 and C2 during surgery (Fig. 1.21).
- Operative incision according to the projection on the body surface: A posterior neck midline incision with a length of 6–10 cm is created downwards along the external occipital protuberance (Fig. 1.22).
- Surgical approaches:
  - The fascia and nuchal ligament are dissected layer by layer from the posterior midline along the skin incision to expose the C1 posterior tubercle and C2 spinous process.
  - The paravertebral muscle is stripped off subperiosteally using a Cobb stripper. When stripping the area near the atlanto-occipital membrane between the atlas and the occipital bone, special attention should be paid to avoid mis-entering the spinal canal.

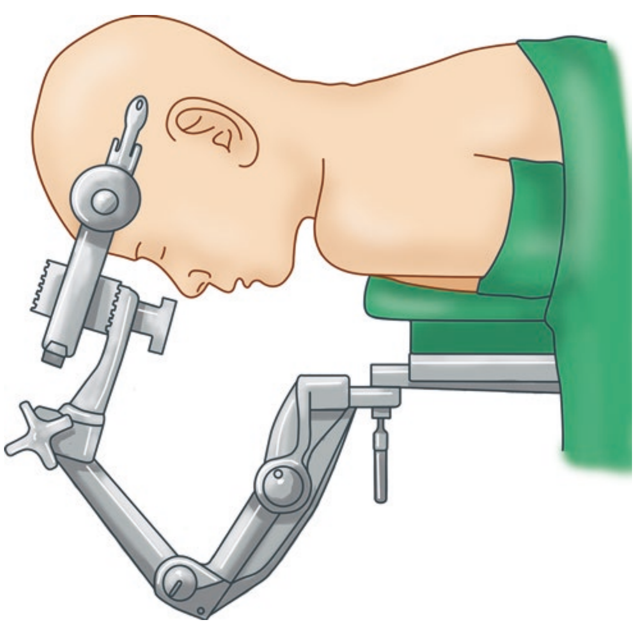

Fig. 1.21 The patient lies prone, with the head secured by a Mayfield skull clamp. The clamp is attached to a Mayfield holder that is connected to the operating table, which maintains the neck in a neutral position. Intraoperative positioning is performed with the aid of the C-arm or CT device

  - The C2 lateral mass is exposed with protection of the C2–C3 joint capsule.
  - When creating an access to the C2 isthmus and the C1–C2 joint capsule above, bleeding in the area near the venous plexus around the C2 nerve, which often occurs and is significant, can be controlled by bipolar electrocoagulation or the use of a gelatin sponge.
- Fracture reduction and fixation.
  - Because the entry point of the C1 lateral mass screw is above the venous plexus around the C2 nerve, the exposure operation often ruptures the venous plexus and causes bleeding. Therefore, it is recommended that the C2 pedicle screw be placed first.
  - C2 pedicle screw placement (Fig. 1.23):

    The first step is determining the entry points, which are the midpoints of the connecting lines of the superior and inferior articular facets that intersect the perpendicular line passing the center of the C2 articular process.

    The ligamentum flavum is pushed aside using a nerve stripper to expose the medial wall of the C2 vertebral pedicle. The needle entry direction is determined.

    A 2.5-mm drill bit is used to drill a path in an upward 20° inclination angle and a convergence angle of 20°–30° with the medial surface of the C2 vertebral pedicle as a landmark reference.

    An awl is used to open the cortex, and then a hand drill is used to create a path for screw placement.

    The integrity of the wall and end of the path is examined using a ball-tipped probe.

    After depth measurement, a screw with the desired length is screwed in place.
  - C1 lateral mass screw placement (Fig. 1.24).

    The C2 dorsal root ganglion is pushed towards the caudal side to expose the entry point of the C1 lateral mass screw, which is below the C1 vertebral lamina and above the C1/2 joint gap.

    After using a gelatin sponge to stop the bleeding from the venous plexus, a 2.5-mm hand drill is used to drill a hole along the direction medially inclined by 10° and upwardly inclined by 10–20° until both cortical layers are penetrated.

    The integrity of the wall and end of the channel is examined using a ball-tipped probe.

    After depth measurement, a 3.5-mm tapper is used for tapping.

    A multiaxial screw with the desired length is placed.
  - The length of the connection rod is measured and adjusted for further fracture reduction and compression or screw distraction, followed by nut locking.
  - The position of the internal fixator is confirmed by CT or the C-arm system during surgery.

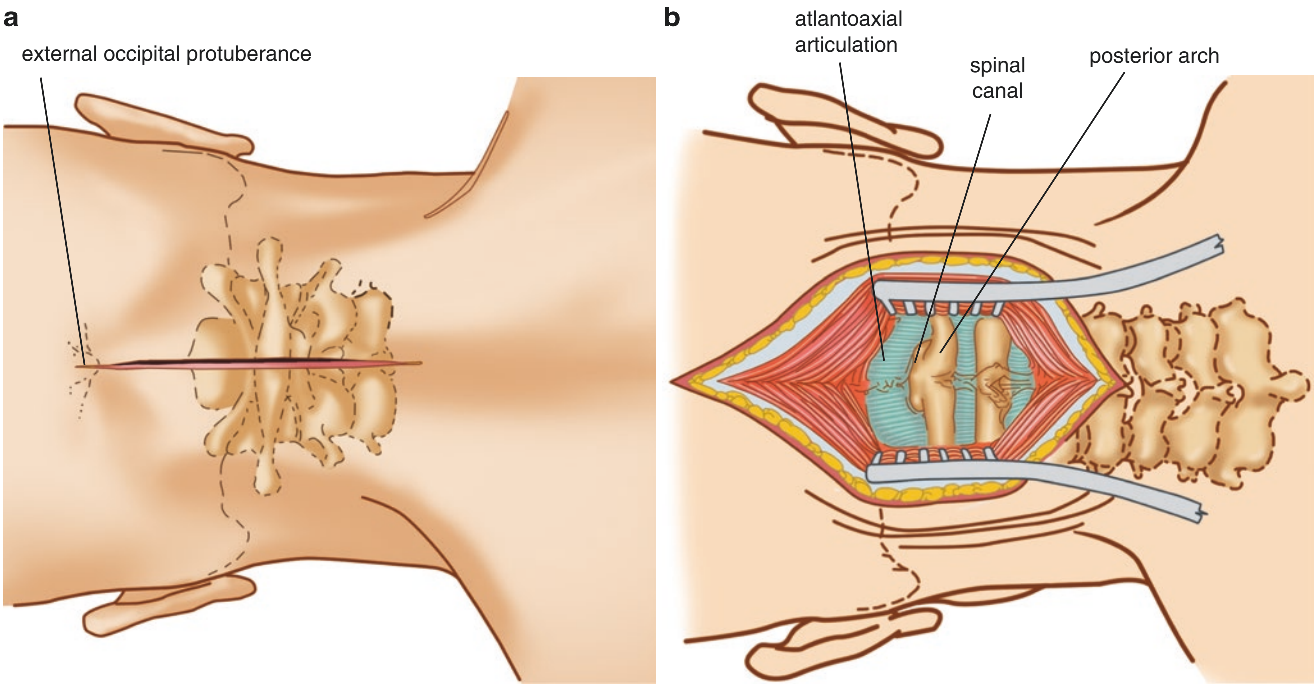

Fig. 1.22 (**a**) A posterior neck midline incision is generated downwards along the external occipital protuberance. (**b**) Tissue separation is performed layer by layer along the midline incision to expose C1–C2

- Incision closure: The surgical wound is cleansed and then sutured layer by layer after placing a drainage tube.
- Postoperative management: The patient is kept in the ICU for postoperative recovery. After 6 weeks of postoperative immobilization with a neck support device, radiographs are obtained to evaluate stability; if the position of the screw is questionable, CT scans should be obtained for confirmation (Fig. 1.25).

1.2.3.4 Posterior C3–C6 Lateral Mass Screw Fixation

- Body position and preoperative preparation:
  – The patient is given general anesthesia and endotracheal intubation.
  – The patient lies prone, with the head secured to the operating table by a Mayfield head holder.
  – To clarify the lateral view of the lower cervical spine under radiography, the arms and elbows of the patient are placed to closely contact the torso, and the shoulders are pulled downwards using rubber bands.
  – C-arm radiography is performed during surgery.
- Incision according to the projection on the body surface: A straight incision is created along the midline of the posterior neck from the center of the affected segment to the protrusion at the level of C7 (Fig. 1.26).
- Surgical approaches:
  – The fascia and nuchal ligament are dissected layer by layer until the spinous process along the midline of the posterior neck.
  – Closely along the periosteum, the deep muscles are stripped off from the spinous process to the lateral edge of the articular process using an electric knife.
  – The C3–C6 lateral masses are exposed with protection of the inferior joint capsule (Fig. 1.27).
- Fracture reduction and fixation:
  – Single-door vertebral laminar decompression and laminoplasty (Fig. 1.28):

    The spinous process should be removed with a bone rongeur; otherwise, the vertebral lamina might lose its “open” state and the muscles on the sides “close the door” after the incision is closed.

    A bone slot is generated at the border between the vertebral lamina and lateral mass on each side. On one side, a high-speed burr drill is first advanced downwards to grind the vertebral lamina and then towards the medial side to grind and remove the outer cortical layer, cancellous bone, and inner cortical layer.

    On the opposite side, a bone slot is created at the same site with only the outer cortical layer and cancellous bone being ground off, while the inner cortical layer is preserved as the “hinge” for “door opening.”

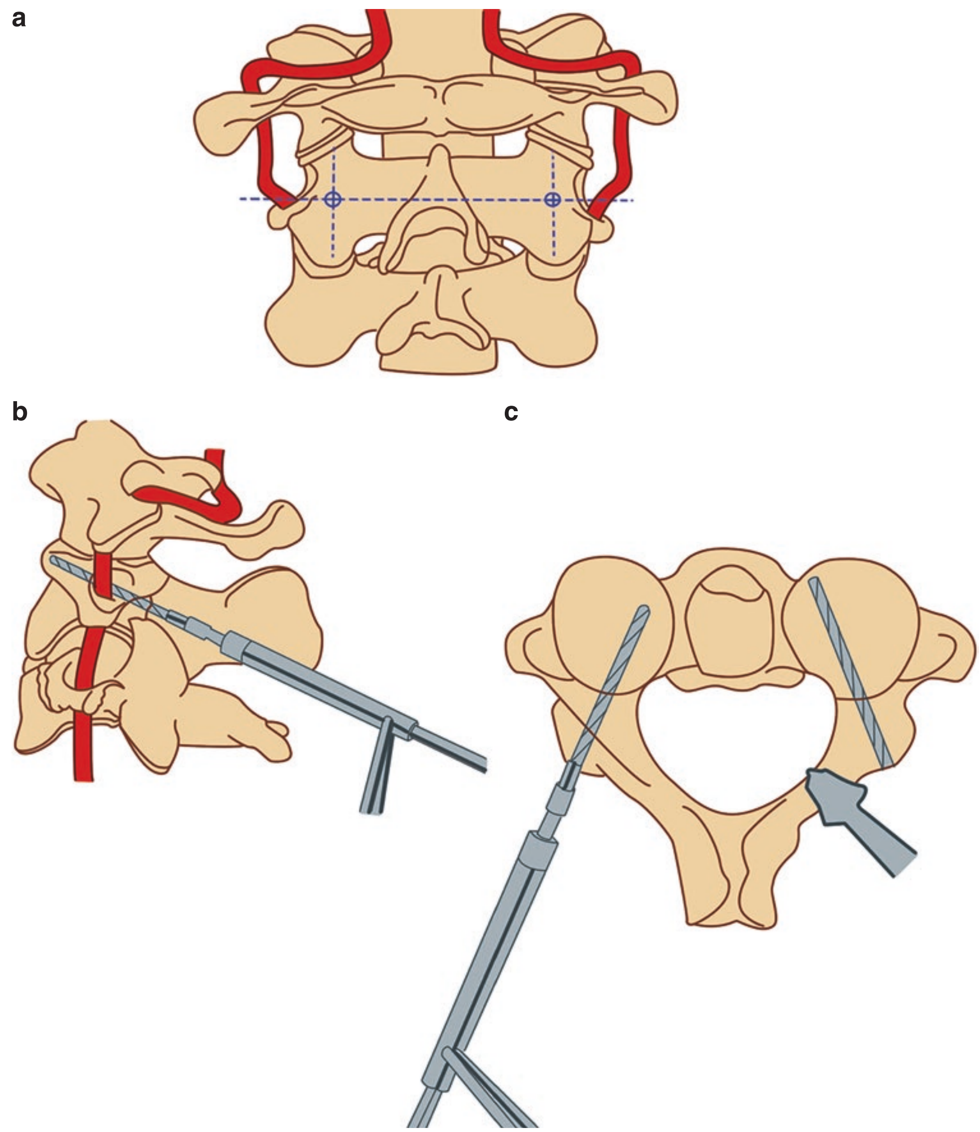

Fig. 1.23 (**a**) The entry points of the C2 pedicle screws. (**b**) The entry direction of the needle should be inclined to the head side by 20°. (**c**) The entry direction of the needle is inclined medially by 20–30°

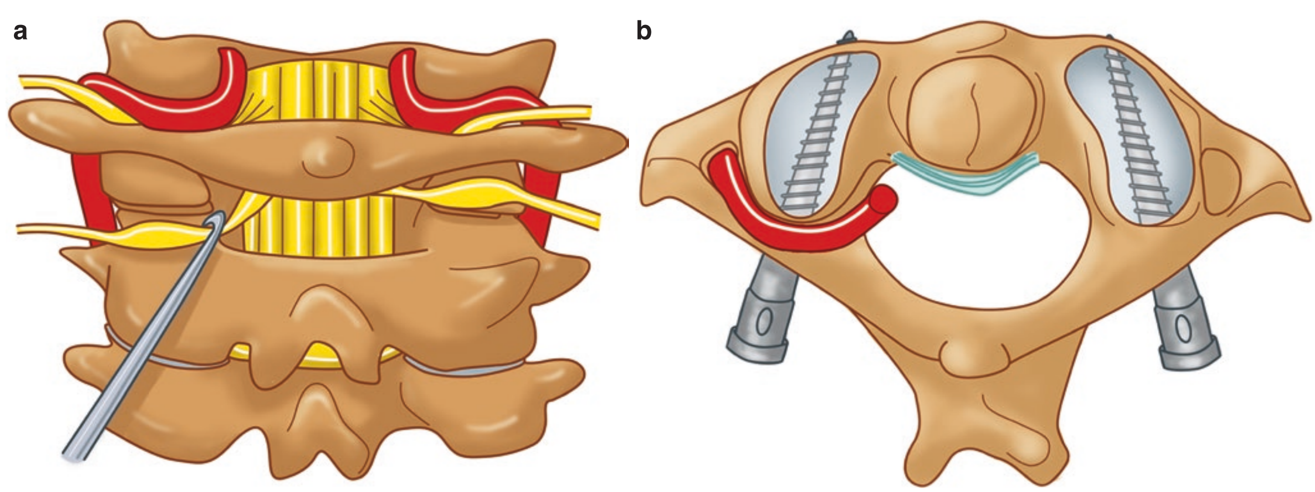

Fig. 1.24 (**a**) The entry point of a C1 lateral mass screw is located below the C1 vertebral lamina and above the C1/2 joint gap. The dorsal root ganglion located herein is gently pulled aside by a nerve stripper to expose the needle entry point. (**b**) Cross-section view: The C1 lateral mass screw should penetrate two cortical layers

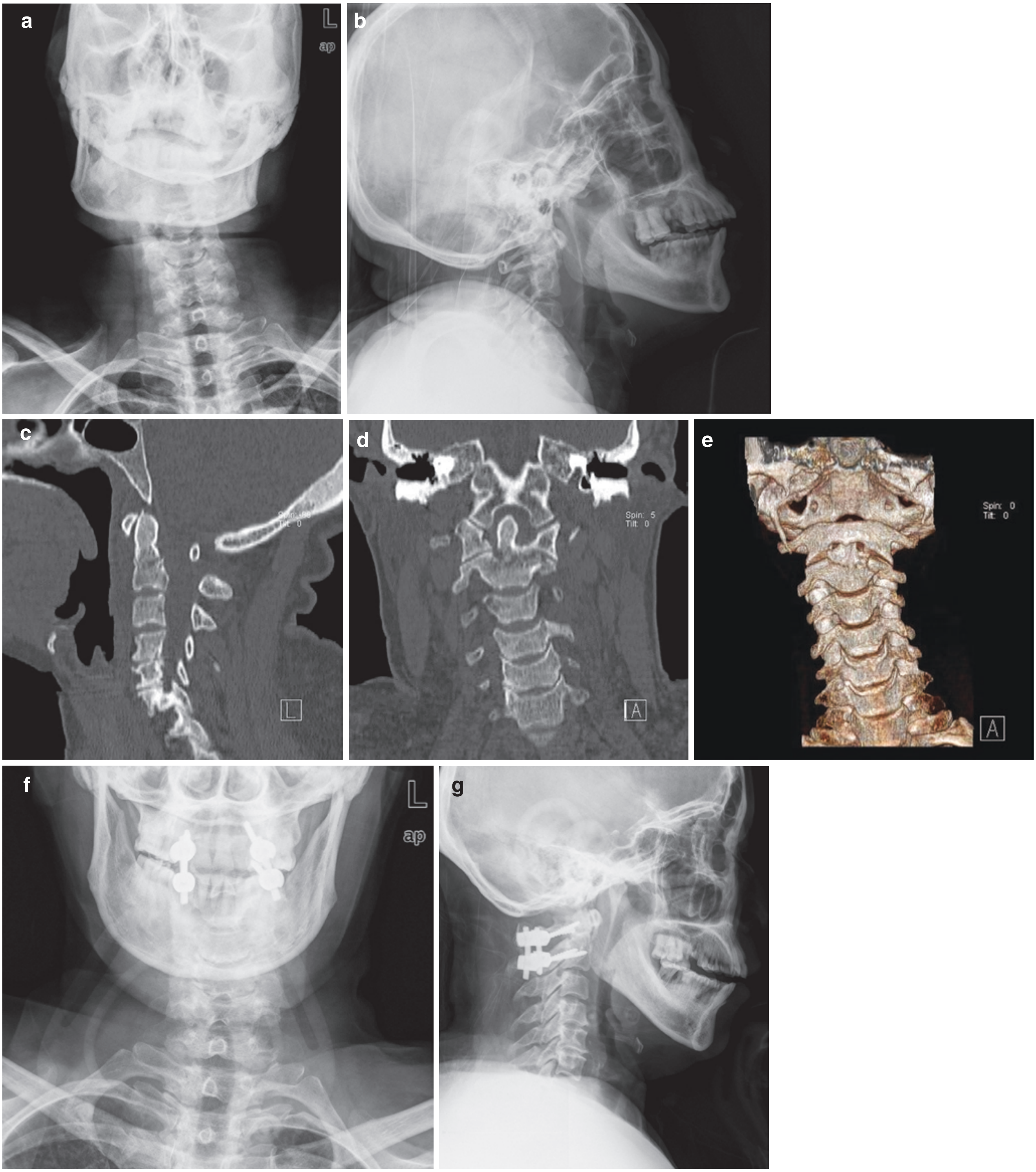

Fig. 1.25 An Anderson type III odontoid process fracture of the axis associated with a lateral mass fracture of the axis. (**a**, **b**) Preoperative AP and lateral radiographs: The atlas was dislocated anteriorly. (**c**) Sagittally reconstructed CT scan: The fracture of the odontoid process extended to the vertebral body. (**d**) Coronally reconstructed CT scan showing a fracture of the left lateral mass of the axis. (**e**) The 3D reconstructed CT scan of the fracture. (**f**, **g**) AP and lateral radiographs obtained after C1 lateral mass screw fixation and C2 pedicle screw fixation combined with atlantoaxial fusion via the posterior approach

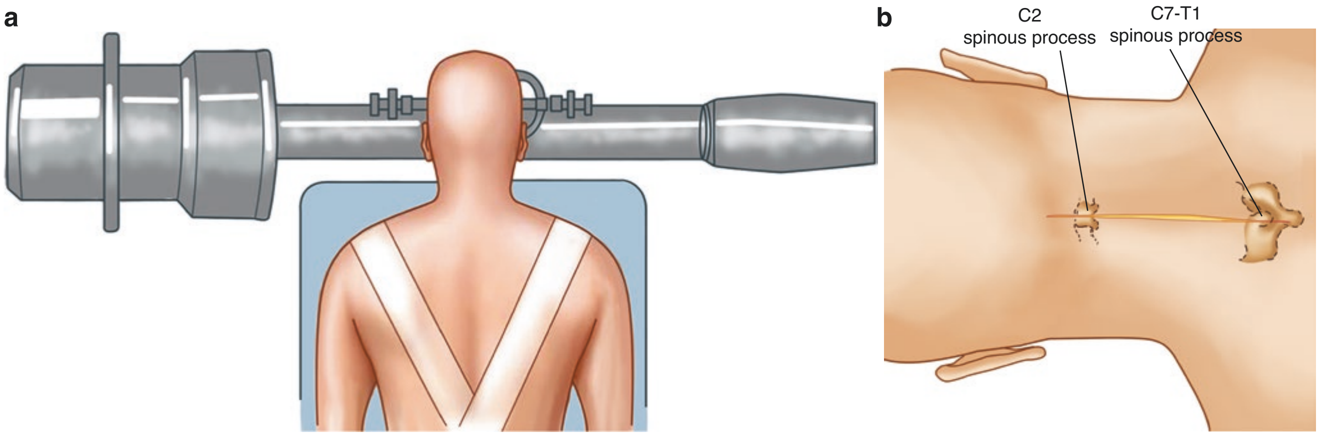

Fig. 1.26 (**a**) The patient lies prone, with the head secured to the operating table by a Mayfield head holder. The head holder is attached to the operating table to maintain the neck in the neutral position. Intraoperative positioning was performed with the aid of the C-arm or CT device. (**b**) The posterior neck midline incision was created up to the C7 protuberance

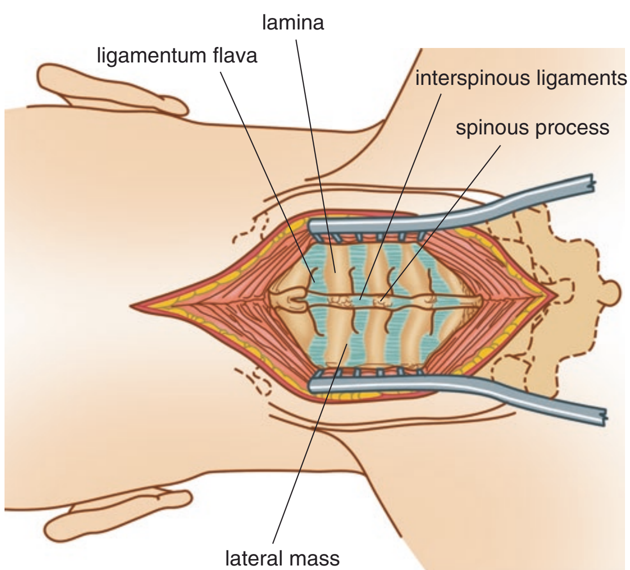

Fig. 1.27 A neck midline incision for exposure of the C3–C6 lateral masses

The ligamentum flavum above and below the area around the decompression "door" is dissociated, and then the vertebral lamina is lifted up with the nerve stripper front the caudal side to the head side.

The epidural veins are coagulated with a bipolar electrocoagulator.

The door can be kept open using a hand surgery miniature plate, inserting and fixing the spinous process fragment in the door, or pulling with a titanium cable.

– C3–C6 lateral mass screw placement:

According to the Magerl technique, the entry point is 2 mm medial to the center of the lateral mass, and the entry direction is inclined laterally by 20–25° and inclined to the head side by 20–40° (parallel to the space between the articular facets of the articular process) (Fig. 1.29).

The cortex at the planned entry point is opened with an awl, and then a vertebral pedicle probe is inserted along the entry direction up to the anterior edge of the bone cortex on the opposite side.

After depth measurement, a 3.5-mm tapper is used to tap the proximal bone cortex.

The multiaxial screw is placed into each of the C3–C6 lateral masses (Fig. 1.30) following the same procedure.

– Based on the measurement result, a rod is trimmed to an appropriate length and pre-bent.
– The rod is placed and used for compression (or expansion) for reduction, followed by nut tightening.
– A transverse connecting bar is placed if needed (Fig. 1.31).
– The positions of all internal fixators are re-confirmed radiographically during surgery (Fig. 1.32).

- Incision closure: The surgical field is cleansed, and the incision is sutured layer by layer after placing a drainage tube.
- Postoperative management: Postoperative management is performed based on the surgical scope and preoperative condition of the patient. The patient is under routine postoperative monitoring. At 48 h following surgery, the drainage tube is removed if the drainage volume meets the requirement. The patient wears a neck support for 6 weeks. In addition, attention is paid to the presence of wound infection.

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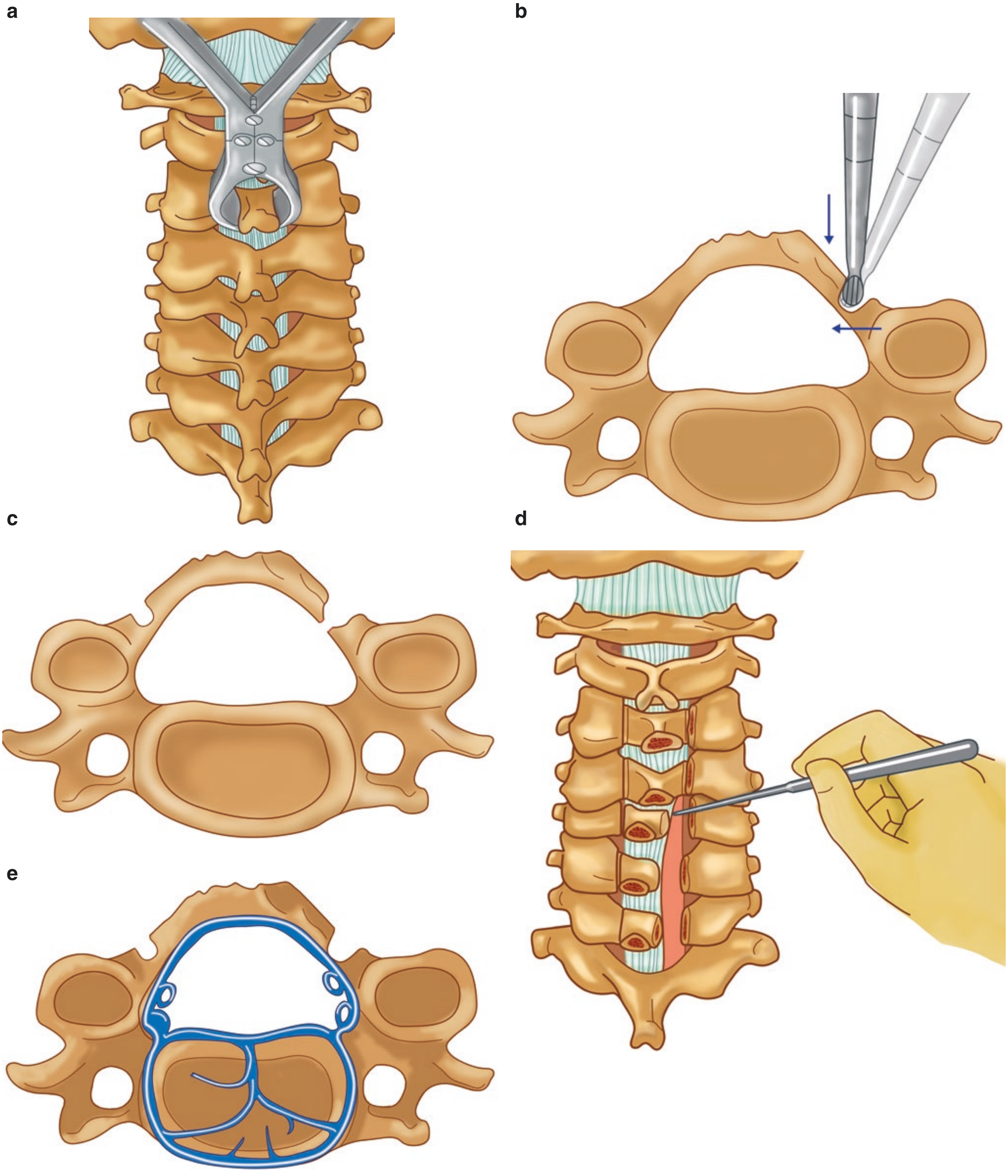

Fig. 1.28 Single-door vertebral laminar decompression and laminoplasty of the cervical spine. (**a**) The spinous process of the decompression segment is nibbled off with a bone rongeur. (**b**) The junction of the vertebral lamina and the lateral mass is ground with a burr drill, first downwards and then inwards under intra-canal space-occupying protection, to remove the outer cortical layer, cancellous bone, and inner cortical layer. (**c**) On the contralateral side, only the outer cortical layer and cancellous bone are ground off, and the inner cortical layer is preserved. (**d**) The vertebral lamina is gradually lifted up from the caudal side with a nerve stripper. (**e**) The bleeding from the epidural veins should be coagulated using bipolar electrocoagulation

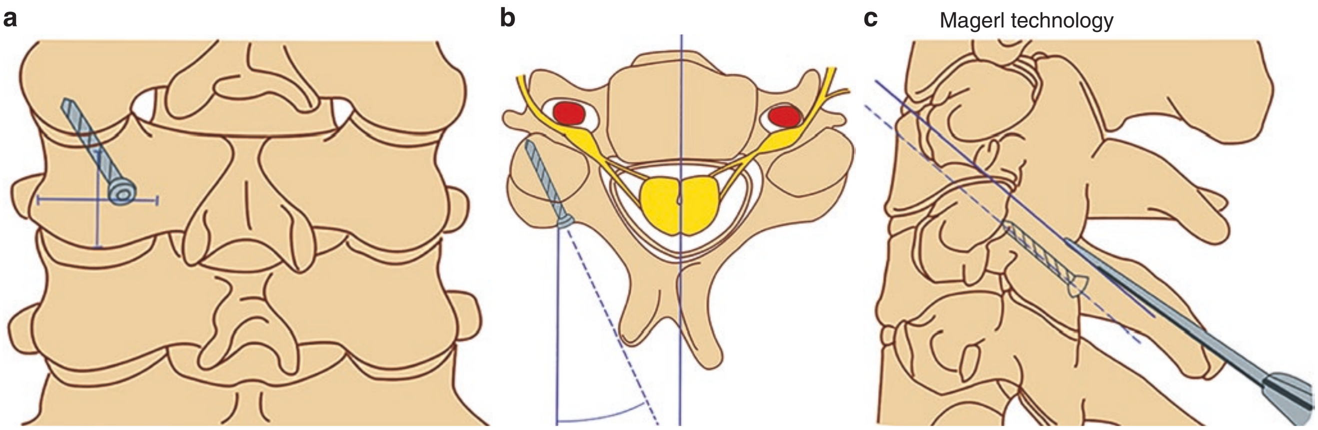

Fig. 1.29 Entry point and direction of lateral mass screws for C3–C6. (**a**) The entry point is located at the site 2 mm medial to the center of the lateral mass. (**b**) The lateral mass screw should be inclined laterally by 20–25°. (**c**) The lateral mass screw should be tilted by 20–40° towards the head side

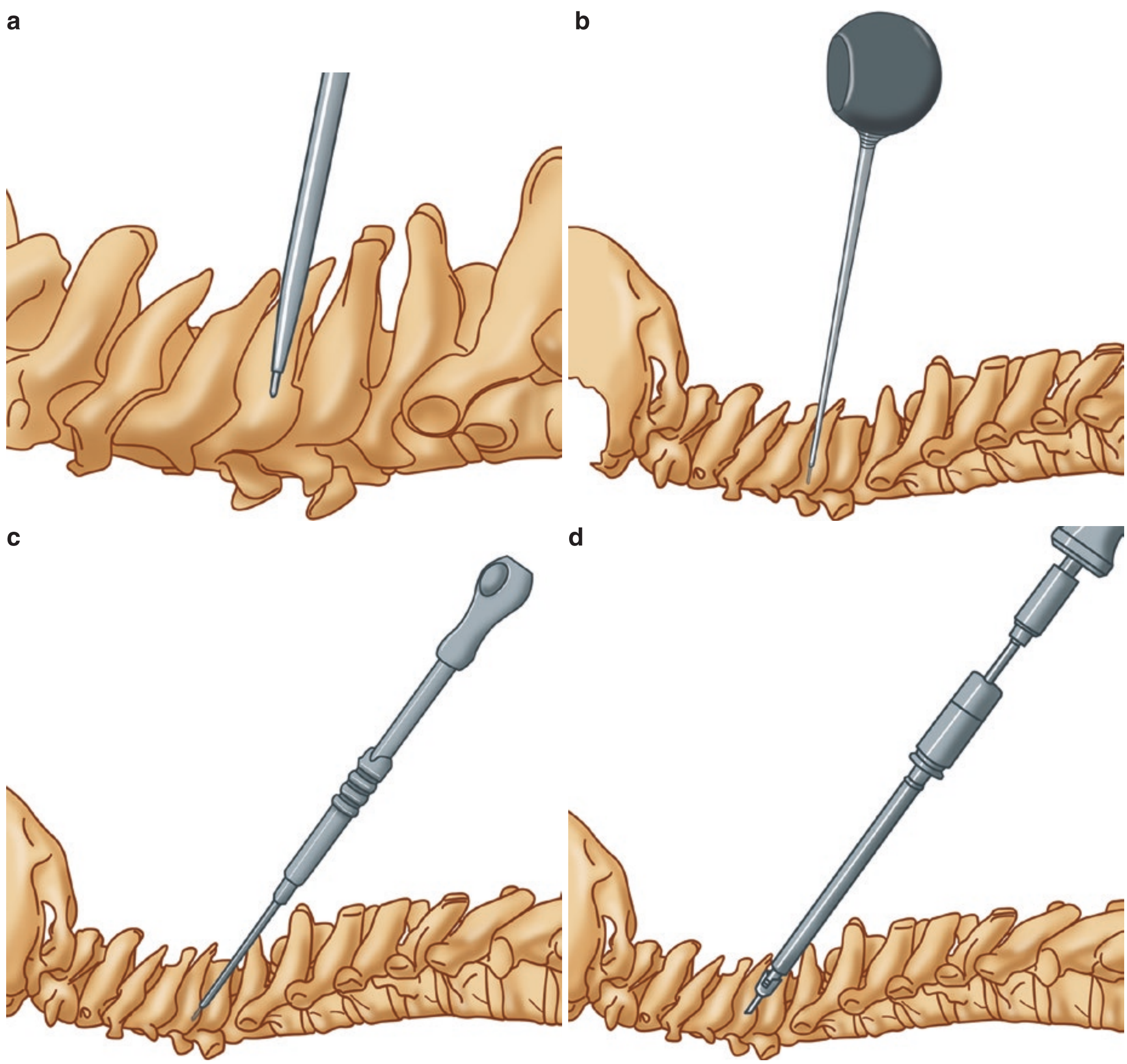

Fig. 1.30 (**a**) The bone cortex at the entry point is opened with an awl. (**b**) The pedicle probe is inserted along the needle direction up to the cortical bone on the opposite side. (**c**) Measurement of the depth. (**d**) A multi-axis screw with the desired depth is placed

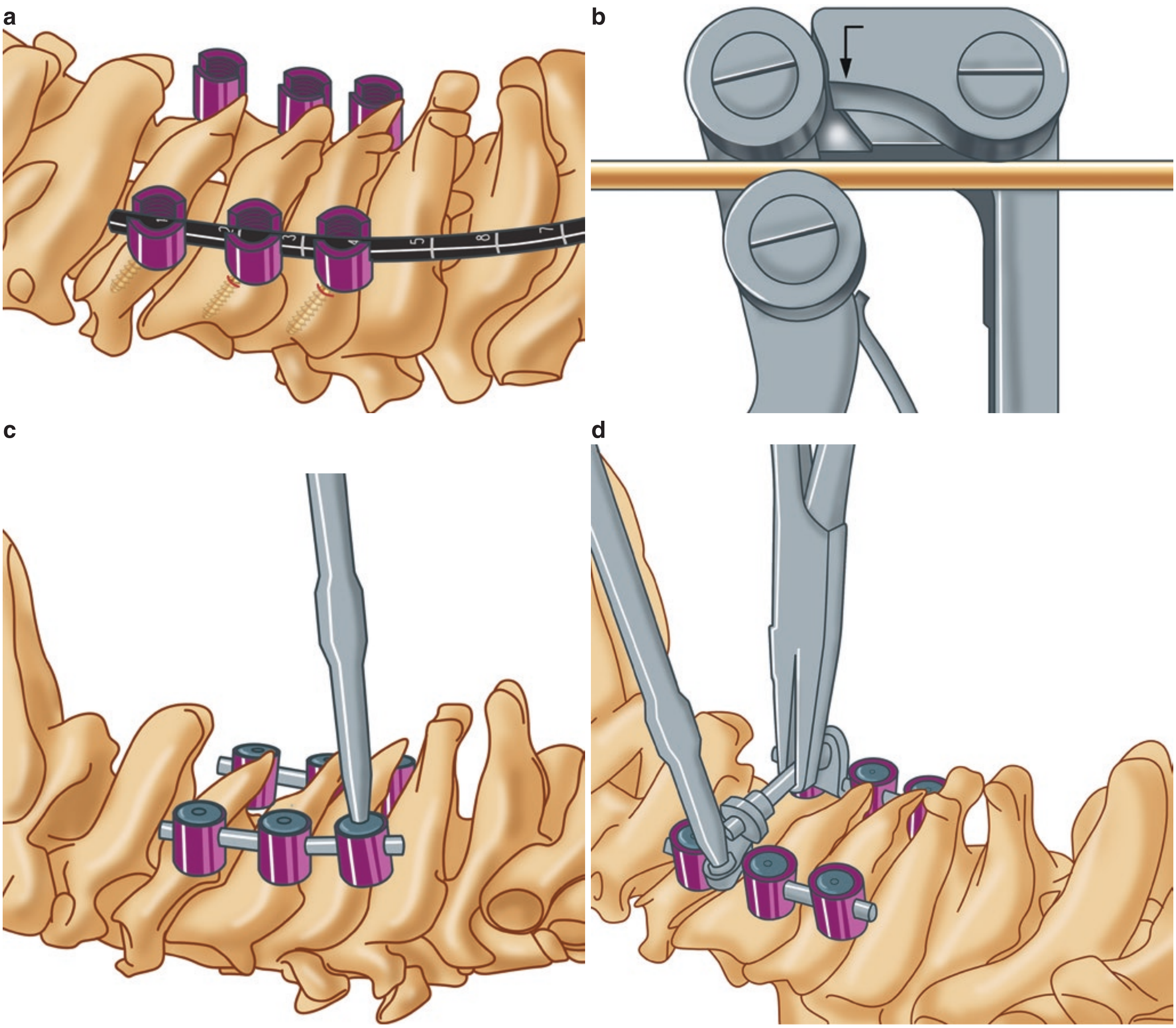

Fig. 1.31 (**a**) The required length of the rod is determined. (**b**) The titanium rod is trimmed to the desired length and pre-bent. (**c**) The multi-axis screw nuts are tightened. (**d**) A transverse connecting bar is placed

1.2.3.5 Posterior Occipitocervical Fusion (OCF)

- Body position and preoperative preparation, operative incision according to the projection on the body surface, and surgical approaches are similar to those for C1 lateral mass screw-C2 pedicle screw fixation and posterior C3–C6 lateral mass screw fixation.
- Fracture reduction and fixation:
  - The lateral mass screw and pedicle screw technique for OCF: Please see the relevant description in the preceding part.
  - Skull pin placement (Figs. 1.33 and 1.34):

    The positions of skull pins should be lower than the external occipital protuberance; inner fixators beyond the external occipital protuberance might damage the transverse sinus and cause more extensive soft-tissue injury or a compression injury of the skin over the occipital bone due to excessive protrusion of the inner fixator after surgery.

    The midline area of the posterior occipital bone that is excessively protruding can be trimmed to make the plate contact the plate and bone closer.

    In the view of the interior of the occipital bone, the posterior skull is divided into four quadrants by the internal protuberance of the occipital bone, superior sagittal sinus groove, and transverse sinus groove, and the intersection area has the thickest bone mass and is an ideal site for occipital screw placement.

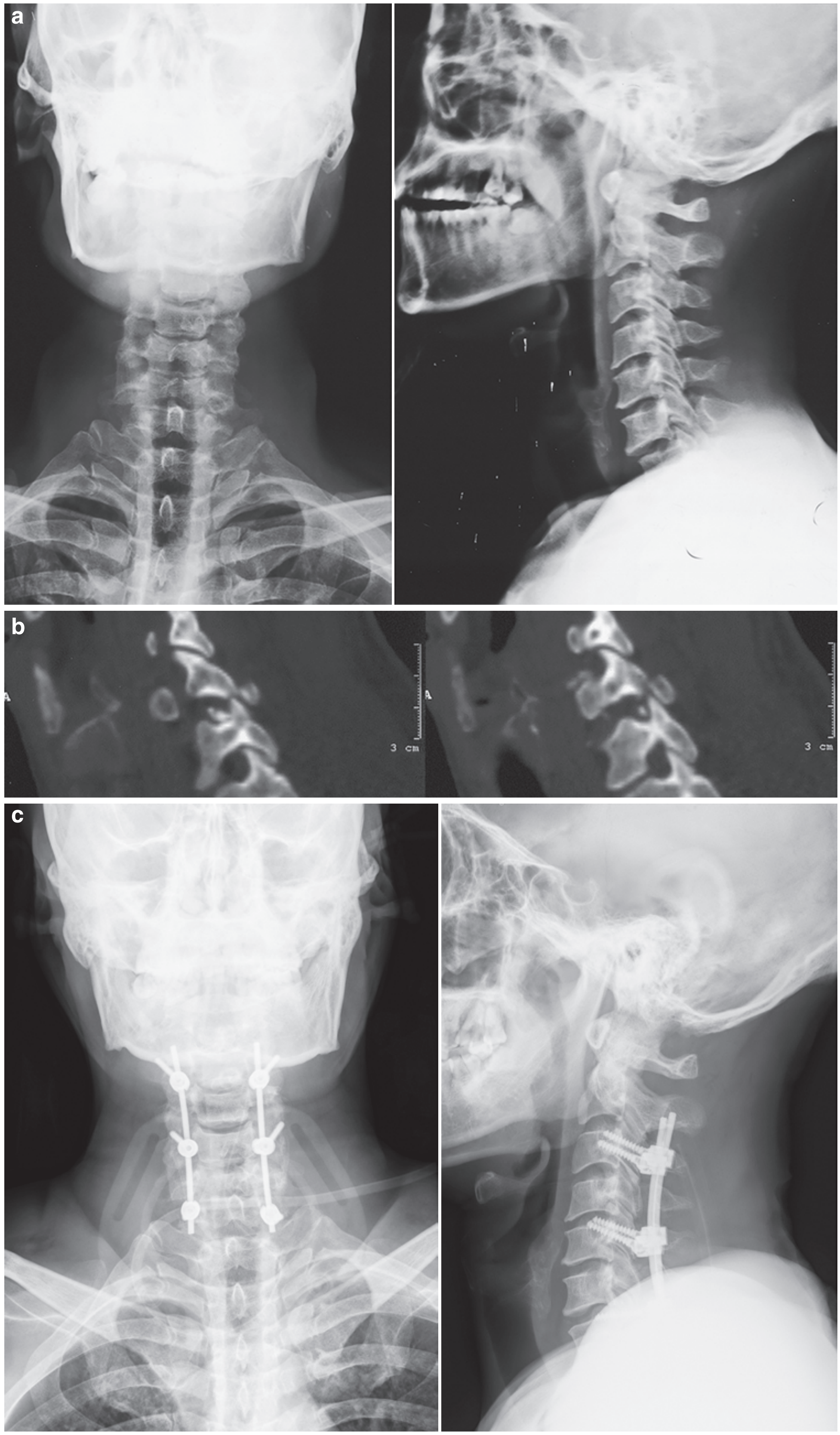

Fig. 1.32 Cervical spine fracture and dislocation. (**a**) Preoperative AP and lateral radiographs: C6 and C7 are dislocated. (**b**) Reconstructed CT scan on the sagittal plane of the joint: The facet joints are fractured and interlocked. (**c**) After the interlocked joints are unlocked, the lateral mass screw fixations of C3 and C5 and the C7 pedicle screw fixation are performed via the posterior approach

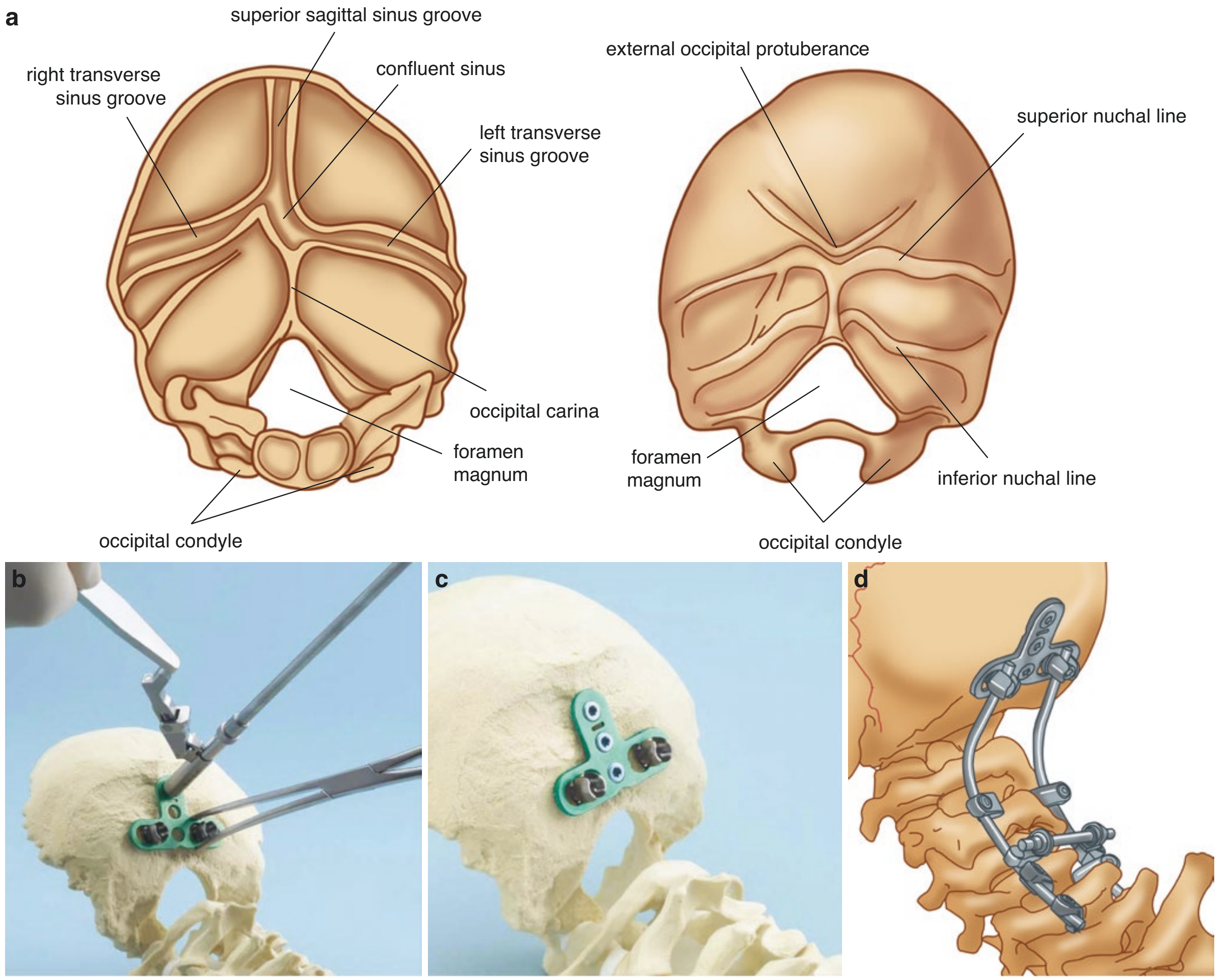

Fig. 1.33 (**a**) Interior and exterior views of the occipital bone: The internal occipital protuberance, superior sagittal sinus groove, and transverse sinus groove divide the inner surface of the occipital bone into four quadrants; the intersection area with the thickest bone is an ideal site for occipital screw placement. The external occipital protuberance is on the outer surface of the occipital bone, below which is an ideal location for steel plate placement. (**b**) An introducer with a depth-limiting mechanism is used to drill the holes, and the drilling starts from a depth of 8 mm and is gradually increased by 2 mm each time to avoid cerebrospinal fluid leakage caused by penetration of the dura mater. (**c**) The steel plate is fixed at a location with thick bone. (**d**) The steel plate is connected to the lateral mass screws, pedicle screws, etc., followed by installation of a transverse connecting rod

A midline screw with a length of 16–20 mm can be placed into the occipital bone, which has a stronger anchorage capacity than the screw placed on the side that reaches a depth of only 8–12 mm (Bransford et al. 2011).

After the plate is pre-shaped, it is placed beneath the external occipital protuberance. Subsequently, an introducer with a depth-limiting mechanism is used to carefully drill holes. The drilling depth starts from 8 mm and is advanced in increments of 2 mm until the desired final depth is achieved, which allows firm double-cortex-layer fixation without complications such as cerebrospinal fluid leakage.

After depth measurement and tapping, the screws with a desired length are screwed in place.

– The cranial plate is connected to the lateral mass screws and pedicle screws; a transverse connecting rod can be considered if necessary.

- The incision is closed following the routine protocol after placement of a drainage tube. The postoperative management is performed as described earlier.

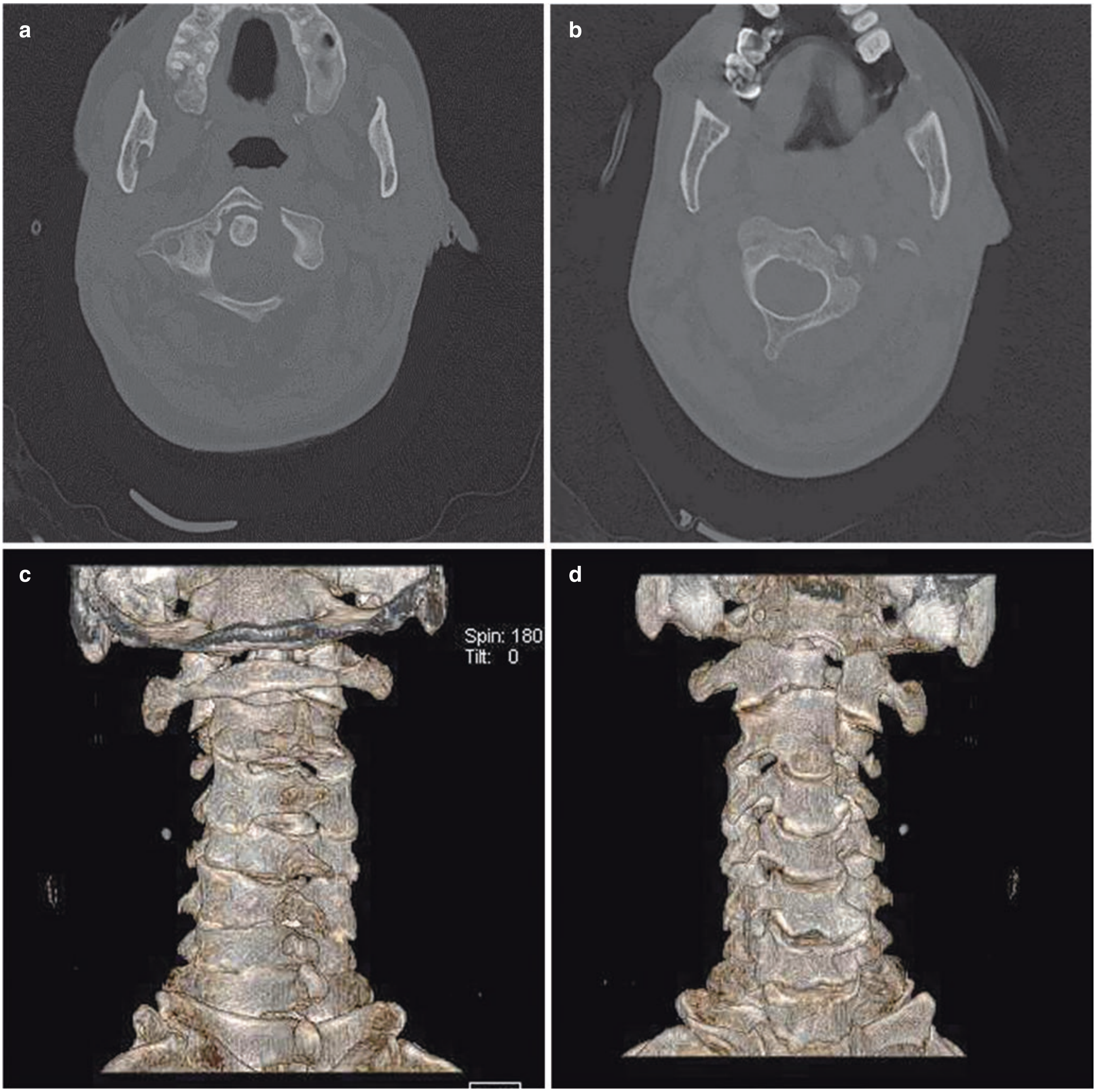

Fig. 1.34 Complex atlantoaxial fractures. (**a**) CT plain scan showing a fracture at the junction between the anterior arch and the left lateral mass of the atlas. (**b**) The left lateral mass of the axis is fractured. (**c**, **d**) Preoperative 3D reconstructed CT scans demonstrating the fractures of the anterior arch of the atlas and the left lateral mass of the axis. (**e**) After the lateral mass screws are placed into C3 and C4 via the posterior approach, cervical occipital fusion is performed

Fig. 1.34 (continued)

1.2.3.6 Anterior Discectomy/Vertebral Arthrodesis and Corpectomy for Decompression with Bone Grafting for Fusion

- Body position and preoperative preparation:
  – The patient undergoes general anesthesia through nasotracheal intubation.
  – The patient lies supine, with the neck posteriorly extended by placing cushions beneath the shoulders.
  – To ease the intraoperative radiography, the arms and hands of the patient are placed to closely contact the torso, and the shoulders are pulled downwards using rubber bands.
  – The head turns slightly towards the opposite side of the incision.
- Operative incision according to the projection on the body surface:
  – Based on the needs for vertebra exposure, an incision is made from the midline to the posterior edge of the sternocleidomastoid muscle along the orientation of the skin texture.
  – The position relationship between the midline structure and the cervical vertebrae: The hyoid bone is on the plane of C3; the thyroid cartilage corresponds to the level of C4–5; the cricoid cartilage corresponds to

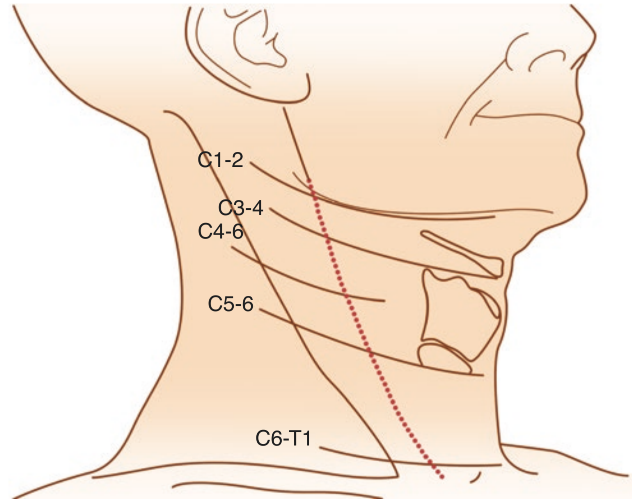

Fig. 1.35 A schematic drawing showing the levels of surgical incisions corresponding to fractures of different segments when the patient lies in a supine position with the head tilted to the contralateral side of the incision

the level of C6, and the carotid tubercles correspond to the level of C6 (Fig. 1.35).
- Surgical approach:
  – The surgical approach is used to expose the two vertebrae above and below the intervertebral disc that must be decompressed following the same procedures described in "Anterior screw fixation for odontoid fractures";
  – Alternately, the exposure is created until the two vertebral bodies above and below the vertebral body that need to be removed.
- Fracture reduction and fixation:
  – Discectomy and artificial intervertebral disc placement for interbody fusion (Fig. 1.36):

    After removal of the intervertebral disc, the articular cartilage and its end plates above and below are removed using a burr drill, and the resection is extended towards both sides up to the uncovertebral joint for decompression.

    The intervertebral space is distracted using the Caspar distraction system. Subsequently, an intervertebral disc template is placed and examined under C-arm radiography to measure the height of the intervertebral gap and determine the desired height of the interbody fusion cage.

    Traction is discontinued after the interbody fusion cage is placed, and the position of the fusion cage is examined by C-arm fluoroscopy.
  – Subtotal corpectomy for fusion (Fig. 1.37):

    First, the uncovertebral joints on both sides are identified, and the lateral edge of the vertebral body is identified.

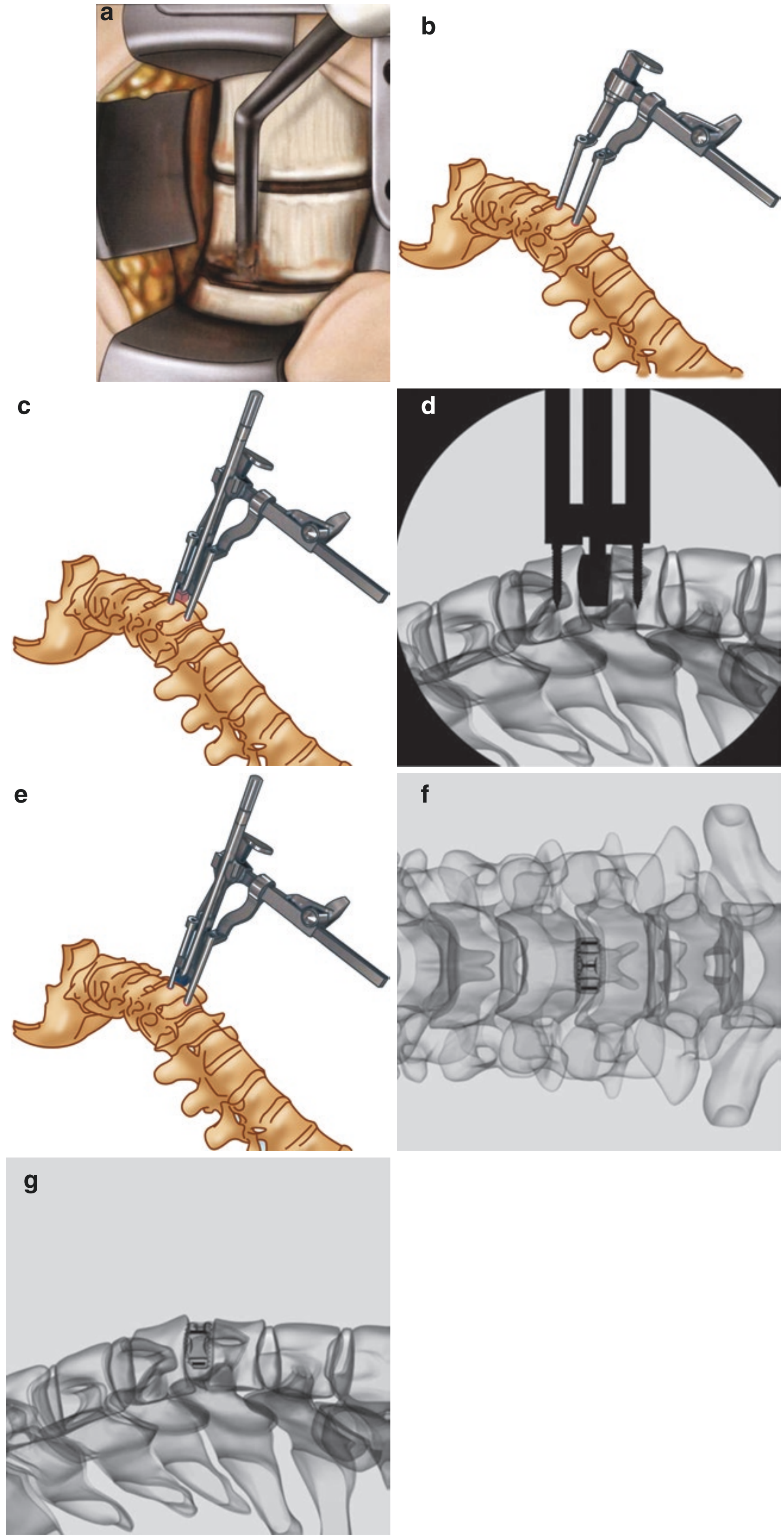

Fig. 1.36 (**a**) The intervertebral disc is nibbled off with a bone rongeur, and the articular cartilage and the upper and lower endplates are ground off with a burr drill. (**b**) A Caspar distractor is applied to open the intervertebral space. (**c**, **d**) Under C-arm radiography, an intervertebral disc template is inserted and used to examine whether the height is appropriate and whether the alignment of the cervical spine can be restored satisfactorily. (**e**) After the appropriate height is determined using the disc template, a suitable intervertebral disc prosthesis is implanted. (**f**, **g**) AP and lateral C-arm fluoroscopies are used to examine the position and reduction quality after prosthesis implantation

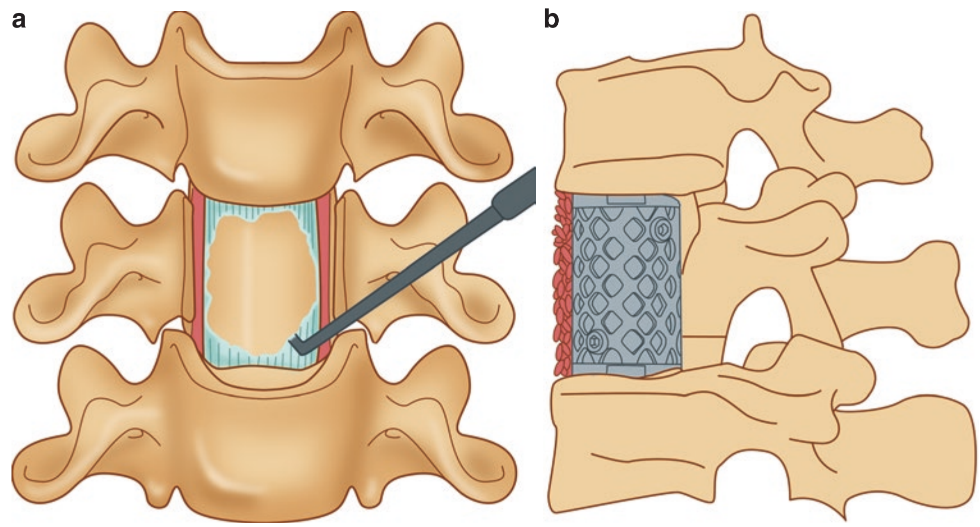

Fig. 1.37 (**a**) Through the anterior approach, the subtotal corpectomy is performed to decompress the affected segment up to the uncovertebral joint from both sides and up to the posterior longitudinal ligament at the posterior aspect. (**b**) The cancellous bone is caged into the titanium cage and then placed into the gap left by the excised vertebral body

After the annular fibrosus is sharply incised, the intervertebral disc of the affected segments is stripped off until the posterior longitudinal ligament.

A subtotal corpectomy is performed with a bone rongeur, which decompresses the affected segment up to the uncovertebral joint from both sides and until the posterior longitudinal ligament at the posterior aspect. The superior and inferior vertebral laminae of the adjacent vertebrae are filed to expose the cancellous bone. Special attention should be paid to the preservation of the posterior rim that can protect the spinal cord from compression caused by backward shifting of the internal fixators.

After length measurement, an ilium fragment with a cortex layer covering three aspects, or a titanium cage with the desired length, is prepared and placed in the remaining space after vertebral body resection.

– Anterior plate fixation (Fig. 1.38):

Although the anterior cervical plate is a curved plate, its forward curvature can be adjusted using a bender according to the actual cervical spine curvature.

After placing a guider into the plate, a drill bit with an appropriate size is used to drill the holes.

Screws are placed diagonally through the plate sequentially, and lastly, all screws are tightened until the screw cap completely enters the area (Figs. 1.39 and 1.40).

- Incision closure: The surgical field is cleansed, and the incision is sutured layer by layer after placing a drainage tube.
- Postoperative management:

  – It is crucial to monitor whether a hematoma in the posterior pharyngeal wall or difficult breathing caused by airway compression is present. The endotracheal tube is retained if needed.
  – Special attention should be paid to examining the presence of recurrent laryngeal nerve damage.
  – The patient must wear a neck support device for 4–6 weeks.

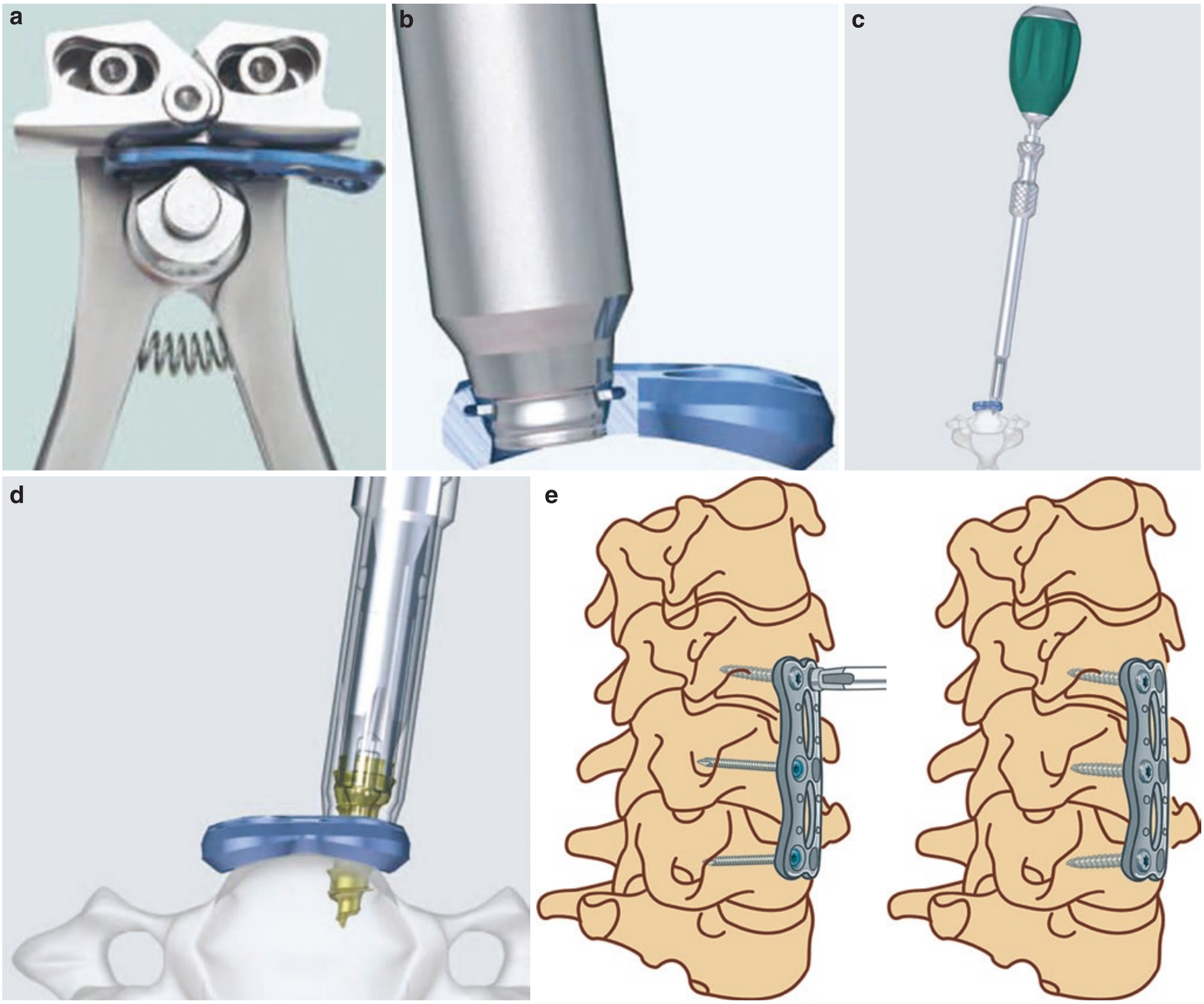

Fig. 1.38 (**a**) The steel plate is pre-shaped to the desired angle with a plate bending during the operation. (**b**) The guider is connected to the steel plate. (**c**) A drill bit with the desired size is used to drill the holes. (**d**) The lock screws are placed. (**e**) The screws are placed diagonally through the plate sequentially, and finally, all the screws are tightened

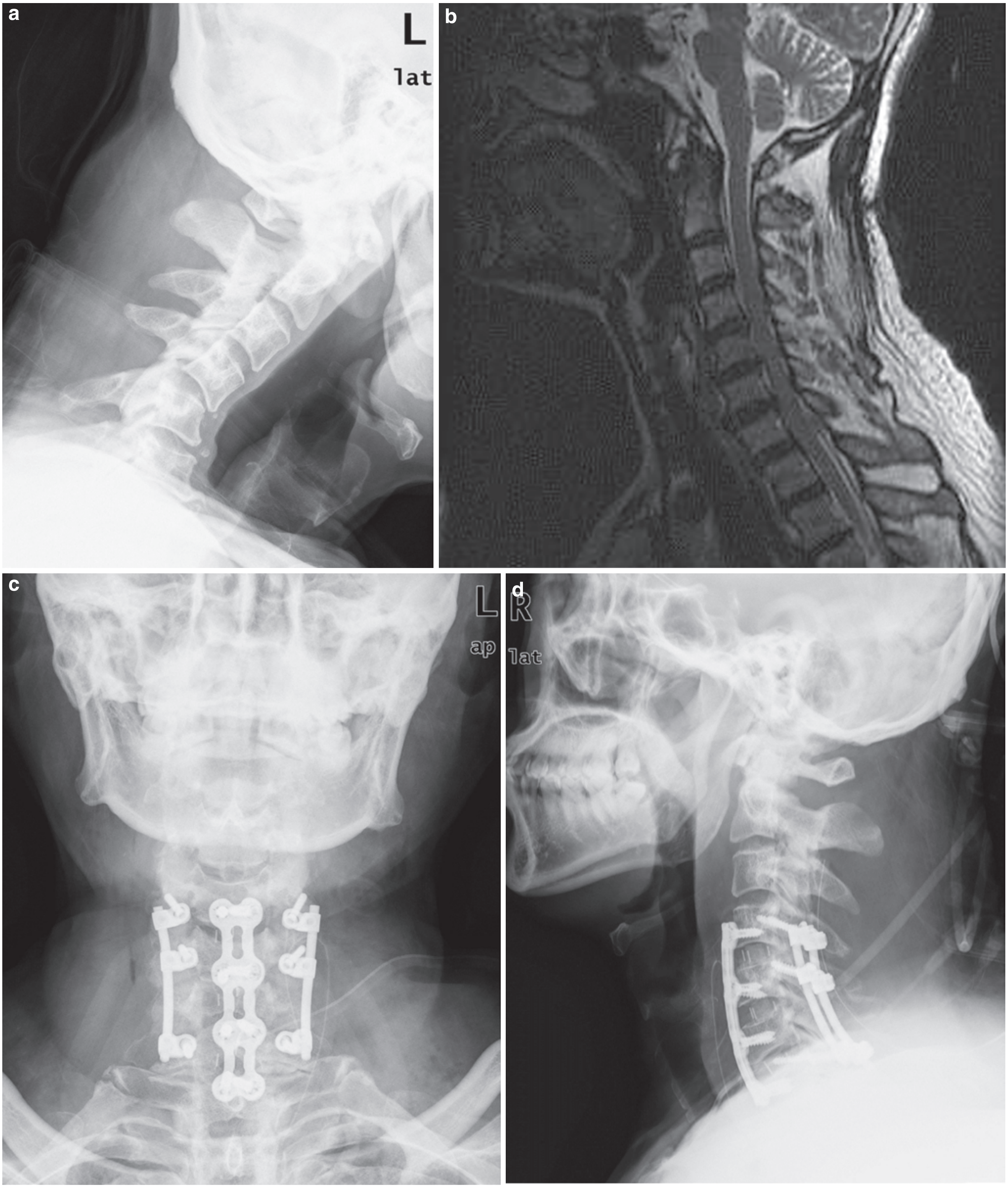

Fig. 1.39 A traumatic C4/C5 dislocation and intervertebral disc herniation causing incomplete paralysis. (**a**) A preoperative lateral radiograph displaying an abnormal angle between the C4 and C5 vertebral bodies. (**b**) Preoperative T2-weighted nuclear magnetic resonance imaging (NMRI): The herniated C4/5, C5/6, and C6/7 intervertebral discs compressed the spinal cord. (**c**, **d**) Due to the serious injury of the posterior tissue, the anterior and posterior approaches were jointly used for surgical treatment. The C3, C4, and C6 lateral mass screws were placed for posterior fixation via the posterior approach. The C4/5, C5/6, and C6/7 intervertebral discs were removed anteriorly, followed by placement of the artificial intervertebral discs and with plate-screw fixation

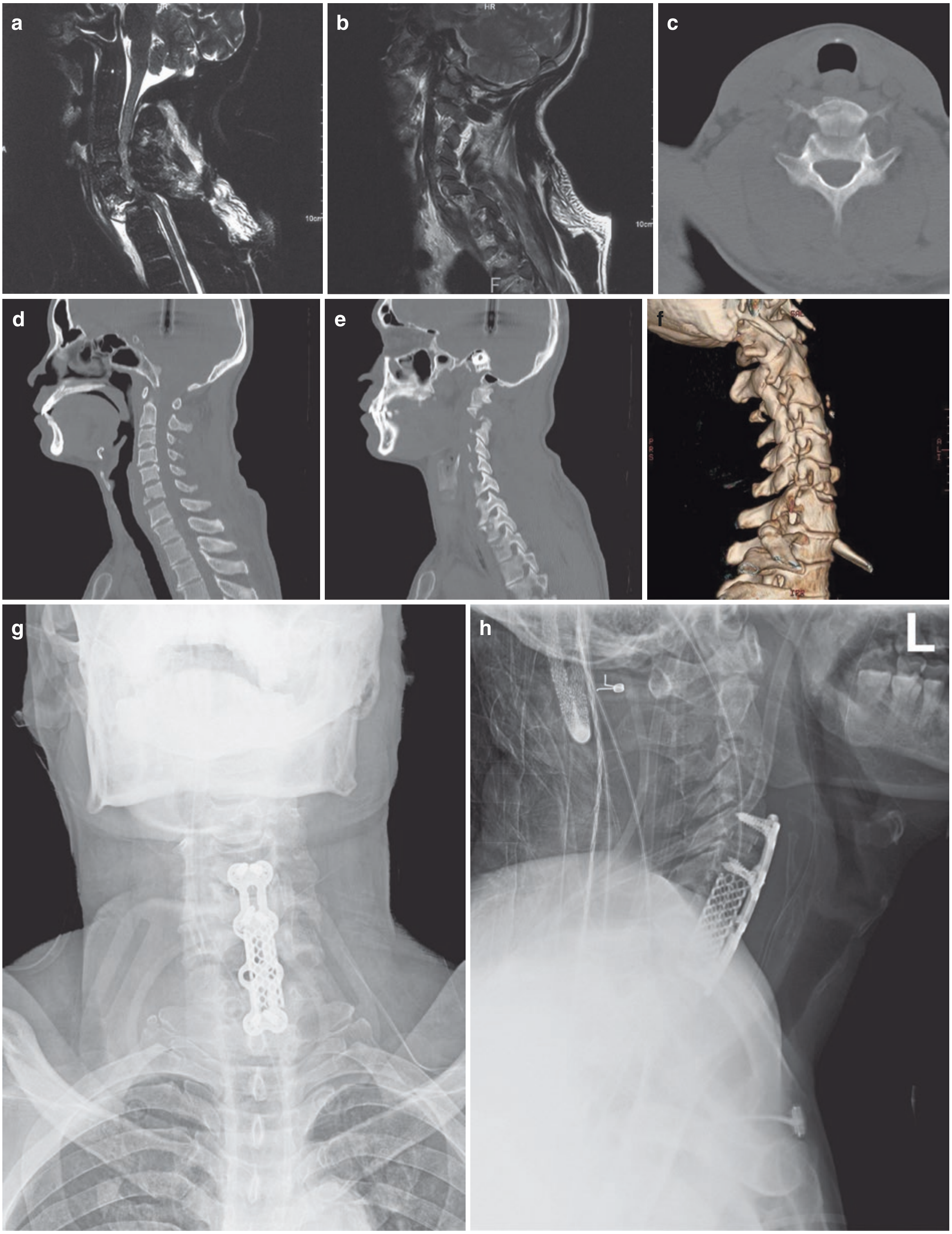

Fig. 1.40 Fracture and dislocation of the C6 vertebral body. (**a**) T2-weighted midline sagittal MRI after injury: The C7 vertebral body was anteriorly dislocated, with obvious compression of the spinal cord. (**b**) Sagittal MRI of the facet joint showing a dislocation and interlocking of the C6 and C7 joints. (**c**) CT plain scan: The C6 vertebral body was fractured and anteriorly dislocated. (**d**) Sagittally reconstructed midline CT plain scan: After skull traction, the vertebral body was partially reduced, and there was a teardrop-shaped bone fragment in front of the vertebral body. (**e**) Sagittal reconstruction of the CT plain scan of the joint: The interlocked joint was reduced, but the C6–C7 intervertebral space was significantly wider than that of other segments, indicating destruction of the ligaments and joint capsule structure. (**f**) The 3D reconstructed CT image: The C6 vertebral body had a teardrop-shaped fracture. (**g**, **h**) Postoperative AP and lateral radiographs: The lesioned vertebral body and intervertebral disc were removed using the anterior approach, followed by titanium caging and plate-screw internal fixation via the anterior approach

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