11 Indications

Zhen-Zhou Li

Percutaneous endoscopic procedures have been and are being employed predominantly for the treatment of lumbar disc herniation, lumbar spinal stenosis, degenerative facet joint cyst, degenerative chronic low back pain, etc.

11.1 Lumbar Disc Herniation

Herniation or protrusion of the gelatinous nucleus pulposus into or through the annulus fibrosus is a well-recognized cause of low back pain and sciatica. The goal of surgery for sciatica due to a disc herniation is to identify the offending fragment and remove it with as little damage to surrounding structures as possible. At the current level of surgical technique, almost all types of lumbar disc herniation can be treated with percutaneous endoscopic discectomy.

Locating the herniated disc (HD) position is critical to selecting the appropriate surgical technique. Based on axial MRI, MSU classification [1] (Fig. 11.1a–c) can be used to precisely position the herniated discs (HDs) in the axial plane. It is also necessary to determine the degree of migration of the HD on the sagittal MRI [2, 3] (Fig. 11.2a, b).

Z.-Z. Li (✉)
The Department of Orthopedics Surgery, The Fourth Medical Center of Chinese PLA's General Hospital, Beijing, China

11.1.1 Far Lateral Lumbar Disc Herniation

The vast majority of far lateral lumbar disc herniation (MSU zone C) can be treated with percutaneous endoscopic discectomy through posterolateral approach or extraforaminal approach. First, the working cannula was inserted into the intervertebral disc through the safe triangular working zone, the loose and free intradiscal nucleus pulposus tissue was removed, and then the working cannula was retreated to the safe triangular working zone to explore and remove the prolapse of the nucleus pulposus (inside-outside technique) (Fig. 11.3).

For patient with nerve root anomalies or hypertrophy of articular processes, the effective safe triangular working zone is small and cannot accommodate the working cannula. The working cannula can be floated on the dorsal side of the exit nerve root and the prolapse of the nucleus pulposus be exposed and removed with endoscopic surgical tools. And then intradiscal free nucleus pulposus removed through safe triangle working zone (outside-inside technique) (Fig. 11.4).

Foraminoplasty can also be used to partially resect anterolateral bony structure of superior articular process so that the expansion of the external opening of the intervertebral foramen and the effective safe triangular working zone

J.-S. Kim et al. (eds.), *Endoscopic Procedures on the Spine*,
https://doi.org/10.1007/978-981-10-3905-8_11

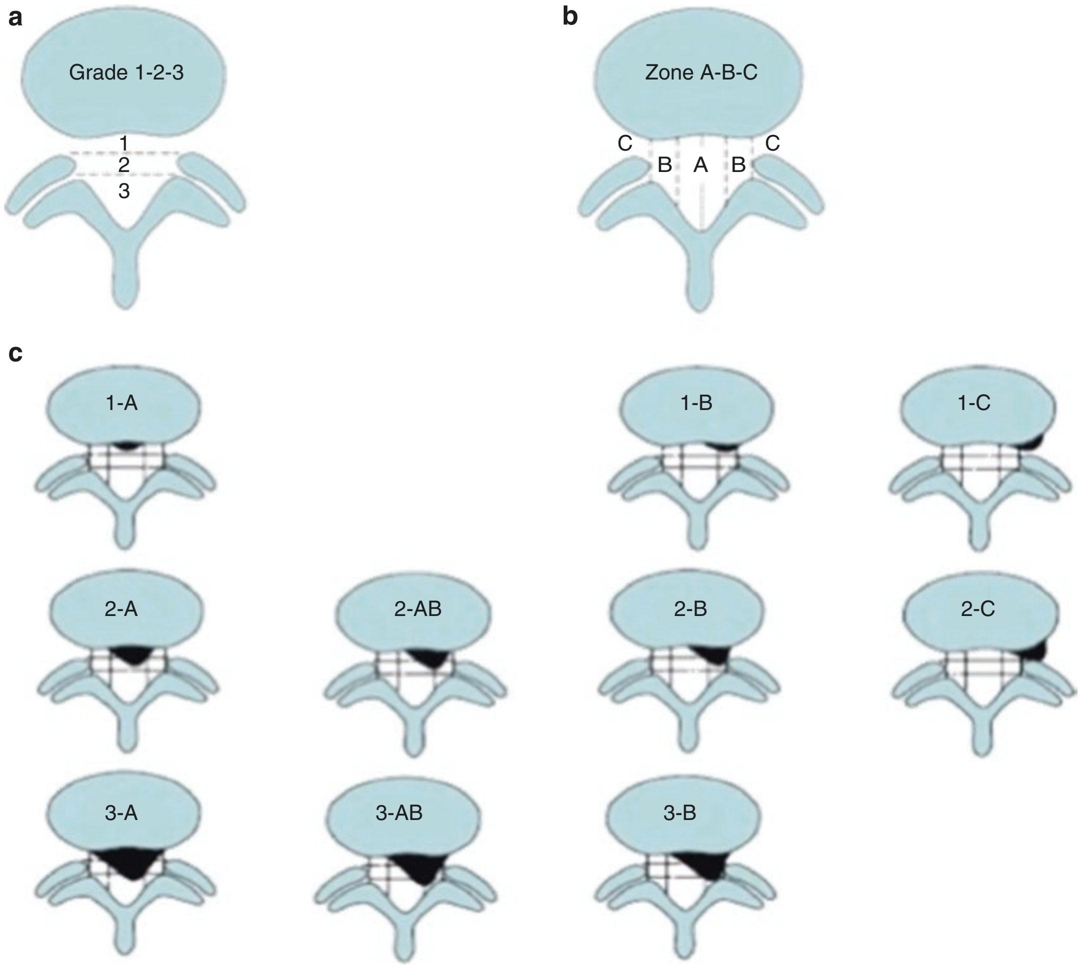

Fig. 11.1 MSU classification of lumbar disc herniation. (**a**) The size and location of disc herniation are measured at the level of maximal extrusion in reference to a single intrafacet line drawn transversely across the lumbar canal, to and from the medial edges of the right and left facet joint articulations. To portray the size of disc herniation, the lesion is described as 1, 2, or 3. In reference to the intrafacet line, a determination is made as to whether the disc herniation extends up to or less than 50% of the distance from the non-herniated posterior aspect of the disc to the intrafacet line (size-1), or more than 50% of that distance (size-2). If the herniation extends altogether beyond the intrafacet line, it is termed a size-3 disc. Grade 1 lesions have little impact and grade 3 have the most impact on nerve compression. (**b**) To further qualify location of the disc herniation, the lesion is described as A, B, or C to more exactly locate the position that is routinely, but less accurately, reported as central, lateral, or far lateral. Three points are placed along the intrafacet line, dividing it into four equal quarters. The right and left central quadrants represent zone-A. The right and left lateral quadrants represent zone-B. A third zone-C is represented at the level of the foramen by the area that extends beyond the medial margin of either facet joint, past the borderline of the lateral quadrants. (**c**) Types of lumbar disc herniations combining size and location. Lesions 2-B are commonly symptomatic. 3-A lesions are often seen in cauda equina. Lesions 2-C are the largest foraminal lesions. Lesions 2-AB are quite common, occurring on the line between zone-A and zone-B

can be achieved for the docking of the working cannula, then the aforementioned inside-outside technique can be used to remove the intradiscal free nucleus pulposus and prolapse of the nucleus pulposus (inside-outside technique with foraminoplasty) (Fig. 11.5).

11.1.2 Intracanal Lumbar Disc Herniation

11.1.2.1 Transforaminal Approach

For contained intracanal lumbar disc herniation with MSU zone A-B and grade 1–2 limited at the

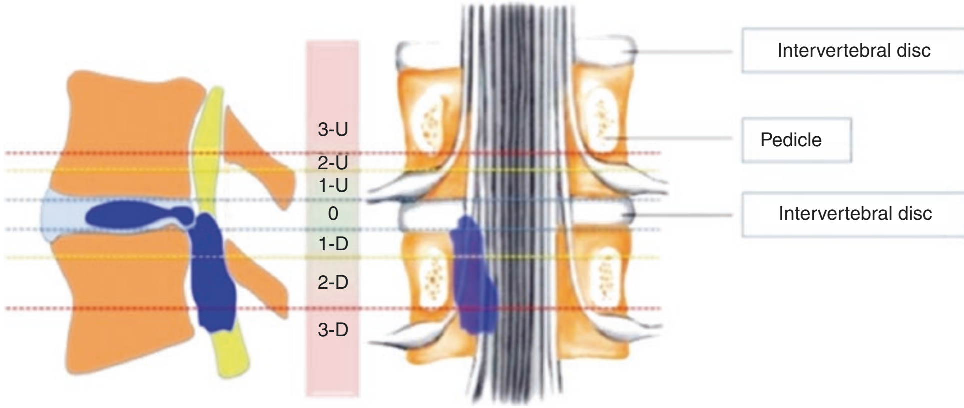

Fig. 11.2 The classification of disc migration. (**a**) Sagittal plane; (**b**) Coronal plane. 0-no migration. 1-low migration. 2-high migration (the herniation was described as highly migrated if the extent of the migration was larger than the measured height of the posterior marginal disc space at the T2-weighted sagittal magnetic resonance image). 3-very high migration (the migrated disc extended beyond the inferior margin of the pedicles). *U* upward, *D* downward

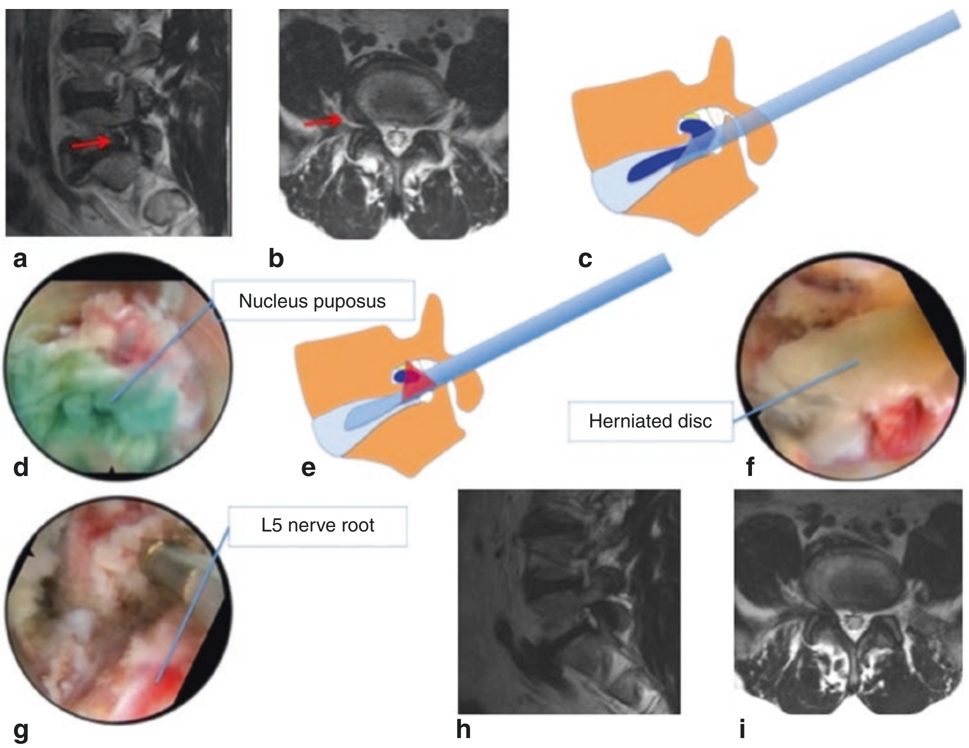

Fig. 11.3 Far lateral L5S1 disc herniation (MSU 1-C, Migration 2-U) treated with percutaneous endoscopic discectomy through extraforaminal approach (inside-outside technique). (**a**) Preoperative sagittal T2-weighted MRI showed far lateral disc herniation at right L5S1. (**b**) Preoperative axial T2-weighted MRI showed far lateral disc herniation at right L5S1. (**c**, **d**) Intradiscal decompression. (**e**, **f**) HD resection. (**g**) Endoscopic view of decompression of right L5 nerve root. (**h**) 3 months postoperative sagittal T2-weighted MRI showed decompression of right L5 nerve root. (**i**) 3 months postoperative axial T2-weighted MRI showed decompression of right L5 nerve root

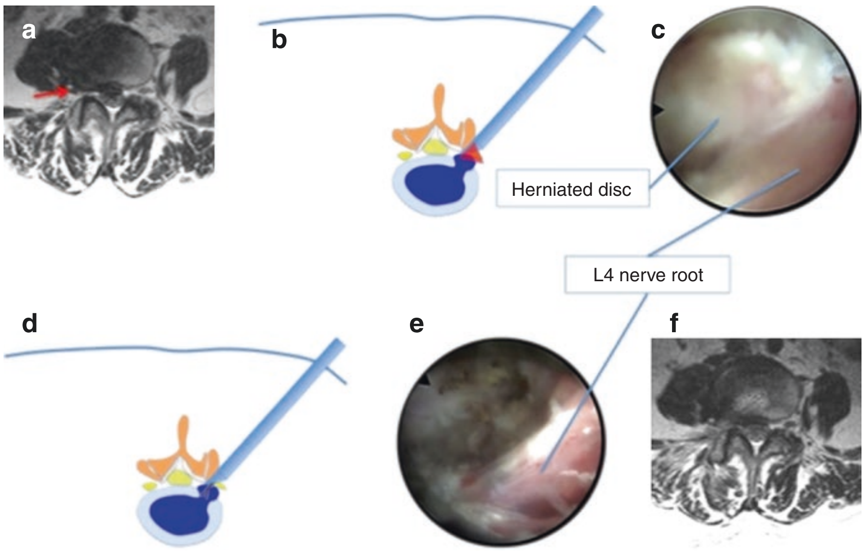

Fig. 11.4 Far lateral L4–5 disc herniation (MSU 1-C, Migration 1-U) with small Kambin triangle treated with percutaneous endoscopic discectomy through extraforaminal approach (outside-inside technique). (**a**) Preoperative axial T2-weighted MRI showed far lateral disc herniation at right L4–5. (**b**, **c**) Expose the HD and right L4 nerve root with working channel floating over the nerve root. (**d**) HD removed with endoscopic surgical tools, and then intradiscal free nucleus pulposus removed through safe triangle working zone. (**e**) Endoscopic view of decompression of right L4 nerve root. (**f**) 1 day postoperative axial T2-weighted MRI showed decompression of right L4 nerve root

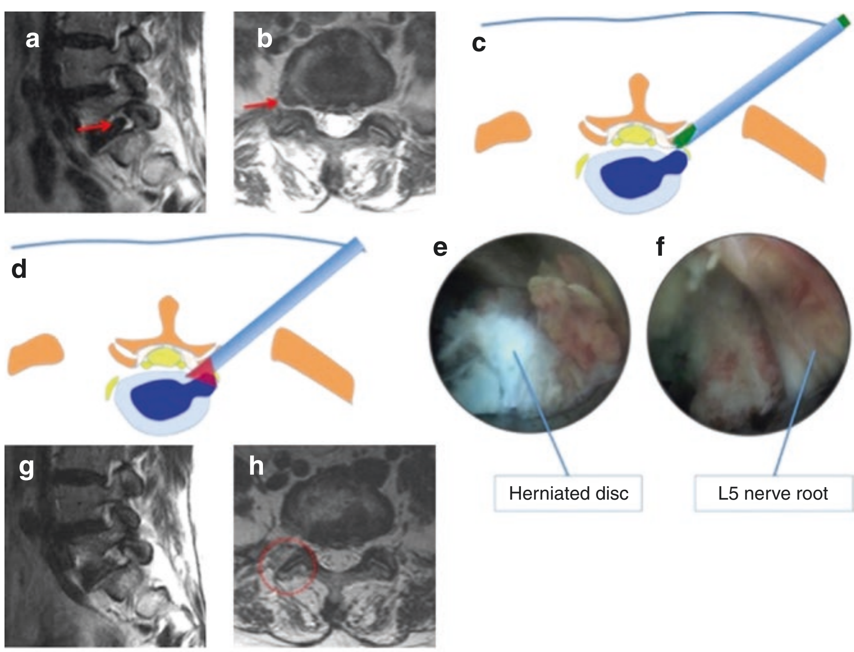

Fig. 11.5 Far lateral L5S1 disc herniation (MSU 1-C, Migration 2-U) with hypertrophied facet joints treated with percutaneous endoscopic discectomy through extraforaminal approach (inside-outside technique with foraminoplasty). (**a**) Preoperative sagittal T2-weighted MRI showed far lateral disc herniation at right L5S1. (**b**) Preoperative axial T2-weighted MRI showed far lateral disc herniation at right L5S1. (**c**) Foraminoplasty with protected trephine system. (**d**, **e**) Expose the HDs. (**f**) Endoscopic view of decompression of right L5 nerve root. (**g**) 1 day postoperative sagittal T2-weighted MRI showed decompression of right L5 nerve root. (**h**) 1 day postoperative axial T2-weighted MRI showed decompression of right L5 nerve root; Foraminoplasty was shown in dotted red circle without compromise of the facet joint stability

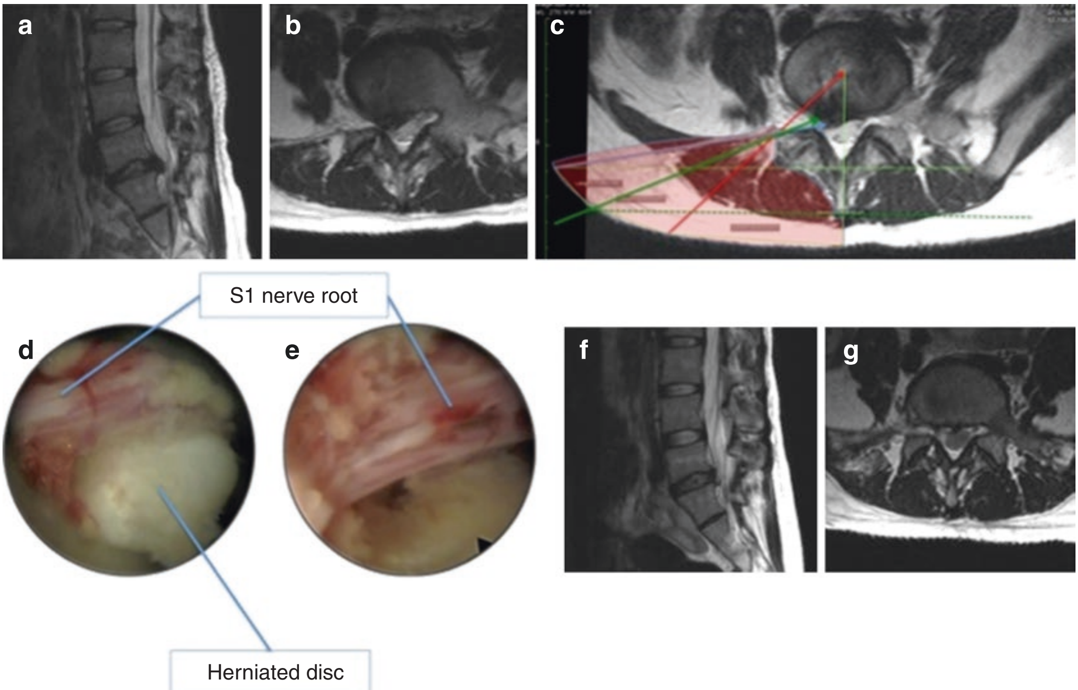

Fig. 11.6 Intracanal lumbar disc herniation (MSU 2-B, Migration 1-D) treated with percutaneous endoscopic discectomy through posterolateral approach (outside-inside technique). (**a**) Preoperative sagittal T2-weighted MRI showed disc herniation at right L5S1. (**b**) Preoperative axial T2-weighted MRI showed disc herniation at right L5S1. (**c**) Different trajectories of posterolateral approach (red arrow-Yeung et al. [4]; blue arrow-Ruetten et al. [5]; green arrow-Li et al. [6]). (**d**) Expose the HDs. (**e**) Endoscopic view of decompression of right S1 nerve root. (**f**) 1 day postoperative sagittal T2-weighted MRI showed decompression of right S1 nerve root. (**g**) 1 day postoperative axial T2-weighted MRI showed decompression of right S1 nerve root

level of intervertebral disc or low-grade migration, conventional percutaneous endoscopic lumbar discectomy (PELD) through posterolateral or far lateral approach is enough to remove the intradiscal free nucleus pulposus and prolapse of the nucleus pulposus [4, 5] (Fig. 11.6).

But conventional PELD with the "inside-outside technique" has a 4.3–10.3% surgical failure rate, especially in central HDs, migrated HDs, and axillary type HDs [7]. PELD with foraminoplasty has been used for complex HDs. Foraminoplasty was defined as "widening of the foramen by undercutting of ventral part of the superior articular process (SAP) with ablation of the foraminal ligament, using bone trephines or an endoscopic drill and side-firing laser to visualize the anterior epidural space and its contents" [8].

For uncontained HDs or MSU grade 3 limited at the level of intervertebral disc or low-grade migration, foraminoplasty with partial resection of ventral bony structure of superior articular process should be adopted to ensure complete removal of herniated intervertebral disc tissue without omission [6] (Fig. 11.7).

For HDs with high-grade upward migration, foraminoplasty with resection of the tip of superior articular process should be adopted to ensure complete removal of herniated intervertebral disc tissue without omission (Fig. 11.8).

For HDs with very high-grade upward migration, foraminoplasty with partial resection of ventral bony structure of cephalad-vertebral isthmus should be adopted to ensure complete removal of herniated intervertebral disc tissue without omission (Fig. 11.9). In some cases, foraminoplasty

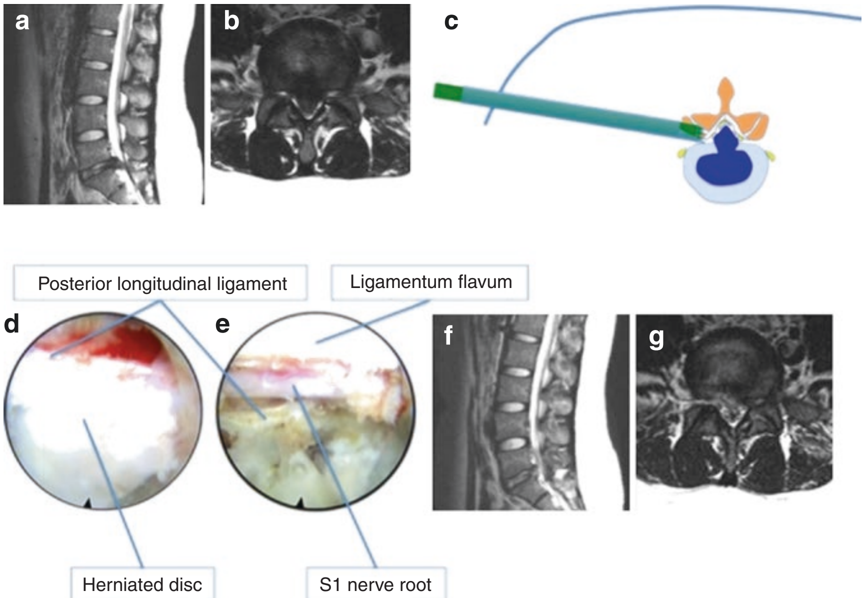

Fig. 11.7 Intracanal lumbar disc herniation (MSU 3-A, Migration 1-D) treated with percutaneous endoscopic discectomy through transforaminal approach with modified foraminoplasty technique [6]. (**a**) Preoperative sagittal T2-weighted MRI showed central disc herniation at L5S1. (**b**) Preoperative axial T2-weighted MRI showed central located high compromised disc herniation at L5S1. (**c**) Modified foraminoplasty. (**d**) Expose the HDs. (**e**) Endoscopic view of decompression of right S1 nerve root. (**f**) 1 day postoperative sagittal T2-weighted MRI showed decompression of dura sac. (**g**) 1 day postoperative axial T2-weighted MRI showed decompression of dura sac

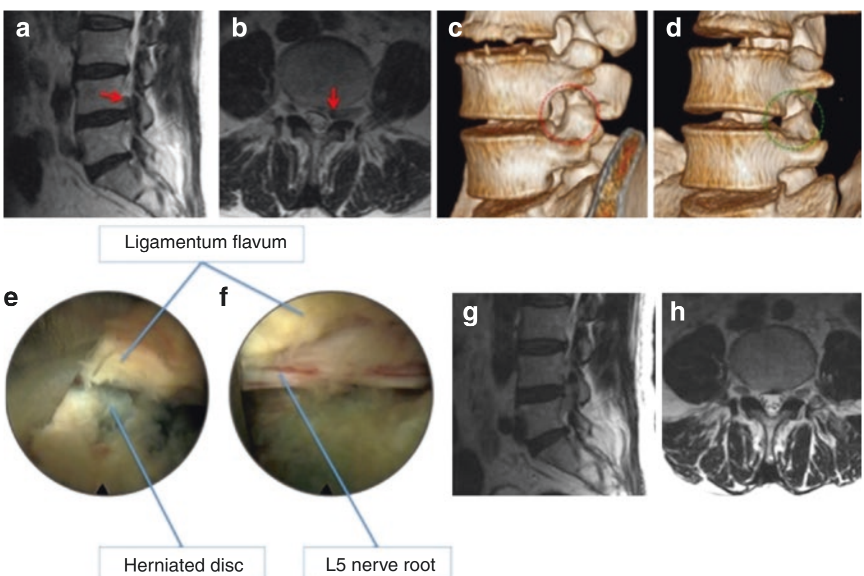

Fig. 11.8 Intracanal lumbar disc herniation (MSU 2-B, Migration 2-U) treated with percutaneous endoscopic discectomy through transforaminal approach with modified foraminoplasty technique [6]. (**a**) Preoperative sagittal T2-weighted MRI showed left disc herniation with upward migration at L4–5. (**b**) Preoperative axial T2-weighted MRI showed left upward migrated disc herniation compressing the left L4 nerve root. (**c**) Preoperative 3D reconstruction CT showed left L4–5 intervertebral foramen. (**d**) Postoperative 3D reconstruction CT showed left L4–5 intervertebral foramen after foraminoplasty. (**e**) Expose the HDs. (**f**) Endoscopic view of decompression of left L5 nerve root. (**g**) 3 months postoperative sagittal T2-weighted MRI showed decompression of left lateral recess. (**h**) 3 months postoperative axial T2-weighted MRI showed decompression of left L4 nerve root

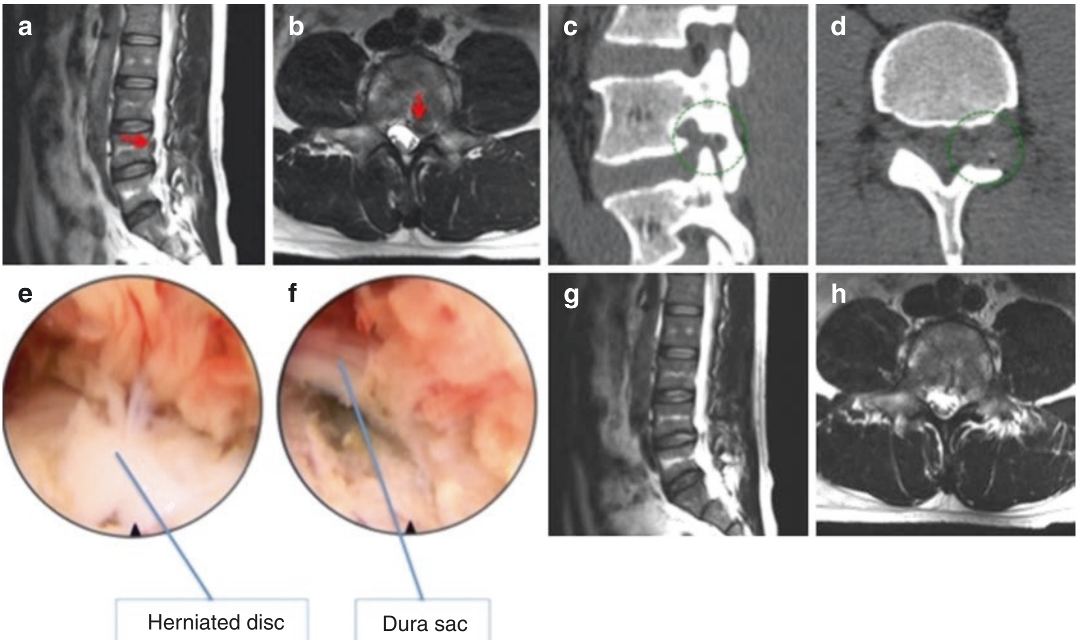

Fig. 11.9 Intracanal lumbar disc herniation (MSU 2-B, Migration 3-U) treated with percutaneous endoscopic discectomy through transforaminal approach with modified foraminoplasty technique. (**a**) Preoperative sagittal T2-weighted MRI showed left disc herniation with very high upward migration at L4–5. (**b**) Preoperative axial T2-weighted MRI showed left very high upward migrated disc herniation compressing the left L4 nerve root. (**c**, **d**) Postoperative 2D reconstruction CT showed left sublaminar foraminoplasty (green dotted circle). (**e**) Expose the HDs medial to left L4 pedicle. (**f**) Endoscopic view of decompression of left L4 nerve root. (**g**) 1 day postoperative sagittal T2-weighted MRI showed decompression of left lateral recess. (**h**) 1 day postoperative axial T2-weighted MRI showed decompression of left L4 nerve root

through suprapedicle or transpedicle approach at the upper level might be combined (Fig. 11.10).

For HDs with high-grade or very high-grade downward migration, foraminoplasty through suprapedicular or transpedicular approach can ensure complete removal of HDs [9] (Fig. 11.11).

11.1.2.2 Interlaminar Approach

Before percutaneous endoscopic lumbar discectomy through interlaminar approach, the surgeon should precisely position the herniated disc. According to relationship between the herniated intervertebral disc and traversing nerve root, herniated discs can be divided into axilla type, ventral type, and shoulder type [10] (Fig. 10.40). The site where the traversing nerve root exits from the dura sac also should be carefully evaluated preoperatively, which may be located cephalad, parallel, or caudal to the intervertebral disc space [11].

For the ventral type or shoulder type herniated discs, removal of the intradiscal free nucleus pulposus and prolapse of the nucleus pulposus should be performed through shoulder approach (lateral to the traversing nerve root) [10] (Fig. 11.12).

For the axilla-type herniated discs with traversing nerve root exiting from dura sac cephala or parallel to the intervertebral space, axillary approach (between the traversing nerve root and dura sac) should be adopted to remove the prolapse of the nucleus pulposus and the intradiscal free nucleus pulposus simultaneously [10] (Fig. 11.13).

For the axilla-type herniated discs with traversing nerve root exiting from dura sac caudal to the intervertebral space, axillary approach should be adopted to remove the prolapse of the nucleus pulposus firstly and then shoulder approach adopted to remove the intradiscal free nucleus pulposus (Fig. 11.14).

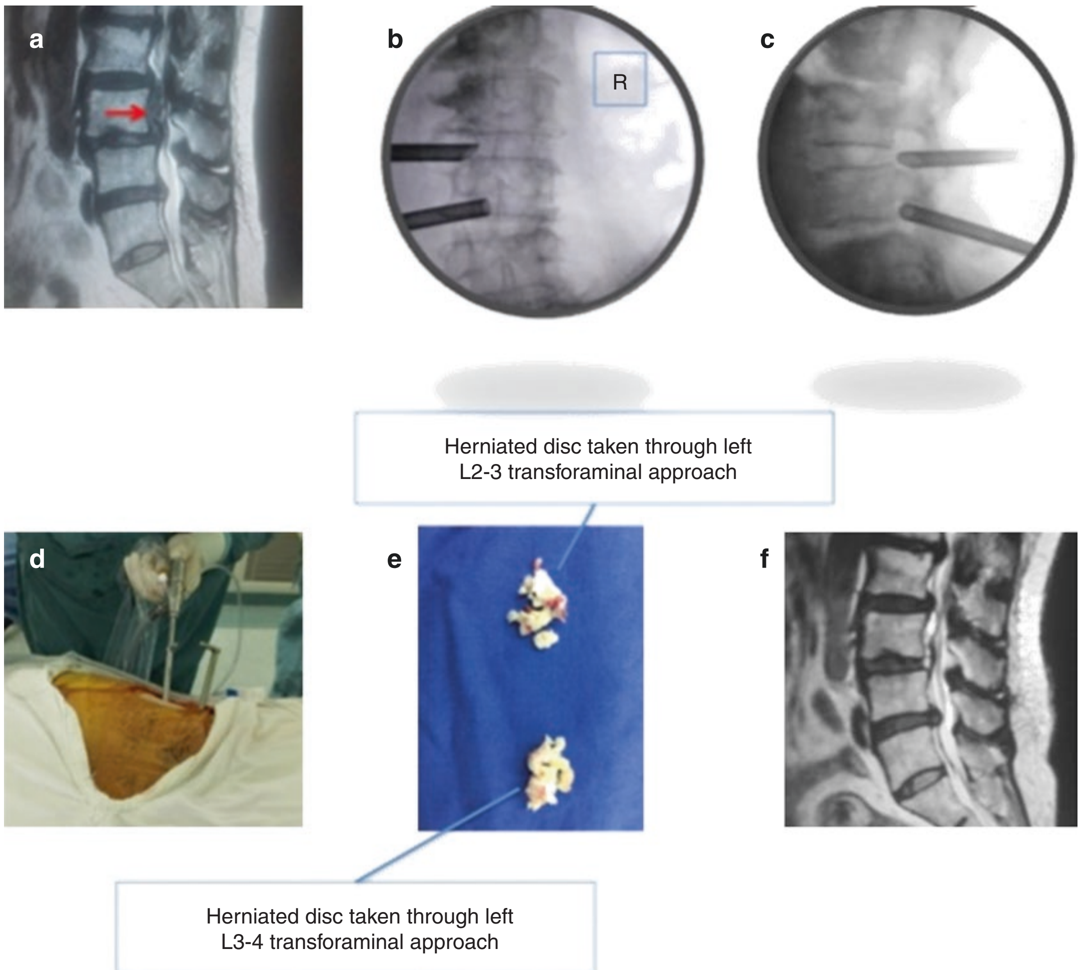

Fig. 11.10 Intracanal lumbar disc herniation (MSU 3-AB, Migration 3-U) treated with percutaneous endoscopic discectomy through two-level transforaminal approach with modified foraminoplasty technique. (**a**) Preoperative sagittal T2-weighted MRI showed disc herniation with very high upward migration at L3–4. (**b**, **c**) AP and lateral views of fluoroscopy during operation showed two-level transforaminal approach through L3–4 and L2–3 simultaneously. (**d**) Placement of two-level working channels. (**e**) HDs removed from two-level transforaminal approaches. (**f**) 1 day postoperative sagittal T2-weighted MRI showed decompression of neural structures. (Permitted by Dr. Xing Gu)

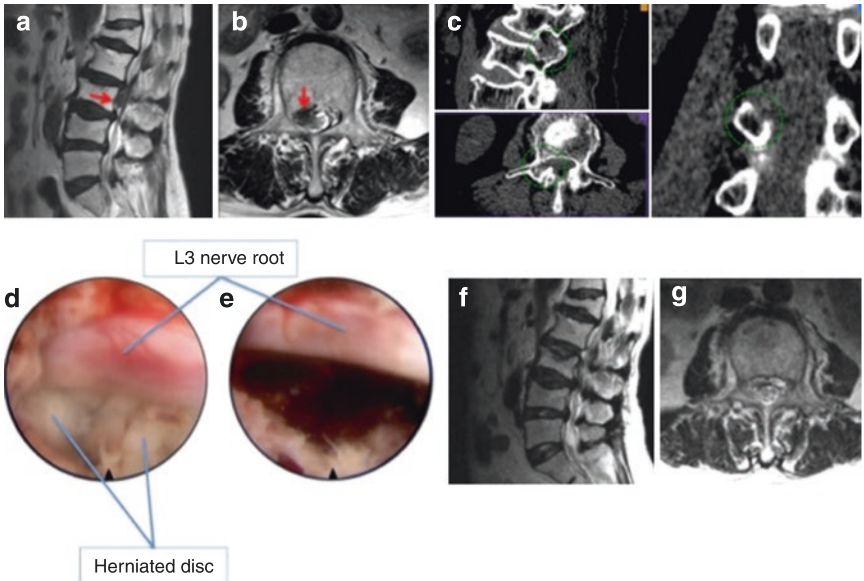

Fig. 11.11 Intracanal lumbar disc herniation (MSU 3-B, Migration 3-D) treated with percutaneous endoscopic discectomy through transforaminal approach with modified foraminoplasty technique. (**a**) Preoperative sagittal T2-weighted MRI showed right disc herniation with very high downward migration at L2–3. (**b**) Preoperative axial T2-weighted MRI showed right very high downward migrated disc herniation compressing the right L3 nerve root. (**c**) Postoperative 2D reconstruction CT showed right transpedicular foraminoplasty (green dotted circle). (**d**) Expose the migrated HDs medial to right L3 pedicle. (**e**) Endoscopic view of decompression of right L3 nerve root. (**f**) 1 day postoperative sagittal T2-weighted MRI showed decompression of right lateral recess. (**g**) 1 day postoperative axial T2-weighted MRI showed decompression of right L3 nerve root

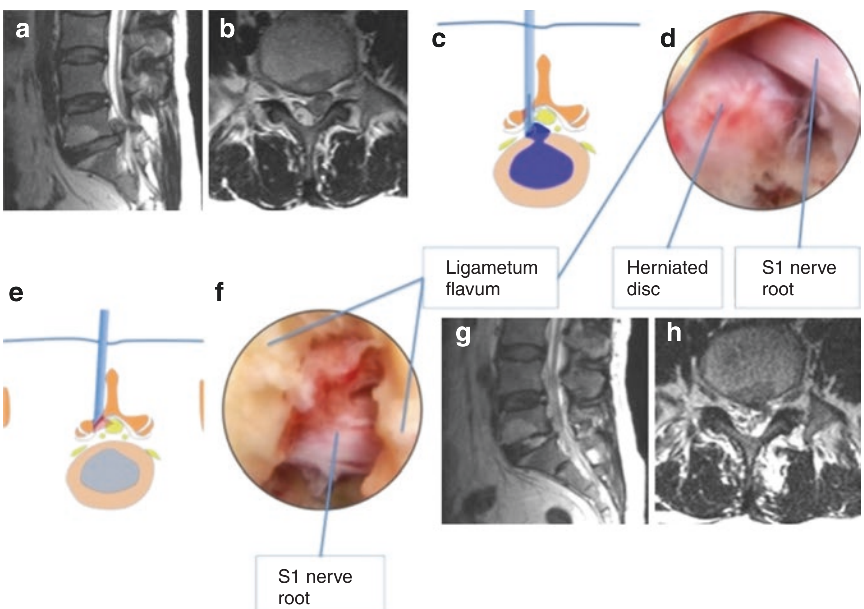

Fig. 11.12 Intracanal lumbar disc herniation (MSU 3-B, Migration 2-U) treated with percutaneous endoscopic discectomy through interlaminar approach (shoulder approach). (**a**) Preoperative sagittal T2-weighted MRI showed left disc herniation with high upward migration at L5S1. (**b**) Preoperative axial T2-weighted MRI showed left high upward migrated disc herniation. (**c**, **d**) Expose the migrated HDs. (**e**, **f**) Endoscopic view of decompression of left S1 nerve root. (**g**) 1 day postoperative sagittal T2-weighted MRI showed decompression of left lateral recess. (**h**) 1 day postoperative axial T2-weighted MRI showed decompression of left S1 nerve root

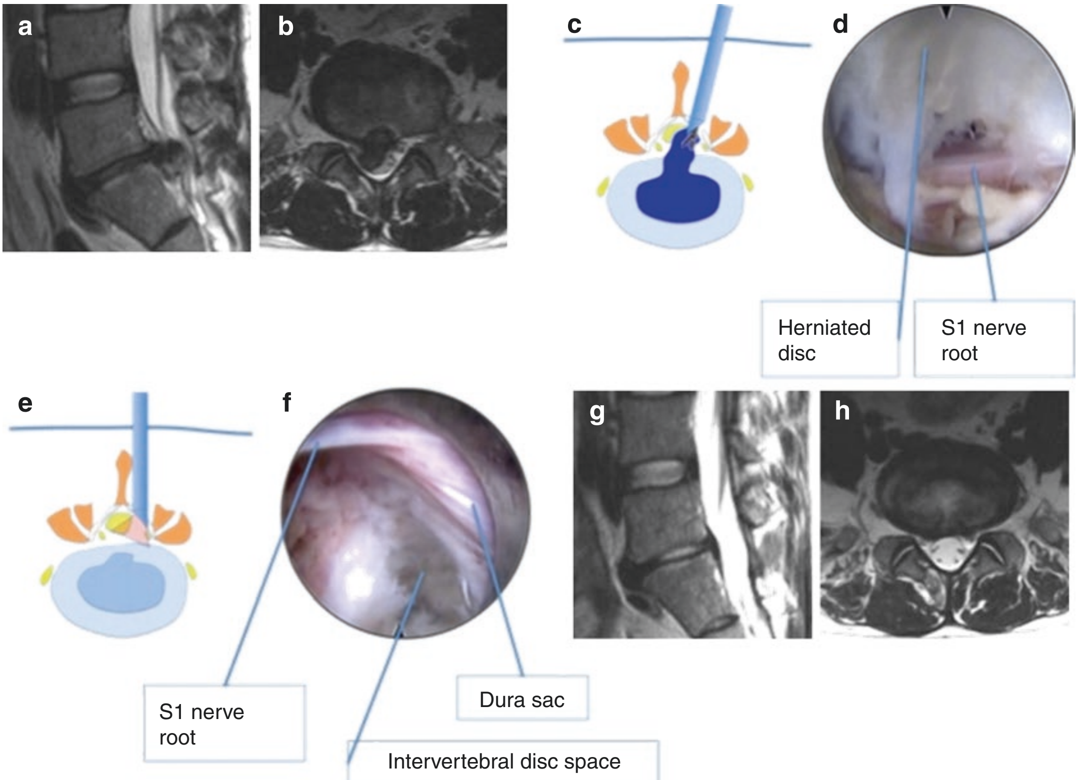

Fig. 11.13 Intracanal lumbar disc herniation (MSU 3-AB, Migration 2-D) treated with percutaneous endoscopic discectomy through interlaminar approach (axilla approach). (**a**) Preoperative sagittal T2-weighted MRI showed right disc herniation with high downward migration at L5S1. (**b**) Preoperative axial T2-weighted MRI showed right high downward migrated disc herniation (axilla type) compressing the right S1 nerve root. (**c**, **d**) Endoscopic exposure and removal of the migrated HDs. (**e**, **f**) Endoscopic view of decompression of right S1 nerve root and dura sac. (**g**) 3 months postoperative sagittal T2-weighted MRI showed decompression of right lateral recess. (**h**) 3 months postoperative axial T2-weighted MRI showed decompression of right S1 nerve root

11.2 Lumbar Spine Stenosis

Lumbar spinal stenosis is narrowing of the lumbar canal, causing compression of the dura sac and nerve roots. Spinal stenosis presents with radiculopathy, neurogenic claudication, or mechanical back pain. An extreme presentation of lumbar stenosis is cauda equina syndrome.

Stenosis may be present in the central canal, the lateral recess, and/or the intervertebral foramen. Decompressive surgery is recommended in patients with progressive neurological loss or patients whose quality of life is affected to a great extent. Wide laminectomies and facetectomies may provide permanent relief.

11.2.1 Intervertebral Foramen Stenosis

The intervertebral foramen is bordered superiorly by the inferior border of the pedicle above and inferiorly by the superior border of the pedicle below. Posterior borders include the pars, ligamentum, and the superior facet. Compression may arise from an intraforaminal disc protrusion or hypertrophy of the medial aspect of the superior facet (Fig. 11.15), or by a pars defect with fibrous overgrowth (Fig. 11.16). The foramen is further subdivided into the midzone and exit zones. The midzone contains the dorsal root ganglion (DRG) and ventral root, whereas the exit

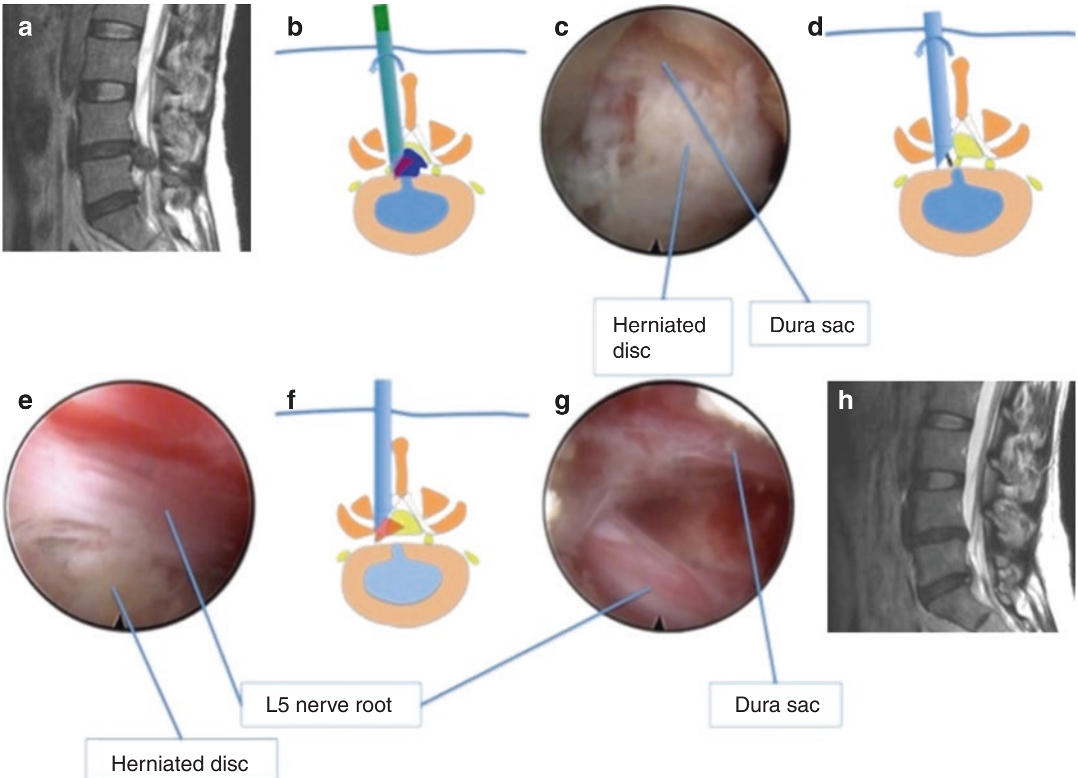

Fig. 11.14 Intracanal lumbar disc herniation (MSU 3-AB, Migration 2-D) treated with percutaneous endoscopic discectomy through interlaminar approach (axilla and shoulder approach). (**a**) Preoperative sagittal T2-weighted MRI showed L4–5 disc herniation with high downward migration. (**b**, **c**) Endoscopic exposure and removal of the migrated HDs through axilla approach. (**d**, **e**) Transfer the working channel to shoulder zone, expose and remove HDs (shoulder approach). (**f**, **g**) Endoscopic view of decompression of axilla and shoulder zone around left L5 nerve root. (**h**) 3 months postoperative sagittal T2-weighted MRI showed decompression of neural structures

zone contains the peripheral nerve. Normal foraminal height is between 20 and 23 mm. Foraminal height less than 15 mm and posterior disc height less than 4 mm are associated with nerve root compression in 80% of patients [12–14].

Intervertebral foramen stenosis can be decompressed with percutaneous endoscopic procedures through ipsilateral transforaminal approach or contralateral interlaminar approach (Fig. 11.17). Hypertrophy of the superior facet, fibrous or cartilaginous overgrowth anterior to the pars defect, and/or intraforaminal disc protrusion can be resected endoscopically so that the release and decompression of the exiting nerve root can be achieved [15–17].

11.2.2 Lateral Recess Stenosis

The lateral recess is also known as the subarticular or entrance zone. It is bordered anteriorly by the posterolateral vertebral body and disc, posteriorly by the pars interclaris and ligamentum flavum, laterally by the superior facet, and medially by the inferior facet. The lateral recess is narrowest at the superior border of the corresponding pedicle. Normally, the lateral recess should be more than 5 mm in height. Relative stenosis is present if the lateral recess height is between 3 and 5 mm, and absolute lateral recess stenosis is present when the height is less than 3 mm [18, 19].

Lateral recess stenosis can be effectively decompressed with percutaneous endoscopic

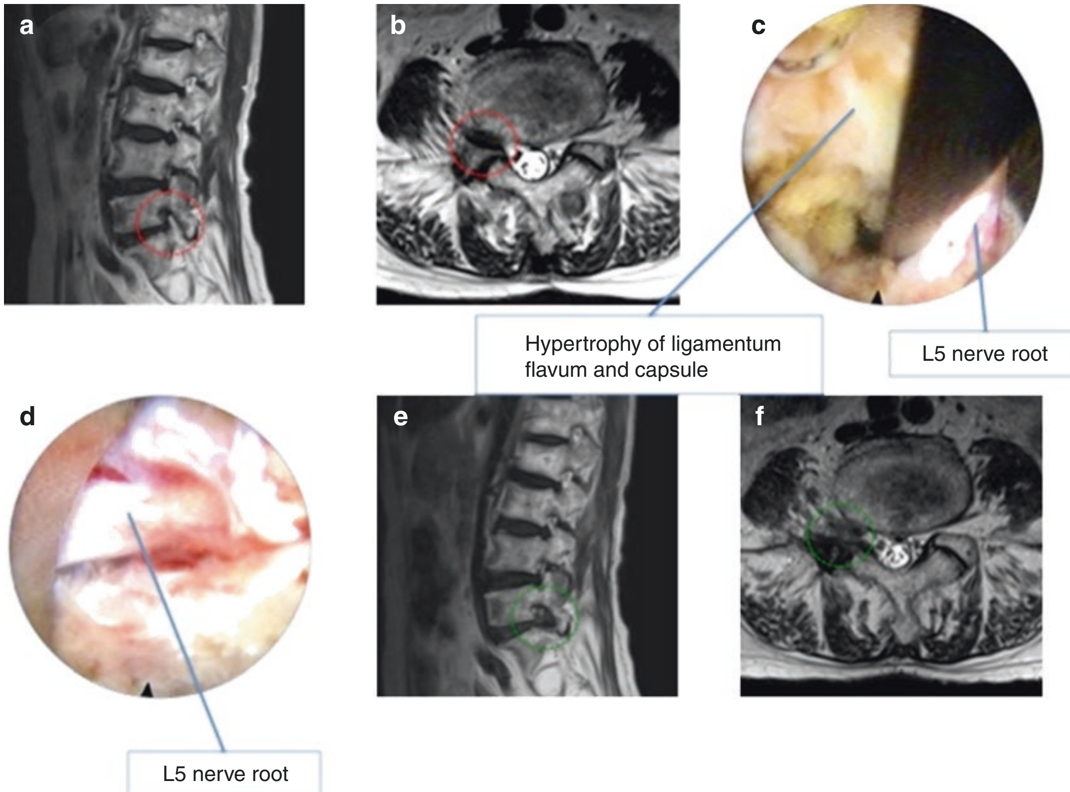

Fig. 11.15 Intervertebral foraminal stenosis caused by hypertrophied facet treated with percutaneous endoscopic decompression through transforaminal approach. (**a**) Preoperative sagittal T2-weighted MRI showed right L5S1 foraminal stenosis. (**b**) Preoperative axial T2-weighted MRI showed right L5S1 foraminal stenosis compressing the right L5 nerve root. (**c**) Endoscopic view of right L5 nerve root compressed by hypertrophied ligamentum flavum and capsule of facet joint. (**d**) Endoscopic view of decompressed right L5 nerve root. (**e**) 1 day postoperative sagittal T2-weighted MRI showed adequate decompression of right L5 nerve root. (**f**) 1 day postoperative axial T2-weighted MRI showed adequate decompression of right L5 nerve root

procedures through ipsilateral transforaminal approach [20] (Fig. 11.18), ipsilateral or contralateral interlaminar approach [21] (Fig. 11.19).

11.2.3 Central Canal Stenosis

The central canal is the region occupied by the dura sac. The lumbar central canal normally has a midsagittal diameter greater than 13 mm. Relative stenosis is defined as an anteroposterior (AP) canal diameter between 10 and 13 mm, and absolute stenosis is present when the AP canal diameter is less than 10 mm. The normal thecal sac measures 16–18 mm. The area of the normal sac should be more than 100 mm^2. When the sac is compressed to an area measuring between 76 and 100 mm^2, the compression is described as moderate stenosis. An area less than 76 mm^2 suggests severe spinal canal stenosis [22, 23].

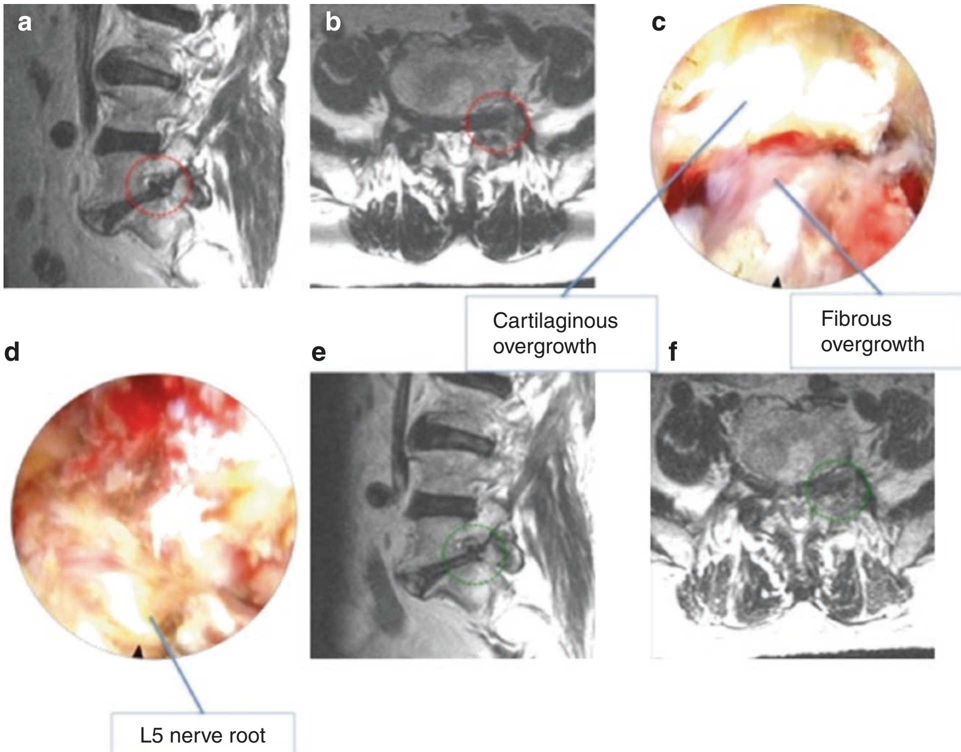

Fig. 11.16 Intervertebral foraminal stenosis caused by a pars defect with fibrous overgrowth treated with percutaneous endoscopic decompression through transforaminal approach. (**a**) Preoperative sagittal T2-weighted MRI showed left L5S1 foraminal stenosis. (**b**) Preoperative axial T2-weighted MRI showed left L5S1 foraminal stenosis compressing the left L5 nerve root. (**c**) Endoscopic view of right L5 nerve root compressed by hypertrophied ligamentum flavum and ligamentous and cartilaginous overgrowth around the pars defect. (**d**) Endoscopic view of decompressed left L5 nerve root. (**e**) 1 day postoperative sagittal T2-weighted MRI showed adequate decompression of left L5 nerve root (green dotted circle). (**f**) 1 day postoperative axial T2-weighted MRI showed adequate decompression of left L5 nerve root (green dotted circle)

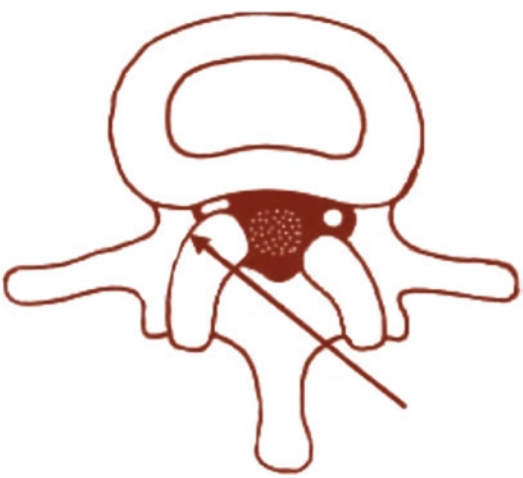

Fig. 11.17 Intervertebral foraminal stenosis can be undercutting decompressed through contralateral interlaminar approach

Central canal stenosis can be effectively decompressed with percutaneous endoscopic procedures through bilateral transforaminal approach [20] (Fig. 11.20) or interlaminar approach [24] (Fig. 11.21). Percutaneous endoscopic bilateral decompression through unilateral interlaminar approach is another option for the treatment of lumbar central canal stenosis (Fig. 11.22).

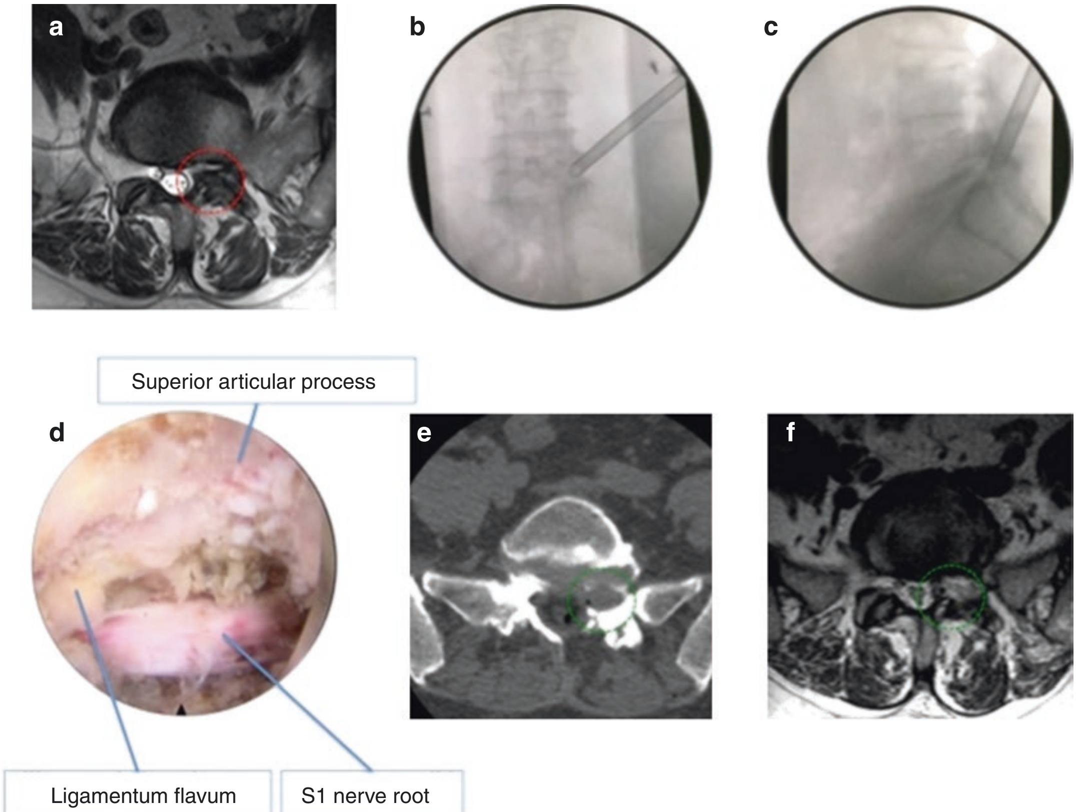

Fig. 11.18 Lateral recess stenosis caused by hypertrophied facet and ligamentum flavum treated with percutaneous endoscopic decompression through transforaminal approach. (**a**) Preoperative axial T2-weighted MRI showed left L5S1 lateral recess stenosis compressing the left S1 nerve root. (**b**, **c**) Position of working channel from fluoroscopic AP and lateral views. (**d**) Endoscopic view of decompressed left S1 nerve root. (**e**) 1 day postoperative CT scan showed adequate decompression of left S1 nerve root (green dotted circle). (**f**) 1 day postoperative axial T2-weighted MRI showed adequate decompression of left S1 nerve root (green dotted circle)

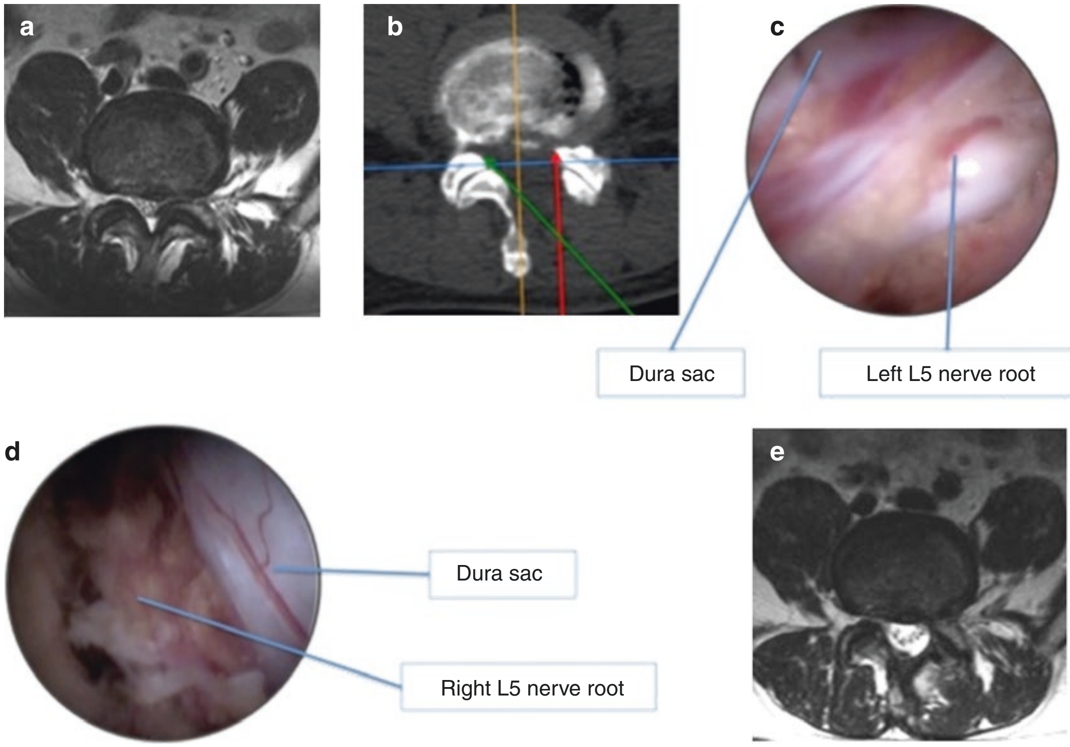

Fig. 11.19 Bilateral lateral recess stenosis caused by hypertrophied facet and ligamentum flavum treated with percutaneous endoscopic bilateral decompression through unilateral interlaminar approach. (**a**) Preoperative axial T2-weighted MRI showed bilateral L4–5 lateral recess stenosis compressing bilateral L5 nerve roots. (**b**) 1 day postoperative CT scan showed the strategy of bilateral decompression through unilateral interlaminar approach. (**c**) Endoscopic view of decompressed ipsilateral L5 nerve root. (**d**) Endoscopic view of decompressed contralateral L5 nerve root and dura sac. (**e**) 3 months postoperative axial T2-weighted MRI showed adequate decompression of bilateral L5 nerve roots

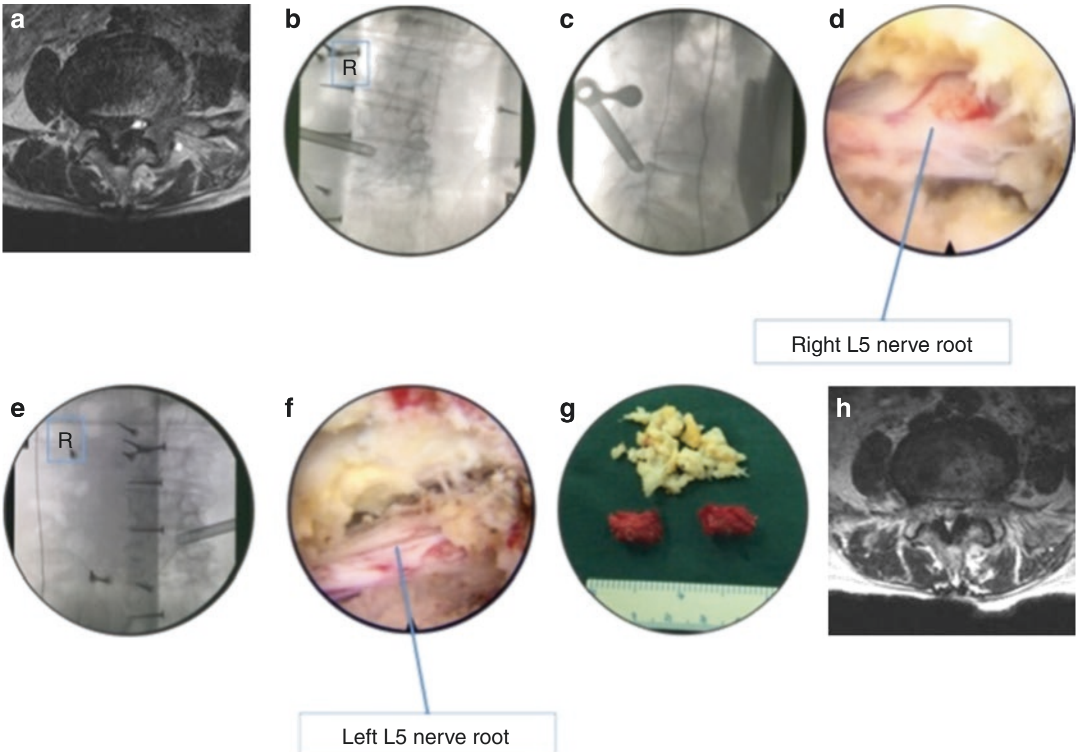

Fig. 11.20 Central stenosis caused by hypertrophied facet and ligamentum flavum posteriorly and HDs anteriorly treated with percutaneous endoscopic decompression through bilateral transforaminal approach. (**a**) Preoperative axial T2-weighted MRI showed L4–5 central stenosis. (**b**, **c**) Position of right working channel from fluoroscopic AP and lateral views. (**d**) Endoscopic view of decompressed right L5 nerve root. (**e**) Position of left working channel from fluoroscopic AP view. (**f**) Endoscopic view of decompressed left L5 nerve root. (**g**) Resected bony structure, HDs, and hypertrophied ligamentum flavum. (**h**) 1 day postoperative axial T2-weighted MRI showed adequate decompression of L4–5 lumbar canal

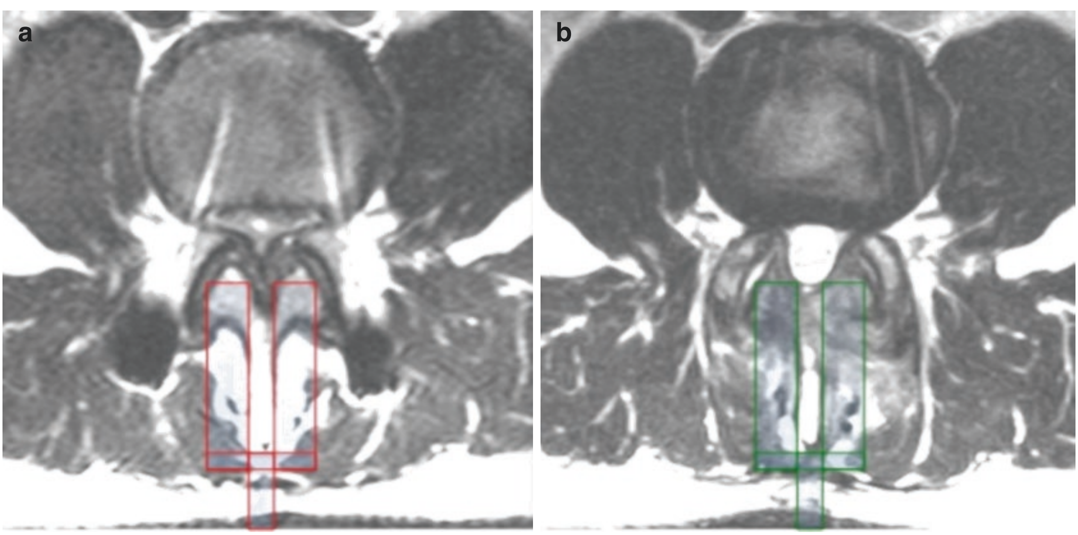

Fig. 11.21 Central stenosis treated with percutaneous endoscopic decompression through bilateral interlaminar approach with one incision. (**a**) Preoperative axial T2-weighted MRI showed L3–4 central stenosis. (**b**) 3 months postoperative axial T2-weighted MRI showed adequate decompression of L3–4 lumbar canal

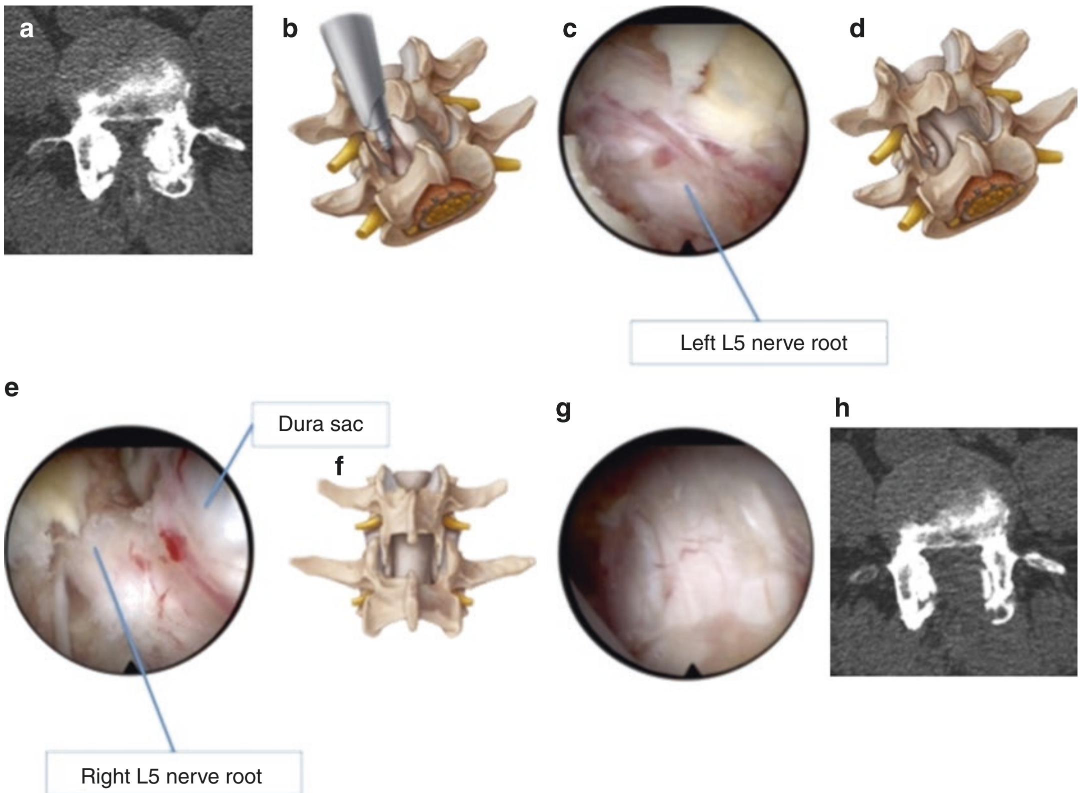

Fig. 11.22 Central stenosis caused by hypertrophied facet and ligamentum flavum treated with percutaneous endoscopic bilateral decompression through unilateral interlaminar approach. (**a**) Preoperative CT scan showed L4–5 central stenosis. (**b**, **c**) Ipsilateral laminotomy and endoscopic view of ipsilateral decompression of nerve root and dura sac. (**d**, **e**) Contralateral undercutting decompression and endoscopic view of contralateral decompression of nerve root and dura sac. (**f**, **g**) Endoscopic view of decompression of dura sac. (**h**) 1 day postoperative CT scan showed the bilateral decompression through unilateral interlaminar approach

11.3 Chronic Low Back Pain

Chronic low back pain lasts greater than 12 weeks. Spondylogenic pain originates in the spinal column and/or the associated soft tissues such as the intervertebral discs, facet joints, and paraspinal musculature. The buttock may also be the site of back-dominant pain since the buttock share the same segmental nerve supply with the lumbosacral regions (L4, L5, S1). The sinu-vertebral nerve innervates the posterior longitudinal ligaments, the ventral aspect of the dura sac, blood vessels, and the posterior part of the annulus fibrosis. Although the nucleus pulposus is not innervated, the superficial annular fibers are innervated by the sinu-vertebral nerve and branches of the lumbar ventral rami. Pressure on the posterior surface of the intervertebral disc or irritation of the superficial fibers of a herniated lumbar disc has been shown to elicit pain in the lumbosacral region or the ipsilateral hip and buttock. Lumbar facet joints are innervated by medial branches of the dorsal primary rami. Degenerative changes of the facet joints may lead to the development of two sources of pain: first, damage to the articular cartilage of the facet may lead to pain similar to osteoarthritis of any joint surface; and second, degenerative changes of the facet joint such as bony overgrowth and osteoarthritis may lead to nerve root compression [25, 26]. In addition, irritation or distention of the vertebral periosteum by a space-occupying lesion is a possible cause of axial back pain in patients with infections or tumors.

11.3.1 Discogenic Low Back Pain

The most common clinical manifestation of discogenic low back pain is persistent axial back pain, which may or may not be associated with radicular symptoms. Prolonged sitting, bending, lifting, and straining often precipitate discogenic low back pain. Pain relief may occur with rest or change in position.

Discogram and disc provocation with intradiscal injection of contrast will provoke characteristic pain and will allow for a radiographic visualization of the annular tear and disc protrusion. CT scan after discogram can reveal the site of annular tear and its severity [27, 28] (Fig. 11.23).

Although the majority of discogenic lower back pain can be successfully managed nonoperatively, surgical intervention may be utilized for the management of persistent pain in patients with identified pathology. Surgical treatment has been described for axial back pain in patients with degenerative changes secondary to internal disc derangement. Traditional treatment methods for disc derangement include spinal fusions with and without instrumentation. More recently, total disc arthroplasty has been added to the spine surgeon's armamentarium. Percutaneous endoscopic selective discectomy and annuloplasty is another treatment option for discogenic low back pain, in which the impinged nucleus pulposus is taken out and the annular tear is denervated [29–31].

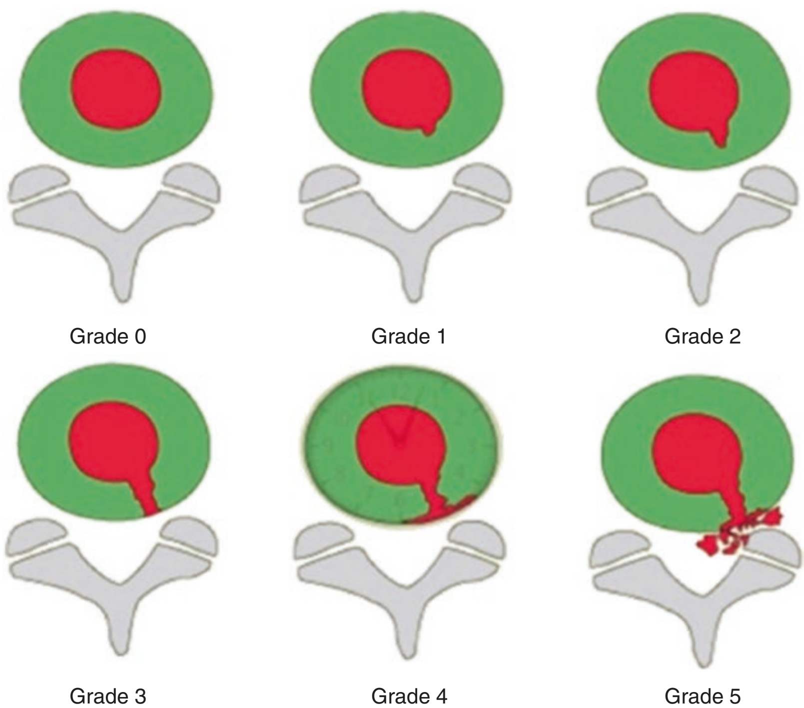

Fig. 11.23 Modified Dallas Discogram Classification [27]. The grade 0 is a normal disc, where no contrast material leaks from the nucleus. The grade 1 tear will leak contrast material only into the inner 1/3 of the annulus. The grade 2 tear will leak contrast through the inner 1/3 and into the middle 1/3 of the disc. The grade 3 tear will leak contrast through the inner and middle annulus. The contrast spills into the outer 1/3 of the annulus. The grade 4 tear further describes a grade 3 tear. Not only does the contrast extend into the outer 1/3 of the annulus, but also it is seen spreading concentrically around the disc. To qualify as a grade 4 tear the concentric spread must be greater than 30 degrees. Pathologically, this represents the merging of a full-thickness radial tear with a concentric annular tear. The "evil" grade 5 tear describes either a grade 3 or grade 4 radial tear that has completely ruptured that outer layers of the disc and is leaking contrast material out of the disc. This type of tear can cause a chemical radiculopathy in one or both of the extremities

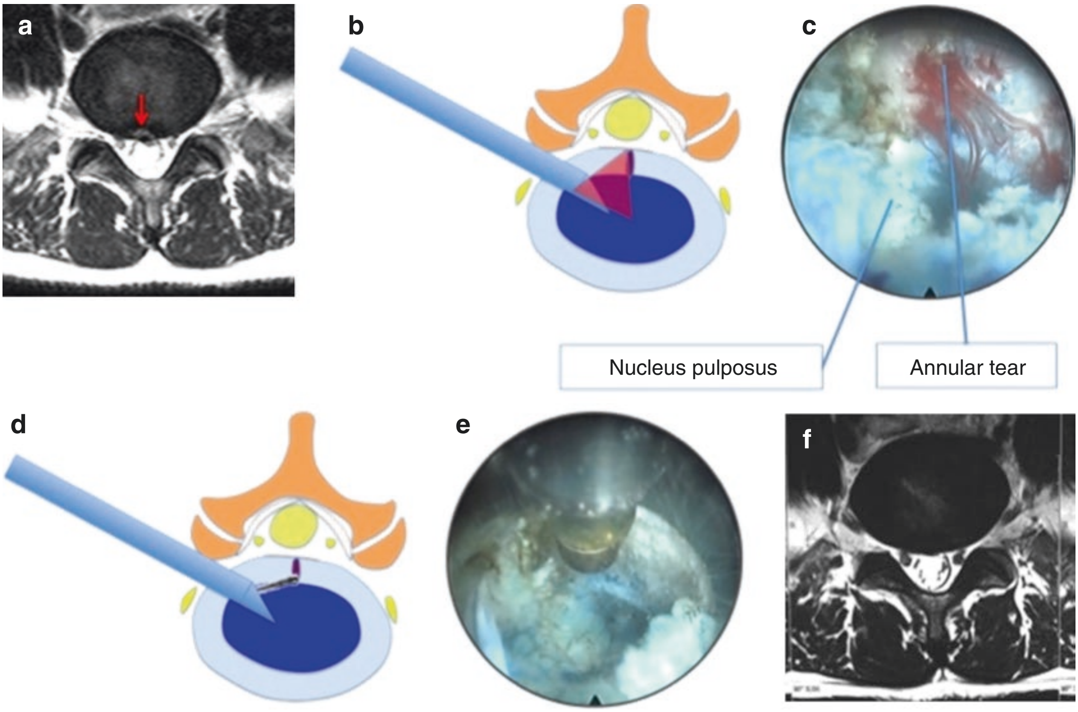

Fig. 11.24 Discogenic low back pain treated with percutaneous endoscopic selective discectomy and thermal annuloplasty through posterolateral approach. (**a**) Preoperative axial T2-weighted MRI showed high-intensity zone (HIZ) in L5S1 posterior annular fibrosus. (**b**, **c**) Endoscopic exposure of impinged nucleus pulposus, annular tear, and bleeding granulation tissue. (**d**, **e**) Endoscopic denervation of the annular tear. (**f**) 3 months postoperative axial T2-weighted MRI showed the disappearance of HIZ in the posterior annular fibrosus

Posterolateral intradiscal decompression and thermal annuloplasty have been reported to treat discogenic low back pain, with which it is difficult to approach the dorsal aspect of the posterior annular fibrosus [29] (Fig. 11.24). More accurate techniques are needed to treat the intradiscal lesions and the dorsal aspect of the posterior annular fibrosus simultaneously. Far lateral approach can be easily applied to directly approach the annular tear at L4–5 level (Fig. 11.25) while transforaminal approach with foraminoplasty (Fig. 11.26) or interlaminar approach (Fig. 11.27) should be needed to target the annular tear at L5S1 level.

11.3.2 Zygapophysial Joint Pain

The zygapophysial joints are true synovial, diarthrodial joints that are richly innervated with sensory nerve fibers. The zygapophysial joints of the lumbar spine carry approximately 18% of the load placed on the lumbar spine. As with any joint, repetitive weight-bearing activities and microtrauma can lead to the development of joint degeneration and osteoarthritis. Patients with degenerative changes of the zygapophysial joints can experience axial back pain. Generally, the zygapophysial joint-related pain is worse with extension and rotation activities. Radiologic findings are often nonspecific and poorly correlate with symptoms [32–34]. Medial branch nerve blocks can be used to detect the presence of zygapophysial joint pain in patients with axial back pain [35, 36].

Denervation of lumbar zygapophysial joints is a procedure historically used for the treatment of back pain caused by disease of these joints. Percutaneous lumbar medial branch neurotomy has been indicated as the effective methods for

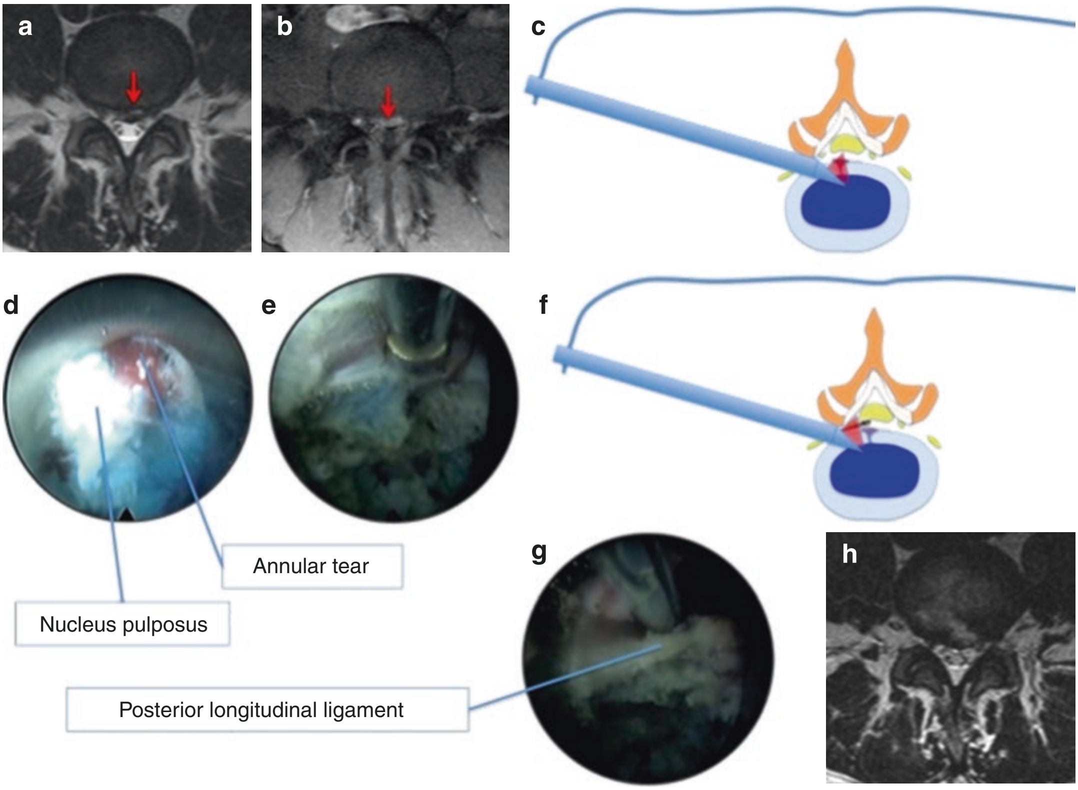

Fig. 11.25 Discogenic low back pain treated with percutaneous endoscopic selective discectomy and thermal annuloplasty through far lateral approach. (**a**) Preoperative axial T2-weighted MRI showed high-intensity zone (HIZ) in L4–5 posterior annular fibrosus. (**b**) Preoperative axial enhanced T1-weighted MRI showed enhancement of anterior epidural space. (**c**, **d**) Endoscopic exposure of impinged nucleus pulposus, annular tear, and bleeding granulation tissue. (**e**) Endoscopic denervation of the annular tear anterior to posterior longitudinal ligament. (**f**, **g**) Endoscopic denervation of the posterior aspect of posterior longitudinal ligament. (**h**) 1 day postoperative axial T2-weighted MRI showed the disappearance of HIZ in the posterior annular fibrosus

the treatment of facetogenic chronic back pain. The theoretical basis of this neurotomy is denaturing the nerves innervating the painful joint and blocks the afferent pathway of the source of the chronic low back pain. The denervation is directed at the medial branches of two adjacent posterior rami of the spinal nerves because each joint receives innervation from both the nerve exiting that level and the superjacent nerve [36–38].

A previous study reported that the effective rate of percutaneous lumbar medial branch neurotomy is only 43–80%. Anatomical variations of the medial branch of dorsal ramus anatomy, incorrect placement of electrode, incomplete ablation, and nerve regeneration may be the important factors affecting the effectiveness of percutaneous neurotomy. In a study, Li et al. [39] found multiple anatomic variants of the medial branch anatomy. In clinical practice, percutaneous puncture technique may not achieve satisfactory therapeutic benefit if it fails to reach the location of the anatomic variants of the nerve. Relief after percutaneous lumbar medial branch neurotomy typically lasts between 6 and 12 months. Pain recurs when the nerves regenerate, but relief can be reinstated by repeated neurotomy. Successful treatment which repeated two and three times has been reported; however, no limit has yet been established as to the number of

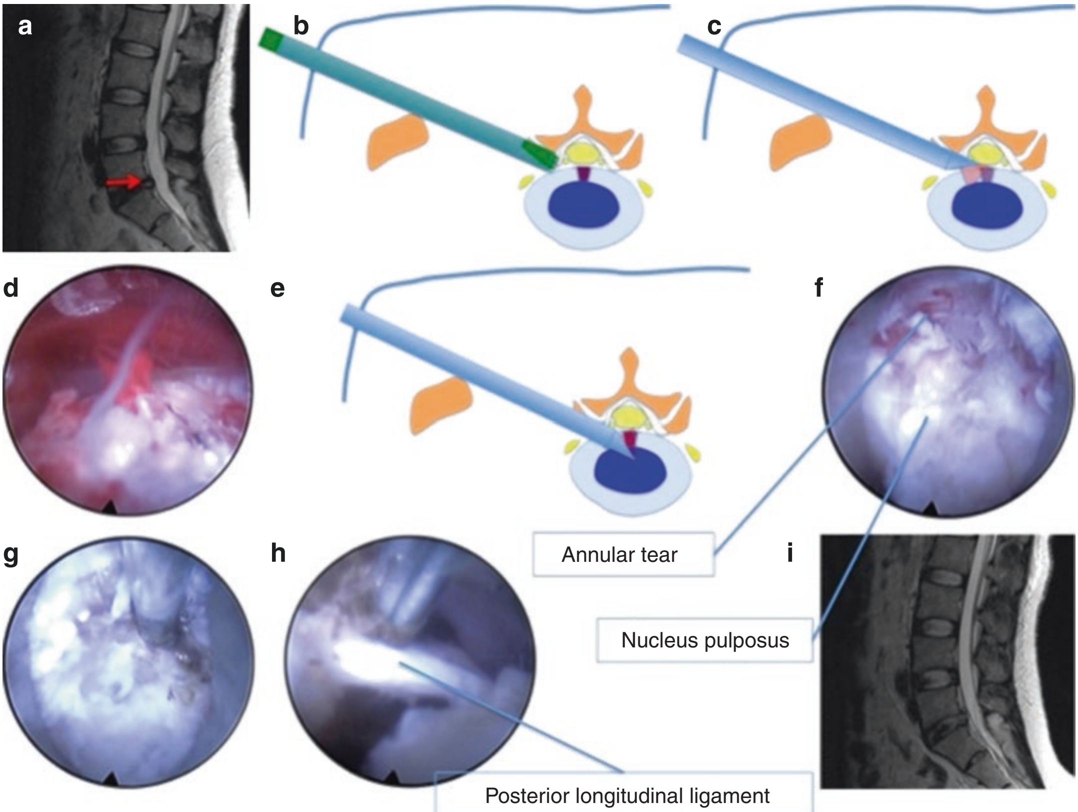

Fig. 11.26 Discogenic low back pain treated with percutaneous endoscopic selective discectomy and thermal annuloplasty through transforaminal approach with foraminoplasty. (**a**) Preoperative sagittal T2-weighted MRI showed high-intensity zone (HIZ) in posterior annular fibrosus of L5S1 disc. (**b**) Modified foraminoplasty used to enlarge the intervertebral foramen. (**c**, **d**) Working channel approach directively to the HIZ and endoscopic exposure of posterior aspect of inflamed posterior longitudinal ligament. (**e**, **f**) Endoscopic exposure of impinged nucleus pulposus, annular tear, and bleeding granulation tissue. (**g**) Endoscopic denervation of the annular tear anterior to posterior longitudinal ligament. (**h**) Endoscopic denervation of the posterior aspect of posterior longitudinal ligament. (**i**) 1 day postoperative axial T2-weighted MRI showed the disappearance of HIZ in the posterior annular fibrosus

times that the procedure can be successfully repeated to maintain relief of pain [35, 36].

Dorsal endoscopic rhizotomy can contribute to the denaturing of the normal and varied medial branches of the nerve (Fig. 11.28). It can directly cut off the medial branches, which significantly reduces the possibility of the nerve regeneration and results in a low recurrence of pain [39, 40]. In a study, Li et al. [39] found that the excellent/good McNab outcomes of the 1-year postoperative evaluation were recorded as 97.8%, with a recurrence rate of only 2.2%, suggesting that dorsal endoscopic rhizotomy achieved good therapeutic results.

Currently, there has been no consensus on the number and levels of segments for dorsal endoscopic rhizotomy. Segment selection is usually speculated according to the location of the referred pain and local tenderness. Using a comparative double block control, Manchukonda et al. reported that blocking the L2–5 (namely L3–S1 zygapophysial joint) medial branch of the dorsal ramus of the spine nerve was the most effective modality in the diagnosis of the lumbar zygapophysial joint pain. In Li ZZ' study [39], the low back pain mostly arises from the L3–S1 zygapophysial joints, which was consistent with the previous study.

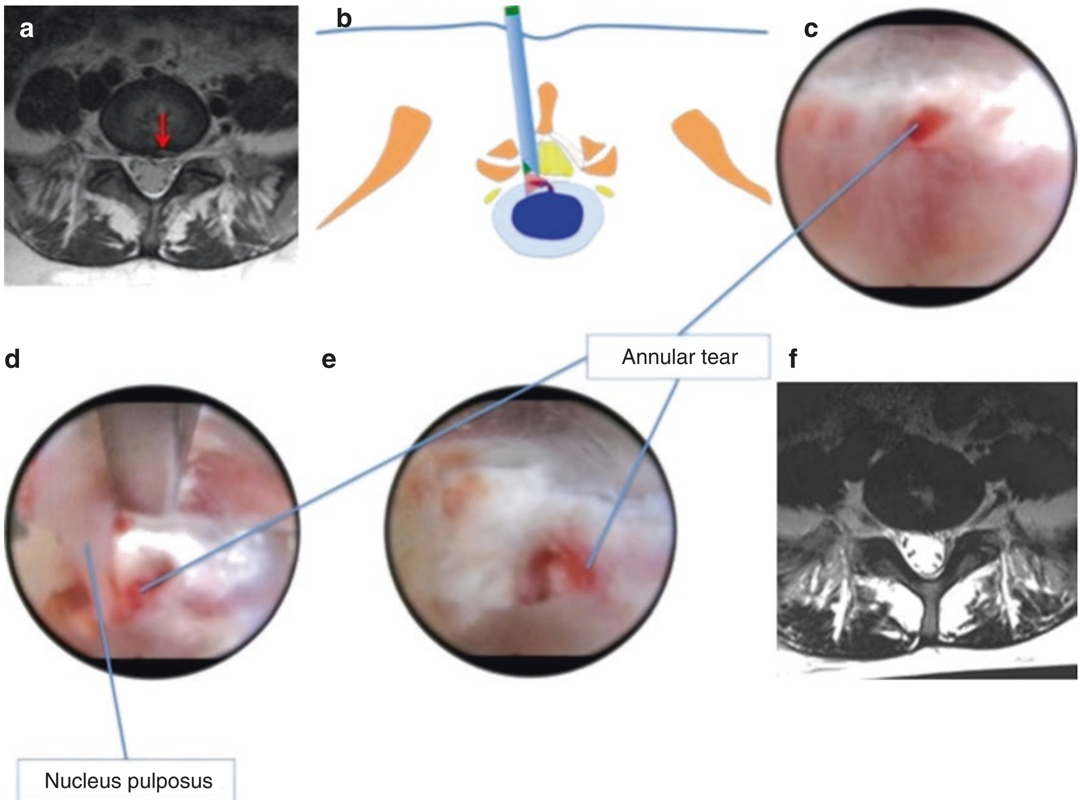

Fig. 11.27 Discogenic low back pain treated with percutaneous endoscopic selective discectomy and thermal annuloplasty through interlaminar approach. (**a**) Preoperative axial T2-weighted MRI showed high-intensity zone (HIZ) in left posterolateral annular fibrosus of L5S1 disc. (**b**, **c**) Endoscopic exposure of posterior aspect of HIZ and inflamed posterior longitudinal ligament. (**d**, **e**) Endoscopic exposure of impinged nucleus pulposus, annular tear, and bleeding granulation tissue. (**f**) 3 months postoperative axial T2-weighted MRI showed the disappearance of HIZ in the posterior annular fibrosus

11.3.3 Sacroiliac Joint Pain

The sacroiliac joint pathology may be a source of axial back pain since branches of the L4–L5 and S1–S2 dorsal rami innervate the sacroiliac joint (SIJ). The SIJs are diarthrodial, encapsulated joints. SIJ disorders often develop in the setting of inflammatory conditions, such as a spondylotic arthropathy, or in a posttraumatic setting. Patients with SIJ arthropathy typically complain of dull, aching pain, gluteal discomfort, especially with weight bearing and with ipsilateral hip and lumbosacral flexion and extension maneuvers. Plain X-rays can assess changes within the SIJs. In addition, diagnostic injections are essential for the diagnosis of SIJ-derived pain [41–43].

If a patient has a positive response to the SIJ injection after having failed nonoperative care, the next treatment option is often radiofrequency denervation or rhizotomy. The innervation of the SIJ varies among individuals, making it more difficult to be confident that the probe is in an appropriate position to effectively desensitize the targeted nerve. Particular attention should be paid to S1, S2, and S3 dorsal rami as in a recent cadaveric study they were found to contribute to the plexus of nerves innervating the SIJ in almost all specimens. Even with successful rhizotomy,

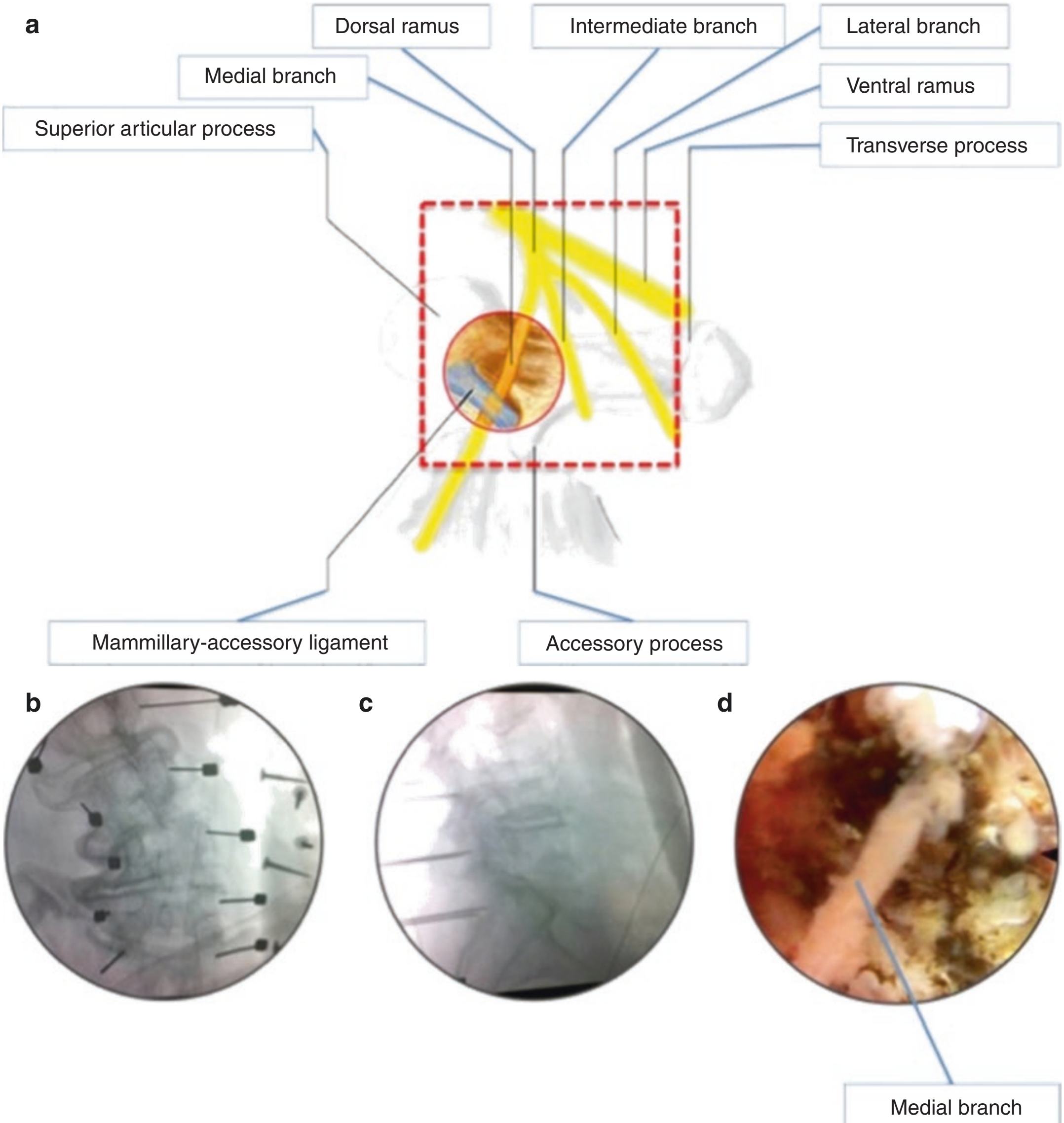

Fig. 11.28 Dorsal endoscopic rhizotomy for chronic zygapophysial joint pain. (**a**) Working zone for dorsal endoscopic rhizotomy (red circle). (**b**, **c**) Fluoroscopic position of working zone on AP and lateral views. (**d**) Endoscopic view of medial branch of dorsal ramus

the desensitized nerve may redevelop and the patient's symptoms return. Results of a meta-analysis evaluating the effectiveness of SIJ radiofrequency ablation at 3- and 6-month follow-up found the treatment to be effective. This was based on the findings that based on a sample size weighted calculation, more than half of the patients experienced at least 50% pain relief at 3 and 6 months after the denervation [44, 45]. Dorsal endoscopic rhizotomy can contribute to the long-lasting denaturing of the normal and varied L5–S2 dorsal ramus [46] (Fig. 11.29).

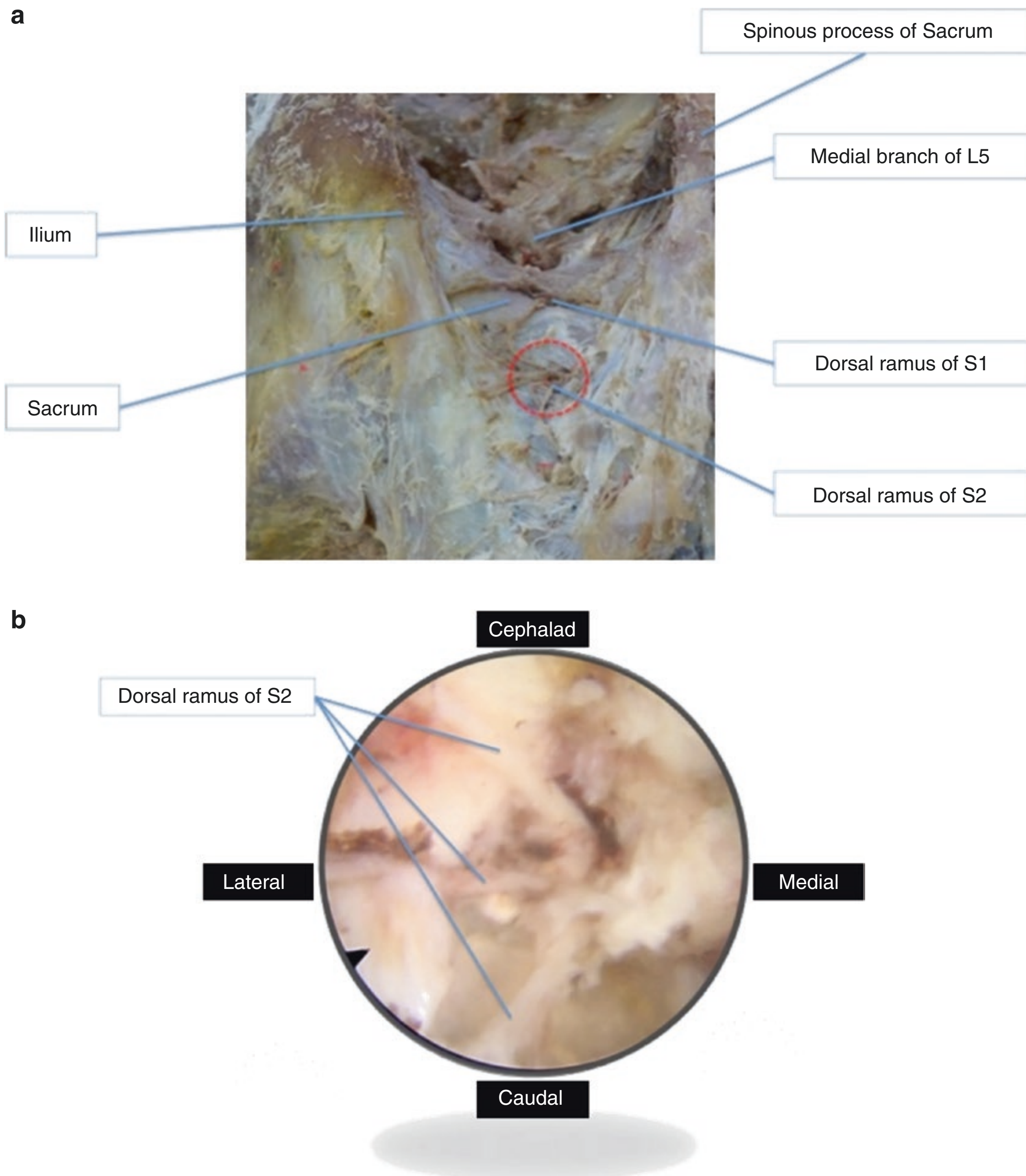

Fig. 11.29 Dorsal endoscopic rhizotomy for chronic sacroiliac joint pain. (**a**) Anatomy of dorsal ramus of S1–S3 nerve root. (**b**) Endoscopic view of dorsal ramus of S2 nerve root

11.4 Zygapophysial Joint Cyst

Synovial cysts are most commonly found in the lumbar spine, mostly at the L4–L5 level. They usually develop in patients with degenerative disc disease, zygapophysial arthropathy, and degenerative spinal stenosis. Quite frequently degenerative spondylolisthesis or zygapophysial joint instability is also found at the level of cyst formation. The latter findings, it is thought, support the notion that increased segmental motion plays a role in the pathogenesis of these cysts. Typically the cysts occupy the posterolateral aspect of the spinal canal (Fig. 11.30) or around the tip of superior articular process (Fig. 11.31), are adjacent to the facet joints, and are attached to the zygapophysial joint capsule. They contain serous or gelatinous fluid and measure up to 2 cm in diameter [47, 48].

MRI will show an extradural lesion with smooth surfaces adjacent to the facet joint. T1-weighted images may show the cyst as hypointense, isointense, or hyperintense when it contains blood. T2-weighted images show a hyperintense lesion that, at times, may communicate with the facet joint. In contrast enhanced studies the cyst's walls may enhance and show its impact on the adjacent nerve roots.

Following the diagnosis of a zygapophysial joint cyst surgery should be considered if no relief is obtained after conservative treatment or when the symptoms recur. Percutaneous endoscopic total cyst excision can be performed in order to prevent cyst recurrence. Spinal stabilization

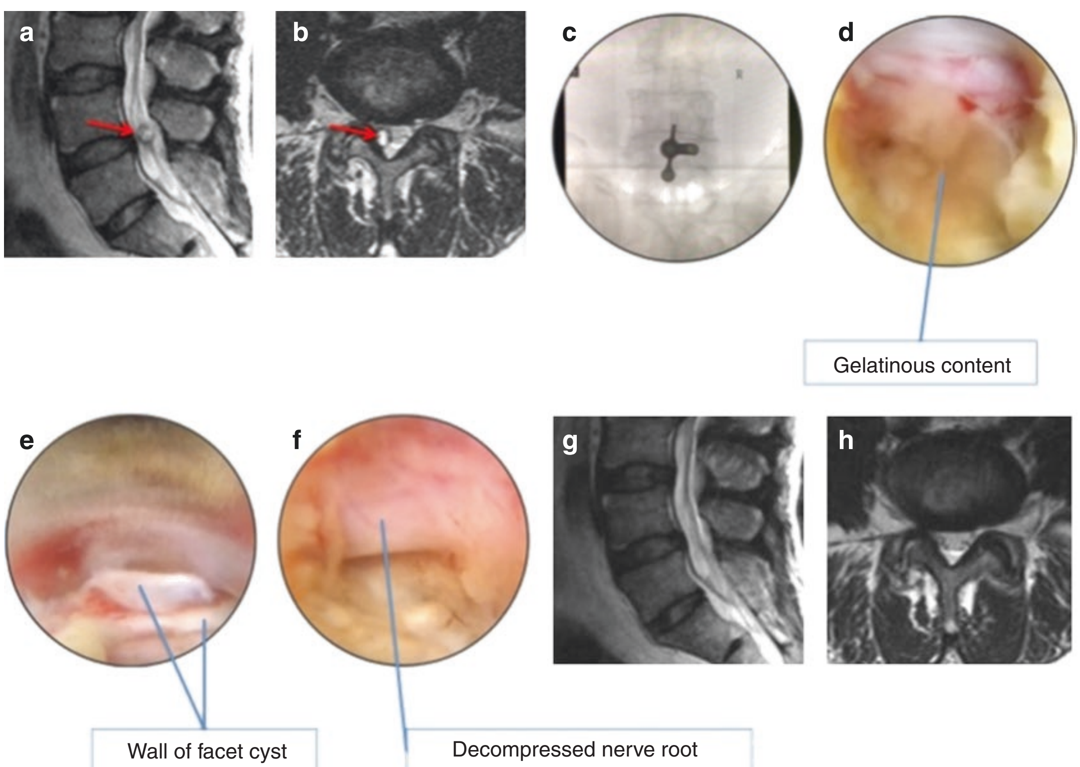

Fig. 11.30 Zygapophysial joint cyst treated with percutaneous endoscopic decompression through interlaminar approach. (**a**) Preoperative sagittal T2-weighted MRI showed right L4–5 zygapophysial joint cyst. (**b**) Preoperative axial T2-weighted MRI showed right L4–5 zygapophysial joint cyst compressing the right L5 nerve root. (**c**) Fluoroscopic position of working channel on AP view. (**d**) Endoscopic view of gelatinous content of cyst. (**e**) Endoscopic view of the cyst wall. (**f**) Endoscopic view of decompressed right L5 nerve root. (**g**) 3 months postoperative sagittal T2-weighted MRI showed resection of zygapophysial joint cyst. (**h**) 3 months postoperative axial T2-weighted MRI showed adequate decompression of right L5 nerve root

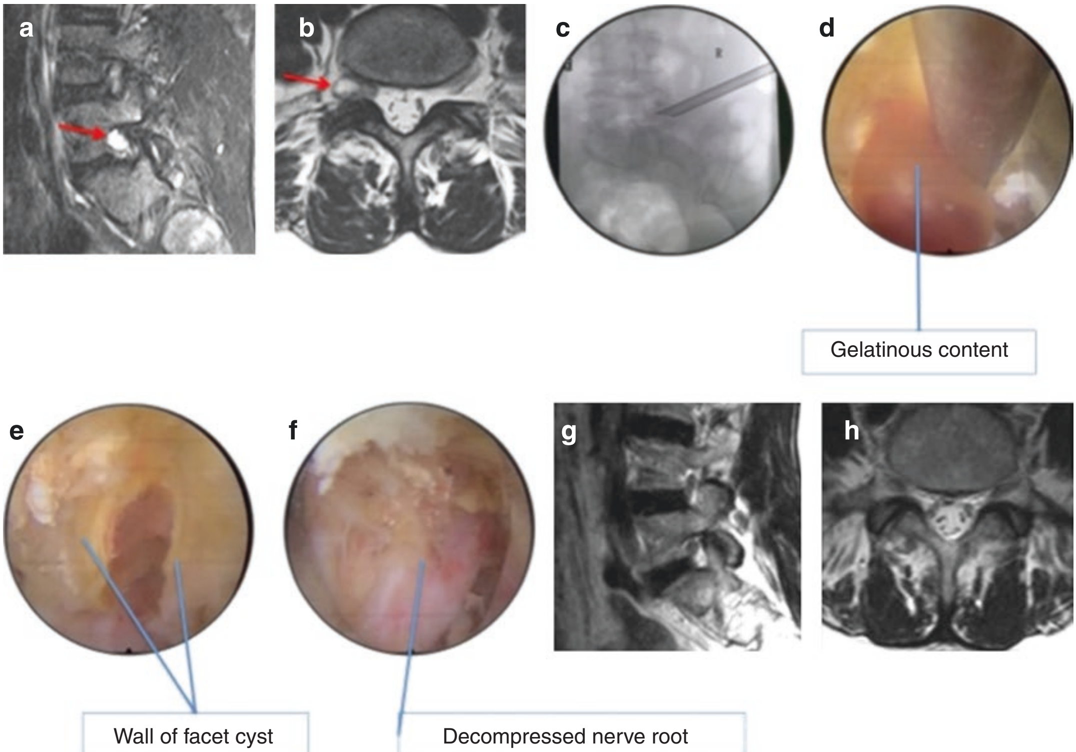

Fig. 11.31 Zygapophysial joint cyst treated with percutaneous endoscopic decompression through transforaminal approach. (**a**) Preoperative sagittal T2-weighted MRI showed right L5S1 zygapophysial joint cyst compressing right L5 nerve root. (**b**) Preoperative axial T2-weighted MRI showed right L5S1 zygapophysial joint cyst compressing the right L5 nerve root. (**c**) Fluoroscopic position of working channel on AP view. (**d**) Endoscopic view of gelatinous content of cyst. (**e**) Endoscopic view of the cyst wall. (**f**) Endoscopic view of decompressed right L5 nerve root. (**g**) 3 months postoperative sagittal T2-weighted MRI showed resection of zygapophysial joint cyst. (**h**) 3 months postoperative axial T2-weighted MRI showed adequate decompression of right L5 nerve root

should be performed in patients with local instability. Most patients do well postoperatively.

11.5 Osteoid Osteoma

Osteoid osteoma is a benign tumor found in young males in the second decade of life. Typically, the tumor is located in the posterior elements—the pedicles (Fig. 11.32), facet, or the laminae. Most of these tumors are found in the lumbar region and, less frequently, in the cervical region [49, 50].

Patients complain of unrelenting axial pain that is worse at night. The pain responds well to aspirin and NSAIDs. Antalgic scoliosis may be observed on physical examination.

Patients with unrelenting symptoms should be operated on. Percutaneous endoscopic total excision offers permanent cure [50, 51].

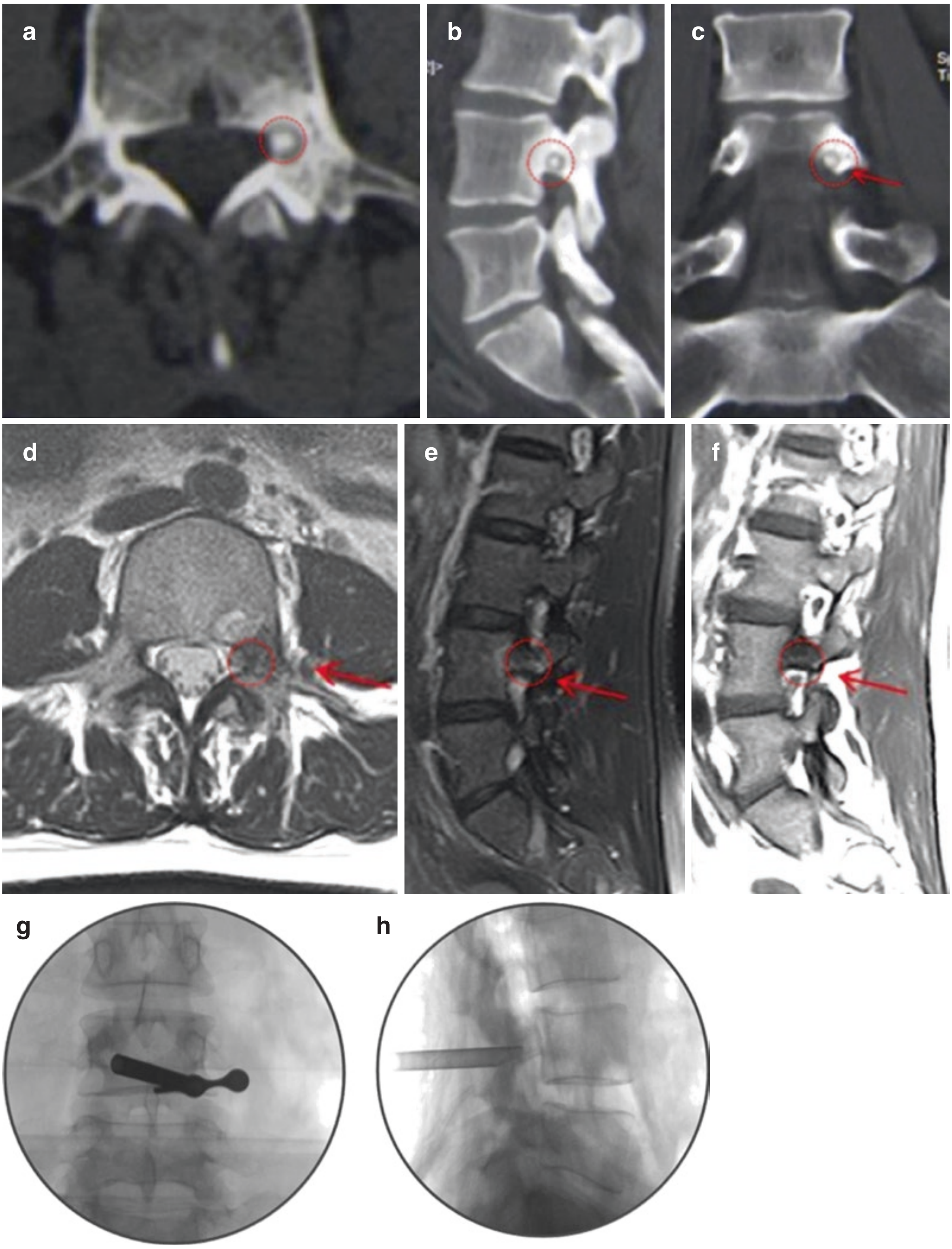

Fig. 11.32 Osteoid osteoma in left L4 pedicle treated with percutaneous endoscopic resection. (**a–c**) Preoperative 2D CT reconstruction showed a well-circumscribed, hypodense round lesion within the pedicle with a "spotted" appearance of sparse thickened trabeculae surrounded by hypodense fat in left L4 pedicle. (**d–f**) Preoperative MRI showed the lesion (hypointense on T1WI, the nidus may appear hyperintense on T2WI, and the surrounding sclerotic bone will appear hypointense, the nidus enhanced postcontrast) in left L4 pedicle. (**g**, **h**) Fluoroscopic position of working channel on AP and lateral views. (**i**) Endoscopic view of osteoid osteoma. (**j**) Endoscopic view of decompressed left L4 nerve root after resection of lesion. (**k–m**) Postoperative 2D CT reconstruction showed complete resection of lesion. (**n–p**) Series of axial T2-weighted MRI showed the clearance of lesion and the decompression of left L4 nerve root. (Permitted by Dr. Jian-Cheng Zeng)

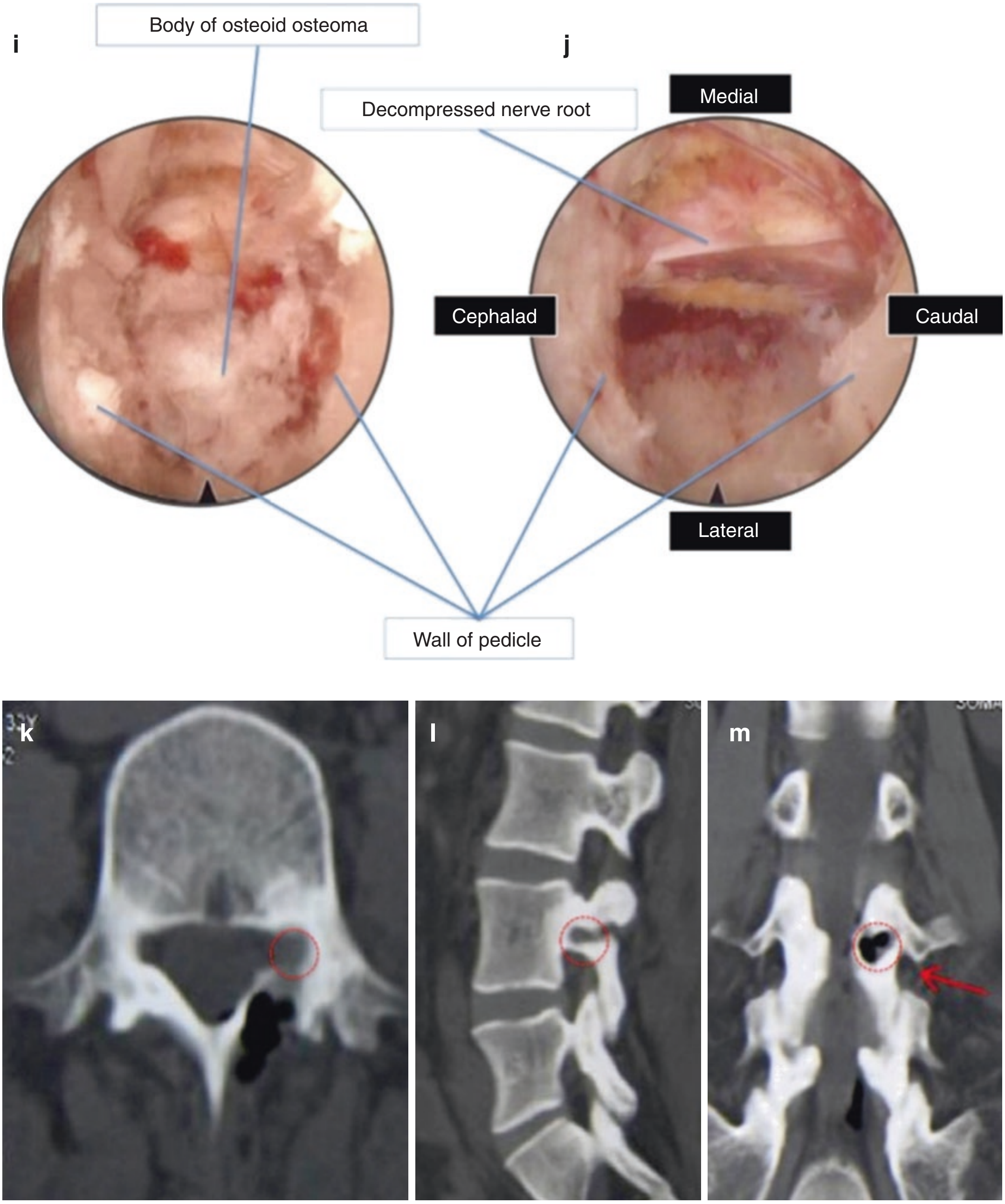

Fig. 11.32 (continued)

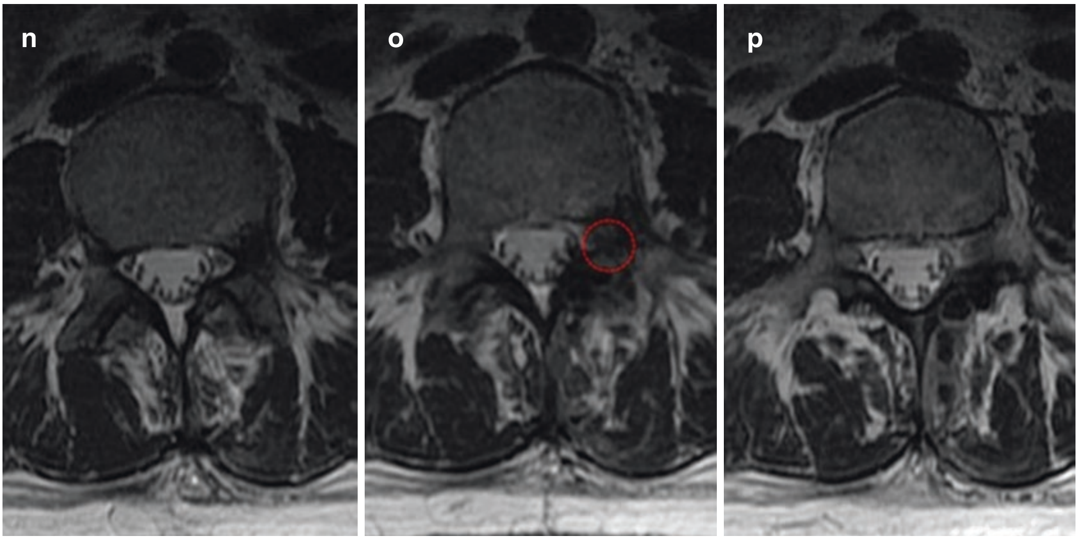

Fig. 11.32 (continued)

11.6 Burst Fractures

In lumbar burst fracture, the vertebral body is partially or completely comminuted and fragments of the posterior wall are retropulsed into the spinal canal, occasionally causing neural injuries. A minor vertical split through the posterior arch may also be found in these injuries; however, its contribution to instability is negligible because the posterior ligamentous complex is intact. Flexion and compression applied to these fractures may result in an additional loss of vertebral body height and spinal canal encroachment with risk of neurological damage.

Common radiological findings include widening and loss of vertebral body height, local kyphotic deformity, shortening of the posterior wall, and increase in the interpedicle distance. The distance between spinous processes should not (or only minimally) increase, even in kyphotic injuries. Displaced fragments into the spinal canal are better visualized on CT or MRI.

Patients with incomplete neurological injuries after a burst fracture who have residual spinal cord compression may benefit from acute surgical decompression and stabilization. Patients who suffer a complete neurological injury after burst fractures do not require immediate surgical decompression, regardless of the presence of spinal cord compression [52, 53].

The surgical goals of treating burst fractures are to decompress the spinal canal, if needed, and to restore spinal alignment. Neural structures can be decompressed either through indirect reduction, posterior or anterior approach. Sometimes retropulsed fragments can be reduced indirectly by the application of distractive forces (ligamentotaxis) and realignment of the kyphotic curvature. This procedure is successful as long as the posterior longitudinal ligament is intact during the application of distractive forces across the affected segment. When the posterior longitudinal ligament is injured or in the subacute setting, particularly when soft tissue healing prevents adequate reduction and realignment, percutaneous endoscopic direct decompression is possible through a transforaminal approach by performing a foraminotomy and partial resection of pedicle (Fig. 11.33). Percutaneous pedicle screw system can be applied to restore spinal alignment and stability [54–56].

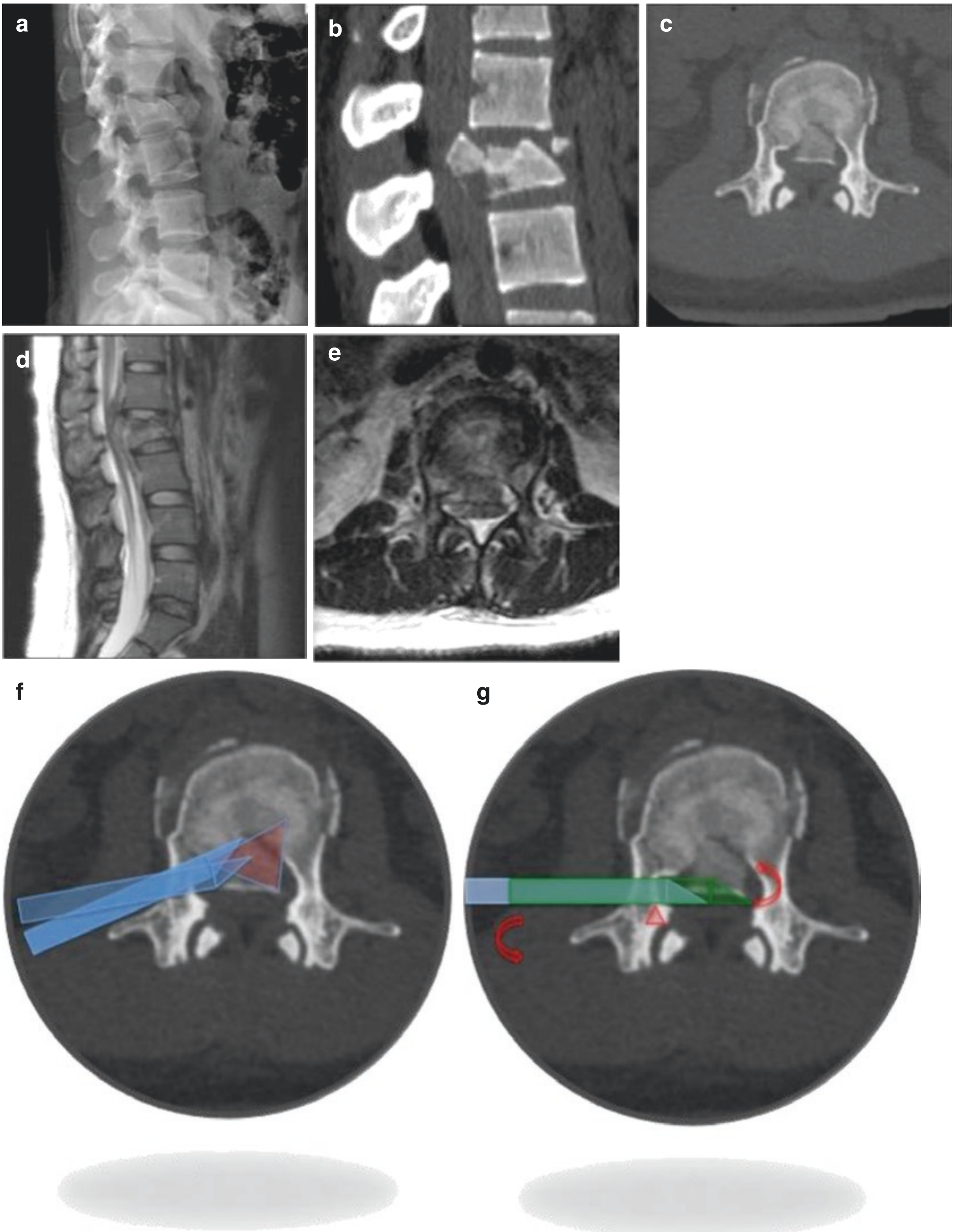

Fig. 11.33 Lumbar burst fracture treated with hybrid surgery of percutaneous endoscopic decompression and percutaneous reduction and fixation. (**a–c**) Preoperative radiography and CT showed burst fracture of L2 vertebra. (**d**, **e**) Preoperative MRI showed significant compression on the neural structure. (**f**) Preoperative planning of intrabody decompression. (**g**) Preoperative planning of resection of the cortex part of retropulsed bony fragment. (**h**) Endoscopic view of retropulsed bony fragment. (**i**) Endoscopic view of decompressed dura sac. (**j**) Postoperative radiography showed restored alignment of lumbar spine fixed with percutaneous pedicle system (Sextant reduction system, Medtronic). (**k**, **l**) 1 day postoperative 2D CT reconstruction showed adequate decompression of lumbar canal. (**m**, **n**) 3 months postoperative T2-weighted MRI showed adequate decompression of dura sac

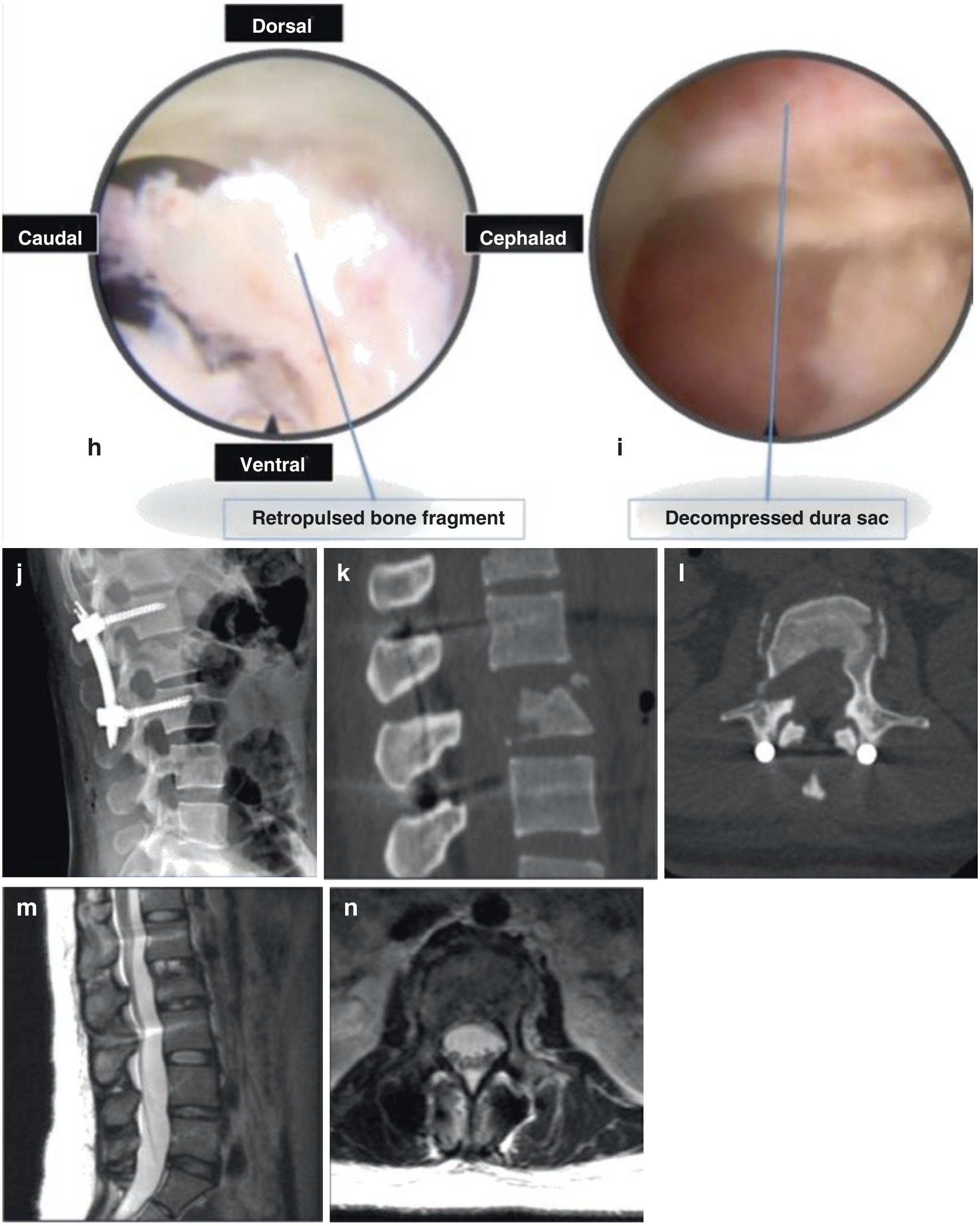

Fig. 11.33 (continued)

11.7 Lumbar Segmental Instability

Lumbar segmental instability represents the inability of the spinal motion segment to bear physiologic loads resulting in abnormal motion between two lumbar vertebrae. The most common complaint is back pain, usually mechanical in nature, although leg pain or neurologic findings from dynamic stenosis may also be seen [57–59]. The diagnosis may be made on the basis of abnormal motion on flexion/extension radiographs. Lateral flexion/extension radiographs demonstrating sagittal plane translation of greater than 12% of the AP diameter of the vertebral body or relative sagittal plane angulation of greater than 11° are the commonly accepted definition of instability [60]. Spinal fusion is often needed. Percutaneous endoscopic decompression combined with insertion of expandable cages through transforaminal or interlaminar approach can be applied to treat lumbar segmental instability [61, 62] (Fig. 11.34).

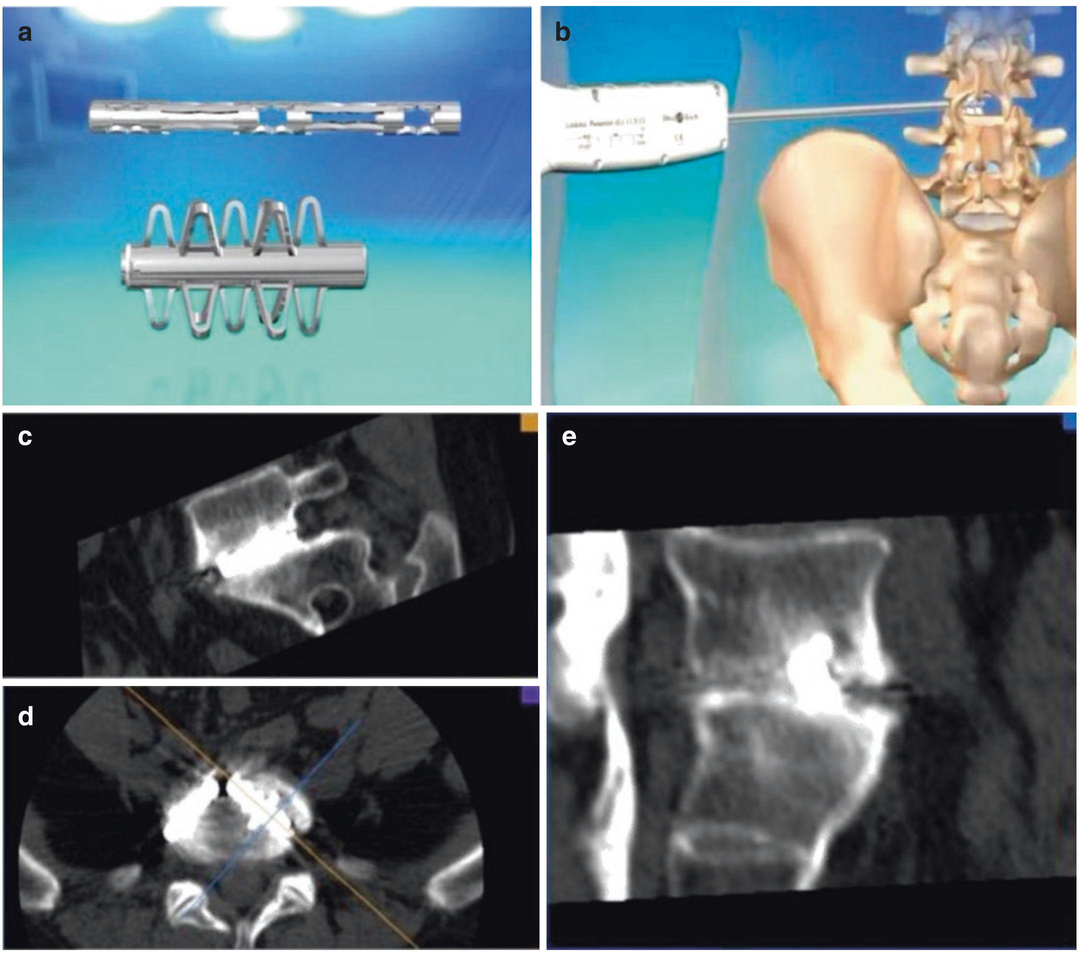

Fig. 11.34 Lumbar segmental instability can be treated with percutaneous transforaminal interbody fusion with expandable cage. (**a**) Expandable cage of B-twin. (**b**) B-twin can be inserted through transforaminal approach. (**c–e**) Postoperative 2D CT reconstruction showed interbody fusion and proper position of B-twin through transforaminal approach. (**f**) B-twin can also be inserted through interlaminar approach. (**g-i**) Postoperative 2D CT reconstruction showed interbody fusion and proper position of B-twin through interlaminar approach

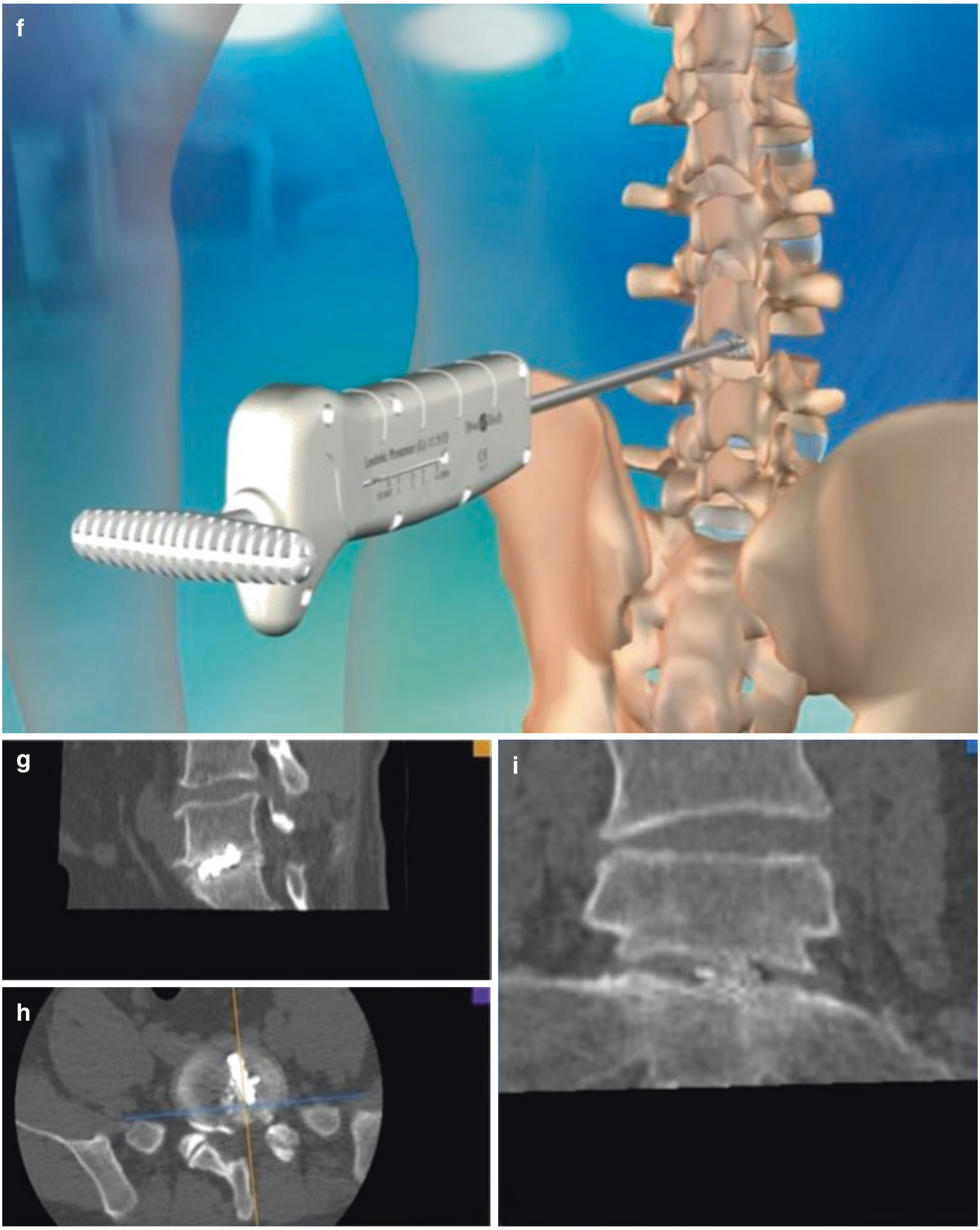

Fig. 11.34 (continued)

References

1. Mysliwiec LW, Cholewicki J, Winkelpleck MD, Eis GP. MSU classification for herniated lumbar discs on MRI: toward developing objective criteria for surgical selection. Eur Spine J. 2010;19(7):1087–93. https://doi.org/10.1007/s00586-009-1274-4.
2. Kim CH, Chung CK, Woo JW. Surgical Outcome of Percutaneous Endoscopic Interlaminar Lumbar Discectomy for Highly Migrated Disk Herniation. Clin Spine Surg. 2016;29(5):E259–66. https://doi.org/10.1097/BSD.0b013e31827649ea.
3. Lee S, Kim SK, Lee SH, Kim WJ, Choi WC, Choi G, Shin SW. Percutaneous endoscopic lumbar discectomy for migrated disc herniation: classification of disc migration and surgical approaches. Eur Spine J. 2007;16(3):431–7. https://doi.org/10.1007/s00586-006-0219-4.
4. Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases. Spine. 2002;27(7):722–31.
5. Ruetten S, Komp M, Godolias G. An extreme lateral access for the surgery of lumbar disc herniations inside the spinal canal using the full-endoscopic uniportal transforaminal approach-technique and prospective results of 463 patients. Spine. 2005;30(22):2570–8.
6. Li ZZ, Hou SX, Shang WL, Song KR, Zhao HL. Modified percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar discectomy: instrument design, technique notes, and 5 years follow-up. Pain Physician. 2017;20(1):E85–98.
7. Lee SH, Kang BU, Ahn Y, Choi G, Choi YG, Ahn KU, Shin SW, Kang HY. Operative failure of percutaneous endoscopic lumbar discectomy: a radiologic analysis of 55 cases. Spine. 2006;31(10):E285–90. https://doi.org/10.1097/01.brs.0000216446.13205.7a.
8. Choi G, Lee SH, Lokhande P, Kong BJ, Shim CS, Jung B, Kim JS. Percutaneous endoscopic approach for highly migrated intracanal disc herniations by foraminoplastic technique using rigid working channel endoscope. Spine. 2008;33(15):E508–15. https://doi.org/10.1097/BRS.0b013e31817bfa1a.
9. Wang D, Pan H, Hu Q, Zhu H, Zhu L, He Y, Wang J, Jia G. Percutaneous endoscopic transpedicle approach for herniated nucleus pulposus in the lumbar hidden zone. Asian J Endosc Surg. 2017;10(1):87–91. https://doi.org/10.1111/ases.12320.
10. Li ZZ, Hou SX, Shang WL, Song KR, Zhao HL. The strategy and early clinical outcome of full-endoscopic L5/S1 discectomy through interlaminar approach. Clin Neurol Neurosurg. 2015;133:40–5. https://doi.org/10.1016/j.clineuro.2015.03.003.
11. Suh SW, Shingade VU, Lee SH, Bae JH, Park CE, Song JY. Origin of lumbar spinal roots and their relationship to intervertebral discs: a cadaver and radiological study. J Bone Joint Surg. 2005;87(4):518–22. https://doi.org/10.1302/0301-620X.87B4.15529.
12. Cinotti G, De Santis P, Nofroni I, Postacchini F. Stenosis of lumbar intervertebral foramen: anatomic study on predisposing factors. Spine. 2002;27(3):223–9.
13. Lee S, Lee JW, Yeom JS, Kim KJ, Kim HJ, Chung SK, Kang HS. A practical MRI grading system for lumbar foraminal stenosis. AJR Am J Roentgenol. 2010;194(4):1095–8. https://doi.org/10.2214/AJR.09.2772.
14. Hasegawa T, An HS, Haughton VM, Nowicki BH. Lumbar foraminal stenosis: critical heights of the intervertebral discs and foramina. A cryomicrotome study in cadavera. J Bone Joint Surg Am. 1995;77(1):32–8.
15. Lewandrowski KU. “Outside-in” technique, clinical results, and indications with transforaminal lumbar endoscopic surgery: a retrospective study on 220 patients on applied radiographic classification of foraminal spinal stenosis. Int J Spine Surg. 2014;8 https://doi.org/10.14444/1026.
16. Knight MT, Jago I, Norris C, Midwinter L, Boynes C. Transforaminal endoscopic lumbar decompression & foraminoplasty: a 10 year prospective survivability outcome study of the treatment of foraminal stenosis and failed back surgery. Int J Spine Surg. 2014;8 https://doi.org/10.14444/1021.
17. Ahn Y, Lee SH, Park WM, Lee HY. Posterolateral percutaneous endoscopic lumbar foraminotomy for L5-S1 foraminal or lateral exit zone stenosis. Technical note. J Neurosurg. 2003;99(3 Suppl):320–3.
18. Lee CK, Rauschning W, Glenn W. Lateral lumbar spinal canal stenosis: classification, pathologic anatomy and surgical decompression. Spine. 1988;13(3):313–20.
19. Ciric I, Mikhael MA. Lumbar spinal-lateral recess stenosis. Neurol Clin. 1985;3(2):417–23.
20. Li ZZ, Hou SX, Shang WL, Cao Z, Zhao HL. Percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar decompression for lateral recess stenosis through transforaminal approach: technique notes and 2 years follow-up. Clin Neurol Neurosurg. 2016;143:90–4. https://doi.org/10.1016/j.clineuro.2016.02.008.
21. Ruetten S, Komp M, Merk H, Godolias G. Surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach versus conventional microsurgical technique: a prospective, randomized, controlled study. J Neurosurg Spine. 2009;10(5):476–85. https://doi.org/10.3171/2008.7.17634.
22. Park HJ, Kim SS, Lee YJ, Lee SY, Park NH, Choi YJ, Chung EC, Rho MH. Clinical correlation of a new practical MRI method for assessing central lumbar spinal stenosis. Br J Radiol. 2013;86(1025):20120180. https://doi.org/10.1259/bjr.20120180.
23. Lee GY, Lee JW, Choi HS, Oh KJ, Kang HS. A new grading system of lumbar central canal stenosis on MRI: an easy and reliable method. Skelet Radiol. 2011;40(8):1033–9. https://doi.org/10.1007/s00256-011-1102-x.

24. Komp M, Hahn P, Oezdemir S, Giannakopoulos A, Heikenfeld R, Kasch R, Merk H, Godolias G, Ruetten S. Bilateral spinal decompression of lumbar central stenosis with the full-endoscopic interlaminar versus microsurgical laminotomy technique: a prospective, randomized, controlled study. Pain Physician. 2015;18(1):61–70.
25. Lee CK, Vessa P, Lee JK. Chronic disabling low back pain syndrome caused by internal disc derangements. The results of disc excision and posterior lumbar interbody fusion. Spine. 1995;20(3):356–61.
26. Schwarzer AC, Wang SC, Bogduk N, McNaught PJ, Laurent R. Prevalence and clinical features of lumbar zygapophysial joint pain: a study in an Australian population with chronic low back pain. Ann Rheum Dis. 1995;54(2):100–6.
27. Schellhas KP, Pollei SR, Gundry CR, Heithoff KB. Lumbar disc high-intensity zone. Correlation of magnetic resonance imaging and discography. Spine. 1996;21(1):79–86.
28. Sachs BL, Vanharanta H, Spivey MA, Guyer RD, Videman T, Rashbaum RF, Johnson RG, Hochschuler SH, Mooney V. Dallas discogram description. A new classification of CT/discography in low-back disorders. Spine. 1987;12(3):287–94.
29. Tsou PM, Alan Yeung C, Yeung AT. Posterolateral transforaminal selective endoscopic discectomy and thermal annuloplasty for chronic lumbar discogenic pain: a minimal access visualized intradiscal surgical procedure. Spine J. 2004;4(5):564–73. https://doi.org/10.1016/j.spinee.2004.01.014.
30. Lee JH, Lee SH. Clinical efficacy of percutaneous endoscopic lumbar annuloplasty and nucleoplasty for treatment of patients with discogenic low back pain. Pain Med. 2016;17(4):650–7. https://doi.org/10.1093/pm/pnv120.
31. Ahn Y, Lee SH. Outcome predictors of percutaneous endoscopic lumbar discectomy and thermal annuloplasty for discogenic low back pain. Acta Neurochir. 2010;152(10):1695–702. https://doi.org/10.1007/s00701-010-0726-2.
32. Schwarzer AC, Aprill CN, Derby R, Fortin J, Kine G, Bogduk N. Clinical features of patients with pain stemming from the lumbar zygapophysial joints. Is the lumbar facet syndrome a clinical entity? Spine. 1994;19(10):1132–7.
33. Helbig T, Lee CK. The lumbar facet syndrome. Spine. 1988;13(1):61–4.
34. Eisenstein SM, Parry CR. The lumbar facet arthrosis syndrome. Clinical presentation and articular surface changes. J Bone Joint Surg. 1987;69(1):3–7.
35. Bogduk N. Evidence-informed management of chronic low back pain with facet injections and radiofrequency neurotomy. Spine J. 2008;8(1):56–64. https://doi.org/10.1016/j.spinee.2007.10.010.
36. Hickey RF, Tregonning GD. Denervation of spinal facet joints for treatment of chronic low back pain. N Z Med J. 1977;85(581):96–9.
37. Moussa WM, Khedr W. Percutaneous radiofrequency facet capsule denervation as an alternative target in lumbar facet syndrome. Clin Neurol Neurosurg. 2016;150:96–104. https://doi.org/10.1016/j.clineuro.2016.09.004.
38. Cho J, Park YG, Chung SS. Percutaneous radiofrequency lumbar facet rhizotomy in mechanical low back pain syndrome. Stereotact Funct Neurosurg. 1997;68(1–4 Pt 1):212–7.
39. Li ZZ, Hou SX, Shang WL, Song KR, Wu WW. Evaluation of endoscopic dorsal ramus rhizotomy in managing facetogenic chronic low back pain. Clin Neurol Neurosurg. 2014;126:11–7. https://doi.org/10.1016/j.clineuro.2014.08.014.
40. Yeung A, Gore S. Endoscopically guided foraminal and dorsal rhizotomy for chronic axial back pain based on cadaver and endoscopically visualized anatomic study. Int J Spine Surg. 2014;8 https://doi.org/10.14444/1023.
41. Klang E, Lidar M, Lidar Z, Aharoni D, Eshed I. Prevalence and awareness of sacroiliac joint alterations on lumbar spine CT in low back pain patients younger than 40 years. Acta Radiol. 2017;58(4):449–55. https://doi.org/10.1177/0284185116656490.
42. Vora AJ, Doerr KD, Wolfer LR. Functional anatomy and pathophysiology of axial low back pain: disc, posterior elements, sacroiliac joint, and associated pain generators. Phys Med Rehabil Clin N Am. 2010;21(4):679–709. https://doi.org/10.1016/j.pmr.2010.07.005.
43. Schwarzer AC, Aprill CN, Bogduk N. The sacroiliac joint in chronic low back pain. Spine. 1995;20(1):31–7.
44. Cohen SP, Hurley RW, Buckenmaier CC 3rd, Kurihara C, Morlando B, Dragovich A. Randomized placebo-controlled study evaluating lateral branch radiofrequency denervation for sacroiliac joint pain. Anesthesiology. 2008;109(2):279–88. https://doi.org/10.1097/ALN.0b013e31817f4c7c.
45. Ferrante FM, King LF, Roche EA, Kim PS, Aranda M, Delaney LR, Mardini IA, Mannes AJ. Radiofrequency sacroiliac joint denervation for sacroiliac syndrome. Reg Anesth Pain Med. 2001;26(2):137–42. https://doi.org/10.1053/rapm.2001.21739.
46. Choi WS, Kim JS, Ryu KS, Hur JW, Seong JH, Cho HJ. Endoscopic radiofrequency ablation of the sacroiliac joint complex in the treatment of chronic low back pain: a preliminary study of feasibility and efficacy of a novel technique. Biomed Res Int. 2016;2016:2834259. https://doi.org/10.1155/2016/2834259.
47. James A, Laufer I, Parikh K, Nagineni VV, Saleh TO, Hartl R. Lumbar juxtafacet cyst resection: the facet sparing contralateral minimally invasive surgical approach. J Spinal Disord Tech. 2012;25(2):E13–7. https://doi.org/10.1097/BSD.0b013e31822ac4e5.
48. Deshmukh NV, Kanse P. Lumbar facet synovial cyst. Postgraduate Med J. 2003;79(933):419, 423-414
49. Zou MX, Lv GH, Li J, Wang XB. Osteoid osteoma at the posterior element of lumbar spinal column in a young boy. Spine J. 2016;16(10):e651–2. https://doi.org/10.1016/j.spinee.2016.02.026.
50. Even JL, O'Malley MJ, Ward WT. Osteoid osteoma of the lumbar spine. Spine J. 2012;12(10):971–2. https://doi.org/10.1016/j.spinee.2012.08.176.

51. Yoshioka K, Matsuda E, Murakami H, Tsuchiya H. Microendoscopic excision of osteoid osteoma in the pedicle of the third lumbar vertebra. Asian Spine J. 2015;9(6):958–61. https://doi.org/10.4184/asj.2015.9.6.958.
52. Slosar PJ Jr, Patwardhan AG, Lorenz M, Havey R, Sartori M. Instability of the lumbar burst fracture and limitations of transpedicular instrumentation. Spine. 1995;20(13):1452–61.
53. Ducker TB. Lumbar burst fracture. J Spinal Disord. 1988;1(2):174–5; discussion 176–178
54. Ko SB, Lee SW. Result of posterior instrumentation without fusion in the management of thoracolumbar and lumbar unstable burst fracture. J Spinal Disord Tech. 2014;27(4):189–95. https://doi.org/10.1097/BSD.0b013e31825bfc8e.
55. Kim HY, Kim HS, Kim SW, Ju CI, Lee SM, Park HJ. Short segment screw fixation without fusion for unstable thoracolumbar and lumbar burst fracture: a prospective study on selective consecutive patients. J Korean Neurosurg Soc. 2012;51(4):203–7. https://doi.org/10.3340/jkns.2012.51.4.203.
56. Eck JC. Minimally invasive corpectomy and posterior stabilization for lumbar burst fracture. Spine J. 2011;11(9):904–8. https://doi.org/10.1016/j.spinee.2011.06.013.
57. Alqarni AM, Schneiders AG, Hendrick PA. Clinical tests to diagnose lumbar segmental instability: a systematic review. J Orthop Sports Phys Ther. 2011;41(3):130–40. https://doi.org/10.2519/jospt.2011.3457.
58. O'Sullivan PB. Lumbar segmental 'instability': clinical presentation and specific stabilizing exercise management. Man Ther. 2000;5(1):2–12. https://doi.org/10.1054/math.1999.0213.
59. Fritz JM, Erhard RE, Hagen BF. Segmental instability of the lumbar spine. Phys Ther. 1998;78(8):889–96.
60. Boden SD, Wiesel SW. Lumbosacral segmental motion in normal individuals. Have we been measuring instability properly? Spine. 1990;15(6):571–6.
61. Folman Y, Shabat S, Gepstein R. B-twin expandable spinal spacer for posterior lumbar interbody stabilization: mechanical testing. J Surg Orthop Adv. 2006;15(4):203–8.
62. Folman Y, Lee SH, Silvera JR, Gepstein R. Posterior lumbar interbody fusion for degenerative disc disease using a minimally invasive B-twin expandable spinal spacer: a multicenter study. J Spinal Disord Tech. 2003;16(5):455–60.