Università degli Studi di Firenze

Clinica Neurochirurgica

Surgical treatment of far-lateral lumbar disc herniations: results of the interlaminar contralateral approach and comparison with standard techniques. A retrospective study.

UNIVERSITÀ
DEGLI STUDI
FIRENZE

DOTTORATO DI RICERCA IN

PSICOLOGIA E NEUROSCIENZE

CICLO XXVI

COORDINATORE Prof. Renato Corradetti

Surgical treatment of far-lateral lumbar disc herniations: results of the interlaminar contralateral approach and comparison with standard techniques. A retrospective study.

Settore Scientifico Disciplinare MED/27

Dottorando

Dott. Andrea Di Rita

Tutore

Prof. Nicola Di Lorenzo

Coordinatore

Prof. Renato Corradetti

Anni 2010/2013

INDEX

PREFACE

About 10% of symptomatic lumbar disc herniations are located inside the neural foramen or laterally to it. These, usually referred to as *far-lateral lumbar disc herniations* (FLLDH), may impinge on the spinal nerve and dorsal root ganglion leading to severe, sometimes excruciating pain that is often unresponsive to conservative management and requires surgery. The standard interlaminar approach (microdiscectomy) is ineffective in exposing far lateral herniations. Thus, since the first recognition of FLLDH as a cause of radiculopathy in the 1970s, several other strategies have been devised. Early demolitive procedures such as facetectomy carry a risk of postoperative instability and have been replaced by more conservative and targeted approaches (medial intertransverse, pars interarticularis fenestration, lateral transmuscular and intermuscular). Recently, a microsurgical interlaminar contralateral approach has been proposed for the treatment of FLLDH. This technique nicely exposes the foraminal compartment and allows for direct visualization of both the nerve root and the herniation, without the need of facet joint resection. The approach has proved feasible, safe and effective in case reports and in one small case series. In the present study the interlaminar contralateral approach is compared to standard procedures by means of a retrospective analysis of a single-institution case series, in order to further assess the efficacy of this new technique.

INTRODUCTION

EPIDEMIOLOGY AND CLINICAL PRESENTATION

More than 90% of lumbar disc herniations occur at the posterior edge of the disc and therefore are located inside the spinal canal. These *intracanalicular herniations* are distinguished in median and paramedian (or postero-lateral). They may cause radiculopathy by compressing the nerve root at the lateral recess, just after its origin from the techal sac. Therefore, the involved root is that exiting the canal through the foramen of the interspace caudal to the affected disc (e.g. in the case of a paramedian L4-L5 herniation, the L5 root).

Extracanalicular herniations (*far-lateral lumbar disc herniations* - FLLDH) are located outside the spinal canal, inside the neural foramen -the space bounded cranially and caudally by the pedicles- or in the extraforaminal area, i.e. the space located beyond the lateral margin of the pedicles.

FLLDH usually migrate cranially, following the concavity of the dorsolateral aspect of the vertebral body and cause compressive radiculopathy by impinging on the root and dorsal root ganglion from below. Therefore the involved root is that exiting through the intervertebral foramen of the same interspace of the affected disc (e.g. in the case of a paramedian L4-L5 herniation, the L4 root) (Fig. 1 and 2).

Extraforaminal disc herniations and the associated symptoms due to compression of the exiting nerve root were first described by Macnab in 1971 in his paper about of negative surgical disc space explorations in patients with radiculopathy (Macnab, 1971).

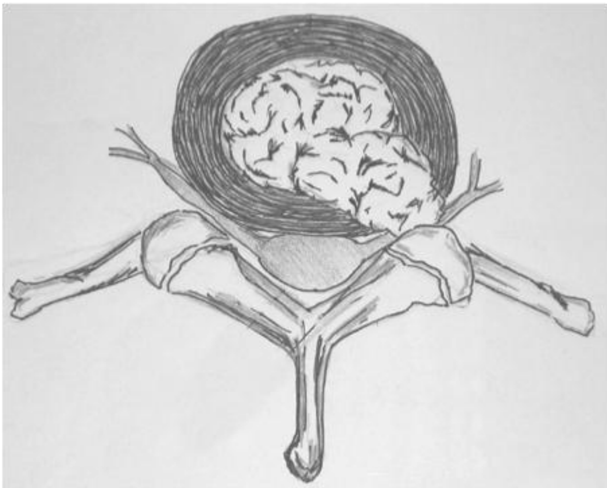

Fig.1 Artist illustration: intraforaminal herniation compressing the nerve root and ganglion (drawing by A.M. Ampollini MD)

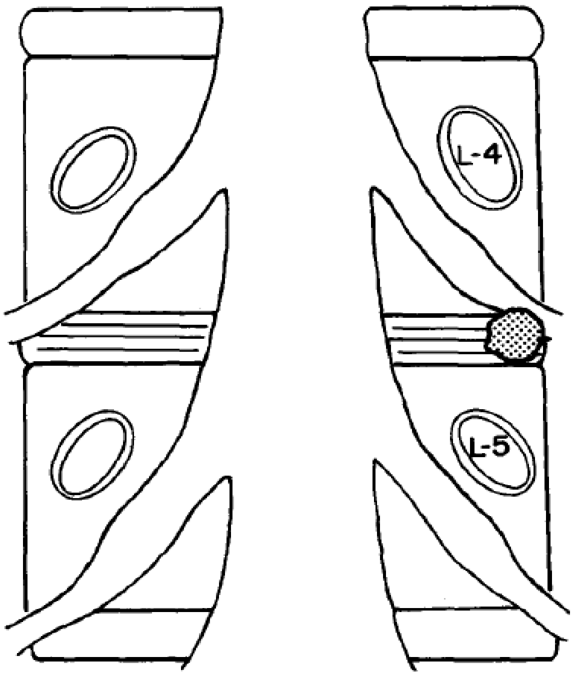

Fig.2 Schematic drawing: relationship between a L4-L5 far lateral herniation and nerve roots (from Abdullah et al., 1975)

Abdullah and colleagues in 1975 provided a detailed description of the clinical syndrome produced by FLLDH (Abdullah, 1974). The “extreme lateral” syndrome described by Abdullah is well characterized and includes marked pain due to involvement of the dorsal root ganglion, with a greater tendency for neurological deficits compared to common posterolateral herniations.

FLLDH accounts for 6.5 to 12% of all lumbar disc herniations (Porchet, 1999; Lew, 2001). Foraminal and intra-extraforaminal lesions seem to be almost equifrequent (3% and 4% respectively) (Siebner, 1990).

Most involved levels are L3-L4 and L4-L5, followed by L5-S1. Proximal levels (L2-L3 and L1-L2) are less frequent, but relatively more common than in classical postero-lateral herniations, with a reported percentage of 28% of all FLLDH. Patient age usually fall within a range from 50 to 78 years of age, with a male to female ratio varying from 1:1 to 2:1 (Ebeling, 1986; An, 1990; Epstein, 1990; Epstein, 1992; Epstein, 1995; Epstein, 1998; Porchet, 1999; Epstein 2006).

The most common clinical presentation is extreme radicular pain, often with sensory and motor impairment and decreased patellar reflex. Back pain may be present, but is usually milder than in intracanalicular herniations. Femoral stretch test (reverse-Lasegue) may be markedly positive.

Radicular pain and paresthesia may be reproduced by lateral bending to the side of the lesion and this is considered a hallmark of intraforaminal root compression (Abdullah, 1974).

In summary, far-lateral disc herniations clinically differ from their more common postero-lateral counterparts because 1) they involve the nerve root exiting at the same level, 2) may have a positive femoral stretch test 3)pain and paresthesia are reproduced by lateral bending to the side of disc herniation 4) pain is often more severe than in central disc herniations, maybe because of direct compression of the dorsal root ganglion.

Tables 1 and 2 synopsize the clinical features of postero-lateral and far-lateral herniations.

Table 1. Clinical differences between postero-lateral and far-lateral herniations

Clinical findings	PLH	FLH
Nerve root involved	At the level below the disc herniation	At the same level of disc herniation
Femoral stretch test	Not always significantly reliable	Markedly positive
Lateral bending	Do not reproduces radicular symptoms	Usually reproduces pain and paresthesia
Severity of pain	Variable	Strong, related to dorsal root ganglion compression

Table 2. Clinical picture of postero-lateral and far-lateral herniations at different levels

Root	PLH level	FLH level	Pain radiation/sensory involvement	Motor involvement	Deep tendon reflex	Radicular stretching test
L3	L2-L3	L3-L4	anterior aspect of the thigh	ileopsoas and/or quadriceps	patellar	Femoral
L4	L3-L4	L4-L5	anterior aspect of the thigh, medial malleolus and medial foot	quadriceps and anterior compartment of the leg	patellar	Femoral
L5	L4-L5	L5-S1	postero-lateral thigh and leg	extensor hallucis longus and dorsiflexors	none	Lasègue
S1	L5-S1	-	posterior thigh and leg, foot (plantar)	triceps surae	Achilles	Lasègue

Legend: PLH postero-lateral herniation; FLH far-lateral herniation

DIAGNOSTIC IMAGING

Preoperative diagnosis and a detailed localization of an extracanalicular herniated disc is crucial for the choice of the appropriate surgical approach.

Before the advent of computed tomography (CT), FLLDH were occult to imaging: in fact root compression is beyond the lateral extension of the subarachnoid space and thus it cannot not be demonstrated on myelographic films (Macnab, 1971).

Nowadays, both magnetic resonance (MR) and CT are able to image disc herniations in intra- and extraforaminal areas with great detail. However, despite advances in neuroimaging, the diagnosis of FLLDH may not be straightforward. Routine spine imaging, in fact, is often limited with regard to slice thinness and lateral extension of the field. Moreover, coexisting degenerative changes such as stenosis or intracanalicular disc bulging can hinder a radicular compression inside the foramen or laterally to it (Van Rijin, 2006). One study by Osborn and coworkers, revealed a 30% rate of misdiagnosis at the first CT or MR report. On the other hand, intracanalicular herniations are rarely overlooked (Osborn, 1988).

The differential diagnosis of FLLDH includes osteophytes, nerve root sheet pathologies (such as conjoined roots, arachnoid, perineural and synovial cysts) and also shwannomas, neurofibromas and ectatic epidural venous plexi (Osborn, 1988).

On CT scans, the extruded disc material is usually hyperdense compared to the adjacent intersomatic not herniated disc (Fig 3). Hosteophytes are more easily identifiable with bone windows. On MR, the herniation is generally hypointense in T1 and hyperintense in T2 to the intersomatic disc; osteophytes show a signal void in both sequences (Fig 4).

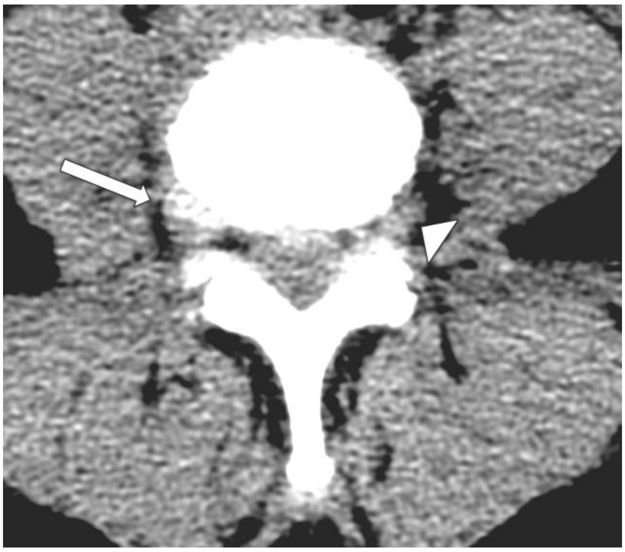

Fig 3. CT: right intra-extraforaminal disc herniation, partially calcified (arrow). The normal course of the contralateral root is shown by arrowhead

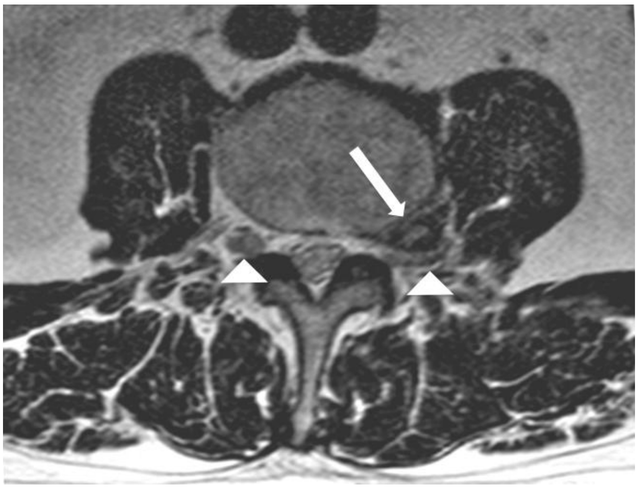

Fig. 4 MR (T2 axial sequence): left extraforaminal disc herniation (arrow). Nerve roots are clearly depicted (arrowheads), the left one being thinned, kinked and dislocated postero-superiorly by the

MR is the best imaging technique in depitcting FLLDH. Compared to MR, CT less reliably shows radicular compression and has a lower resolution for spinal and paraspinal soft tissues (Fig 5 and 6). However, CT can be useful in imaging osteophytes and calcifications (Osborn, 1988; Van Rijin, 2006; In Sook Lee, 2009).

Fig. 5 MR (T1 sagittal sequence): L3-L4 intraforaminal herniation compressing the L3 root. Perineural fat obliteration is evident.

One or more of the following MR findings can be present: 1) focal eccentricities of disc margins, 2) perineural fat tissue obliteration, 3) changes in nerve root thickness, 4) nerve root dislocation. Nerve root thinning is due to a direct compression by the herniated disc while thickening may be caused by edema. Moreover, a finer examination usually reveals that in purely intraforaminal herniations, epidural fat tissue obliteration is predominantly medial to the root, while in intra-extraforaminal hernitations it is found both medially and laterally to the root.

As mentioned above, routine MR studies are often not focused on extraforaminal areas and imaging this region area may be particularly difficult at L5-S1, because the

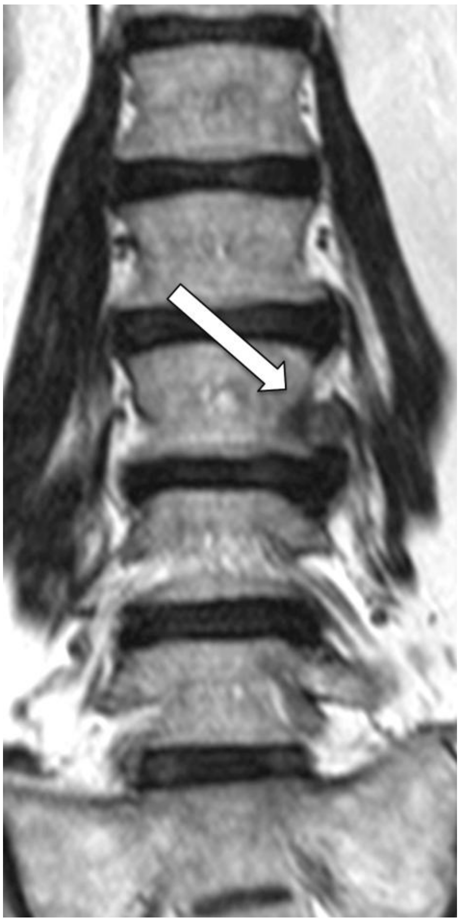

Fig. 6 MR (T1 paracoronal sequence): left L3-L4 extra-foraminal herniation

bony structures of sacral alae and iliac bones tend to overlap. Moreover, the L5-S1 disc is usually involved by degenerative changes that reduce its height and make it difficult to study.

Very often misdiagnosis is due to an incorrect MR protocol.

Axial slices, centered on the sagittal plane, must be strictly parallel to the intersomatic disc. This is essential in order to identify even small focal eccentricities of disc margins and to differentiate true root dislocations from non-pathological asymmetries between roots of the two sides.

In the search for a far-lateral herniation, it is important to perform paracoronal sections (angled 15 to 30 degrees), in order to follow the course of roots and proximal spinal nerves, as well as sagittal sections extending far laterally and covering all the lenght of the foramina .

A dedicated MR protocol includes sagittal sections, from L1 to S1, T1 spin-echo (slice thickness 3 to 4 mm RT 600 ms, ET 8 ms; FOV 300 x 160 mm) and T2 fast- spin-echo (slice thickness 3 to 4 mm RT 3500 ms, ET 100 ms; FOV 300 x 160 mm), T2 weighted fast-spin-echo axial sections (slice thickness 3 to 4 mm RT 4000 ms, ET 120 ms; FOV 200 x 200 mm)parallel to intersomatic discs and T2 weighted fast-spin-echo paracoronal sections from L1 to S1 (slice thickness 4 mm RT 3500 ms, ET 100 ms: FOV 300 x 160 cm) (Osborn, 1988; Van Rijin, 2006; In Sook Lee, 2009).

Contrast agent administration is routinely not necessary. Contrast-enhanced images may be indicated in differentiating a sequestered disc fragment from other pathologies such as shwannomas. In such cases, axial and sagittal T1-weighted spin-echo sequences with fat-saturation pulse can be used. The sequestrated fragment usually enhance peripherally, probably as the consequence of a surrounding inflammatory reaction (Chen, 2006).

In summary: MR is the best imaging technique in diagnosing FLLDH, provided that an adequate protocol is adopted. If MR cannot be performed, multi-slice CT is a reliable alternative. Correct diagnosis and differentiation between intraforaminal and extraforaminal herniations is important for the choice of the appropriate surgical approach.

NEUROPHYSIOLOGY

In the diagnosis of FLLDH, neurophysiology is a complementary but important tool which aids in the differential diagnosis between radiculopathy and other diseases and in the verification of the involved level. It may also provide information about the degree of neural damage.

Different techniques contribute to this evaluation. The ideal workout is based mainly on electromyography, along with findings from nerve conduction studies, H reflex and F wave studies.

Key findings in the diagnosis of a radicular damage are: 1) signs of neurogenic injury in muscles pertaining to the same spinal root with normal (or relatively spared) findings in muscles belonging to nearby roots, 2)involvement of the proximal part of the peripheral nervous system and 3) exclusion of other possible sites of injury that can mimic a radicular lesion, like the lumbo-sacral plexus or single nerves.

Electromyography

The identification of the affected root is usually defined by the pattern distribution of abnormalities. Needle electromyography is thus performed in many muscles, looking for abnormalities in muscles pertaining to a single root and normal findings in muscles belonging to other roots. Also, normal findings in muscles innervated by different roots but belonging to the same nerve or plexus part, help to differentiate nerve or plexus damage from radiculopathy. Unfortunately, each muscle usually belongs to different adjacent roots and each root serves many muscles, making the differential diagnosis sometimes difficult. This is particularly evident in studying upper lumbar radiculopathies, because motor territories of roots L2, L3 and L4 are widely overlapped (Wilbourne, 1998; Nardin, 1999). In such instances paraspinal muscles assessment may be a valuable aid in the identification of the involved level. This should focus on the multifidus muscle, which is believed to receive innervation from a single root, in contrast with other paraspinal muscles (Campbell, 1998). Anyway, paraspinal muscles examination has limitations: fibrillation can be absent in paraspinal muscles in some cases of root injury and these muscle are sometimes difficult to assess, particularly in obese or in patients who are not able to relax the target muscles. Moreover, persistent neurogenic changes due to local trauma can be seen in paraspinal muscles after back surgery, preventing postoperative usefulness of their testing (Daube, 2009).

Electromyography can also give information on the time course and severity of the disease. After acute axonal injury the first expected finding is a reduction of motor unit potential (MUP) recruitment proportional to the extent of the lesion. Fibrillation potentials appear after 2-3 weeks and their abundance is a reliable indicator of the number of lost motor axons. In the subsequent weeks and months, denervated muscular fibers will be eventually recruited in surviving motor units, that will thus show characteristic changes (at first an increase in MUP duration and number of phases, and then of MUP amplitude) (Daube, 2009). Because MUP changes are secondary to motor unit remodeling, increased duration and amplitude of compound potentials are a static finding, that last forever (if the enlarged motor units won't be successively damaged), thus they shouldn't be considered proof of ongoing root injury (Wilbourne, 1998). In some radicular lesions, fibrillation potentials can be the only abnormal finding, if the axonal loss is so small that MUP changes can't be appreciated (Wilbourne, 1998). During the course of the motor unit remodeling, fibrillation gradually subsides and eventually disappears, but in severe or ongoing lesions it can be recorded indefinitely. Recruitment changes can normalize in focal lesions that don't damage axons permanently (like neurapraxic or myelin lesions). The concurrent finding of fibrillation potentials, recruitment deficit and MUP changes help define the onset of injury and the severity of the axonal loss. Therefore, the finding of fibrillation the in absence of MUP changes is usually indicative of an acute injury, while MUP changes without fibrillation are the hallmark of a static o slowly progressive injury.

Sensory and motor nerve conduction studies

An involvement of the dorsal root between the spine and the dorsal root ganglion can spare sensory nerve action potential (SNAP) amplitudes even in presence of a clinical sensory deficit, confirming a radicular involvement and possibly excluding plexus or nerve lesions. However, far lateral disc herniations usually compress the dorsal root in the intervertebral canal and/or in the extraforaminal space, leading to a lesion of the dorsal root ganglion or even of a more distal part of the root. This can result in a reduction in the corresponding SNAP amplitude. For this reason, the findings of sensory conduction studies can be misleading and are not sufficient to differentiate radicular from more distal sites of injury. They will anyway provide information needed to identify or exclude other peripheral nervous system (PNS) diseases.

Motor conduction studies can show a reduction in compound muscle action potential (CMAP) amplitude in muscles belonging to the suffering root, particularly if the axonal loss is severe and the muscle is weak. In milder root injuries, or if the lesion doesn't cause an axonal loss (i.e. in a neurapraxic lesion) the CMAP and distal nerve conduction velocity can be unchanged. It has to be reminded that acute lesions involving both sensory and motor axonal loss cause changes in CMAP only after some time has elapsed (CMAP and SNAP amplitudes halve by 5-7 days after injury) (Chaundry, 1992), i.e. when the nerve fiber and the neuromuscular endplate become unexcitable as a result of the Wallerian degeneration.

H reflex and F wave

The H reflex and the F wave may be occasionally useful in the diagnostic assessment of FLLDH.

The H reflex is the neurophysiological correlate of the myotatic tendon reflex. It is a potential recorded from muscle fibers, elicited by the electrical stimulation of a motor nerve at an intensity lower than that needed to generate the compound muscle action potential (Daube, 2009).

It is readily evaluable in the soleus muscle and usually abnormal with S1 radicular lesions, but less consistently in other limb muscles (Kimura, 2001) . L4 and L5 radiculopathies were only anecdotally associated to changes in a modified H reflex from tibialis anterior muscle (after stimulation of peroneal nerve) (Pradhan, 1993). This accounts for the limited utility of the H reflex in the assessment of FLLDH.

In contrast, the F wave can be recorded from most muscles. It is a small potential recorded from muscle fibers, occurring after the CMAP, and is the result of the backfiring of anterior horn cells activated by an antidromically conducted stimulus. The F wave can be recorded from any nerve, and is a way to assess conduction along proximal nerve segments. Clear abnormal values of F wave associated with normal distal conduction parameters can theoretically detect injuries in proximal PNS sites. Unfortunately, the sensitivity of this technique is rather low, and normal results don't exclude a radicular lesion. Moreover, from some nerves, like the peroneus profundus, the response can be absent in normal people. The value of the F wave in the diagnosis of radicular lesions is thus considered of limited value (Fisher, 1998).

In conclusion, when a radiculopathy is suspected, the neurophysiological evaluation helps identify the suffering root/s, and may provide a semi-quantitative measurement of the extent and stage of the root injury.

However, several limitations of neurophysiological studies in this setting have to be stated. First, in compressive radiculopathies neurophysiology may be not sensitive enough to rule out a radicular injury. Second, the cause of the radicular lesion can't be inferred by neurophysiological assessment alone, and often confounding factors pertaining to anatomical characteristics and patient comorbidities do not allow the accurate determination of the injury site (Wilbourne, 1998).

SURGICAL ANATOMY

Lumbar intervertebral foramen and extraforaminal region

What is currently called the *intervertebral foramen* (IVF) is actually a three-dimensional space situated between the cranial and the caudal pedicle that opens medially in the vertebral canal and laterally in the extra-foraminal region. Therefore, rather than to a foramen, some authors refer to it as the *intervertebral compartment*, the *lateral interpedicular compartment* or the *intervertebral canal* (Pfaundler, 1989; Schlesinger, 1992; Reulen, 1996).

The IVF contains the spinal nerve root, the dorsal root ganglion (DRG) and the proximal spinal nerve, as well as small nerve branches, blood vessels, fat and connective tissue.

In a sagittal section the shape of the IVF is roughly elliptical with the major axis oriented vertically.

The IVF is bounded superiorly by the inferior border of the cranial pedicle (inferior vertebral notch) and inferiorly by the superior border of the lower pedicle (superior vertebral notch). Its ventral wall is given cranially by the concave dorso-lateral aspect of the body of the upper vertebra and caudally by the dorsolateral margin of the disc. The dorsal wall is formed by the isthmus of the upper vertebra cranially and by the superior articular process of the lower vertebra caudally. This bony dorsal wall is covered by the most lateral portion of the ligamentum flavum inserting on the ventral edge of the articular process. The ventral wall is covered by the posterior longitudinal ligament, which is thicker at the disc level and which, from medial to lateral, becomes thinner and blends with the annulus and with the periosteum (Fig 7).

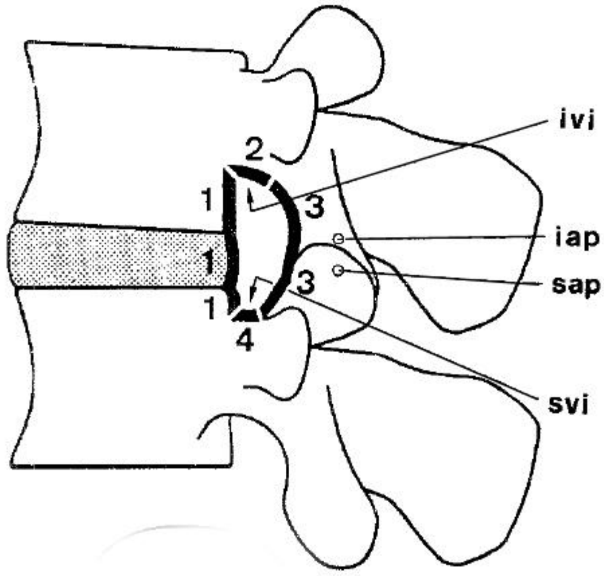

Fig. 7 Schematic drawing of the lumbar intervertebral foramen and its boundaries: 1=anterior wall (superior vertebral body, disc, inferior vertebral body), 2=superior wall, 3=dorsal wall, 4=inferior wall. (ivi= inferior vertebral incisura, iap=inferior articular process, sap=superior articular process, svi=superior vertebral incisura) (adapted from Pfaundler et al. 1989)

Imaging and cadaveric studies show that the size of the IVF varies between different levels (Smith, 1993; Demondion, 2000; Torun, 2006). According to Torun, the mean vertical diameter of the foramen is 19,4 ± 2,7 mm and the mean horizontal diameter is 8,8 ± 1,7 mm. The widest foramen is L5-S1. Foraminal sizes can be arranged, from largest to smallest, as follows: L5-S1, L3-L4, L2-L3, L1-L2 and L4-L5. Moreover, the size of the nerve roots varies, with L3, L4 and L5 root diameter (mean 3,9 mm) being slightly greater than L1 and L2 (mean 3,3 and 3,5 respectively) (Ebraheim, 1997; Torun, 2006; Guvencer, 2007). These morphometric data account for the high frequency of symptomatic foraminal L4-L5 radicular compression and for the common finding of clinically silent foraminal pathology at the L1-L2 and L2-L3 levels. The vertical size of the IVF is highly variable because it depends on disc space height, which in turns is affected by the degree of degenerative changes (Tibrewal, 1985). Moreover, the size and shape of the IVF is not static and varies with loading and movements (Panjabi, 1983; Kirkaldy-Willis, 1984; Fujiwara, 2001).

The configuration of the IVF varies between different levels. In the upper lumbar spine (L1-L3) the IVF more closely resemble a true foramen, while in the lower segments (L3-L5) it is more similar to a canal. This is essentially due to a progressive change in the orientation of pedicles: L1 and L2 pedicles originate more or less vertically from the posterior edge of the vertebral body while in L3, L4 and L5 they progressively turn to a more oblique dorso-lateral direction, while their emergence from the vertebral body extends more laterally (Pfaundler, 1989) (Fig 8).

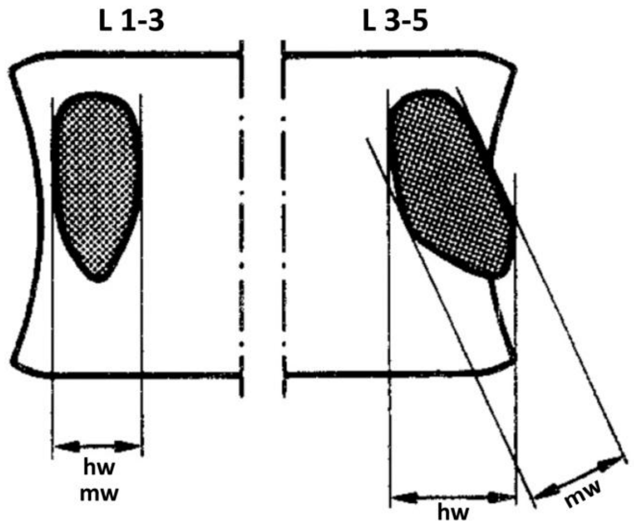

Fig. 8 Lumbar pedicles are elliptical in shape. In the upper lumbar spine they are oriented vertically so that their minimum width (mw) and horizontal width (hw) coincide. In the lower lumbar spine pedicles are more oblique, such that the horizontal diameter is greater than the true minimum diameter. In the upper lumbar spine the IVF resembles a true foramen, while in lower levels it is more similar to a canal. (adapted from Pfaundler et al. 1989)

The nerve root runs close to the inner side of the pedicle in the so called lateral recess and then, in the IVF, it courses close to the lower edge of the pedicle. In the lower lumbar spine the oblique orientation of the pedicles makes the transition between the lateral recess and the IVF more shallow and the identification of the inner opening of the IVF more difficult (Frankhauser, 1987). This accounts for the differences in reported horizontal lenghts for IVF at those levels. According to cadaveric studies, the mean horizontal extension of the IVF is 7,2 mm in L1-L2 (Pfaundler, 1989) and varies from 18,5 to 30 mm in L5-S1 (Dubs, 1950; Dommisse, 1975; Bose, 1984; Pfaundler, 1989).

The progressive increase of the length of the IVF observed from L1-L2 to L5-S1 is paralleled by an increase in the width of the isthmus laminae and by a decrease of the distance between the inferior border of the proximal transverse process and the superior edge of the apophyseal joint, which averages 10 mm in L1-L2 (range 5-16mm), 7,9 mm in L4-L5 (range 3-14mm) and 5,1 mm in L5-S1 (range 0-11mm) (Huber, 1989; Reulen, 1996) (Fig 9).

These changes make lateral extra-spinal surgical approaches to the foramen more difficult at lower levels.

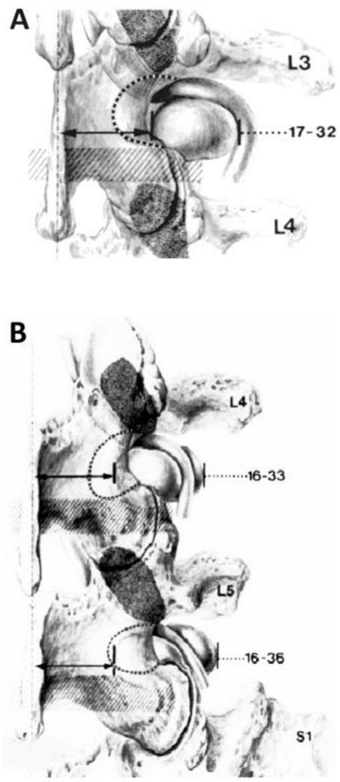

Fig. 9 Representation of the bony structures at L3-L4 (A) and L4-S1 (C), with far-lateral herniations shown as they would typically appear. The numbers indicate at each level the average distances of the medial and lateral margin of an herniation from the midline according to the CT study by Huber et al, 1989. The dotted line indicates the area of the isthmus that may be resected. At lower levels (B) the isthmus and the facet joint hinders the access to the foramen more consistently than at upper levels (A) (from Reulen et al. 1996).

Cadaveric dissections of the lower lumbar spine using sagittal sections combined with cadaveric biomechanical studies revealed four distinct intraforaminal ligaments. Four bands extend radially from the nerve root sleeve, the first being found at the facet capsule posteriorly, two attaching to the superior and inferior pedicles, and the fourth to the disc anteriorly (Grimes, 2000).

Lateral to the foramen, is the *extra-foraminal region*, sometimes referred to as the far-lateral space (Hood, 1993). The boundaries of the extra-foraminal region are the intertransverse ligament postero-laterally, the foramen and the most dorsolateral aspect of the upper vertebral body and of the disc space antero-medially and the psoas muscle, containing the lumbar plexus, antero-laterally. The *intertransverse ligament* (ITL) has an horizontal and a vertical part. The first originates laterally as the fusion of the anterior and middle layers of the thoracolumbar fascia, which encase the quadratus lumborum (Fig. 10). The vertical part originates from the horizontal part and runs ventrally to blend with the periosteum of the dorsolatarel portion of the vertebral body and with the annulus fibrosus. Neurovascular structures (the lumbar nerve and the lumbar artery) run medial to the vertical part of the ITL.

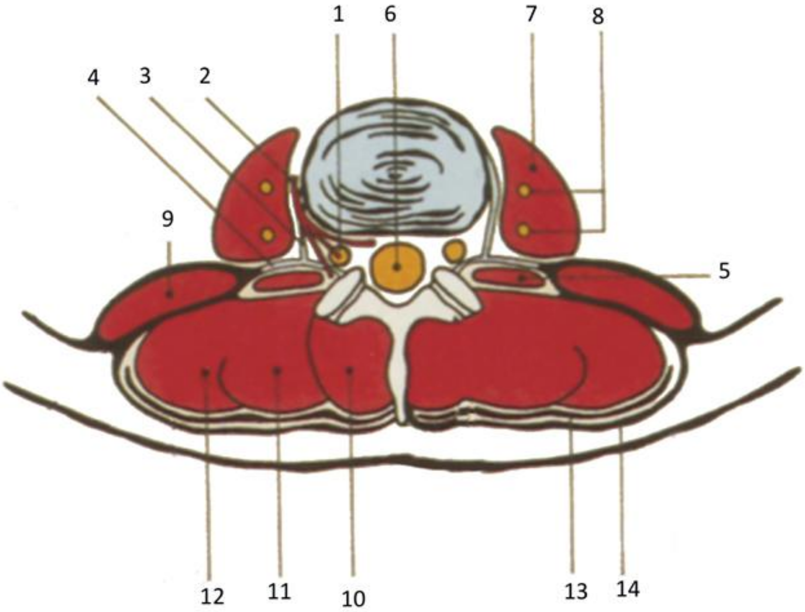

Fig. 10 Schematic drawing of the extra-foraminal region and its relationships. 1=nerve root, 2=lumbar artery, 3=intertransverse ligament (vertical part), 4=intertransverse ligament (horizontal part), 5=intertransverse muscle, 6=dural sac, 7=psoas muscle, 8=lumbar plexus, 9=quadratus lumborum muscle, 10=multifidus muscle, 11=longissimus muscle, 12=iliocostalis muscle, 13=erector spinae aponeurosis, 14=lumbodorsal fascia (adapted from Schlesinger et al. 1992)

Nerve root, spinal nerve and lumbar artery

Moving from L1 to S1, each lumbar nerve root leaves the thecal sac progressively more cranial to the respective pedicle and with a progressively tighter angle (Schlesinger, 1992; Ebraheim, 1997; Gu, 1999; Guvencer, 2007). The dorsal root ganglion is located in the middle of the IVF, just below the cranial pedicle. In the IVF the root and nerve run obliquely in a latero-caudal direction. Due to the aforementioned variations in the configuration of the IVF, the true intra-foraminal course of the root is longer in the lower lumbar spine. Moving from L1 toward lower levels the diameter of the nerve roots increases, their angle to the midline increases, and their distance to the tip of the superior articular process increases (Guvencer, 2007; Ebraheim, 1997). Near its exit from the IVF the spinal nerve divides into its larger ventral and smaller dorsal rami. The ventral ramus turns ventrally, courses lateral to the caudal pedicle and enters the psoas muscle, joining the trunk of the lumbar plexus. The nerve crosses the disc space extraforaminally, lateral and slightly anterior to the posterolateral margin of the disc. The dorsal ramus turns posteriorly, crosses the intertransverse ligament and muscle and runs between the multifidus and longissimus muscles giving off rami to posterior paraspinal muscles and eventually to superficial tissues. The sinuvertebral nerve and rami communicantes arise from the proximal portion of the ventral ramus. Neither of these branches are routinely seen at surgery. The sinuvertebral nerve is a recurrent branch which innervates the posterior longitudinal ligament, the intervertebral discs, the adjacent vessels and the anterior dura of the thecal sac (Breathnach, 1965; Pedersen, 1956).

The extraforaminal nerve root can be directly encountered during dissection at a mean of 5 mm anterior to the supero-medial border of the inferior transverse process (Bae, 1999).

The lumbar artery (LA) courses between the emerging nerve medially and the vertical leaf of the ITL laterally. In this region it gives off the radicular artery and other proximal branches. The ventral ramus from the next cranial segment, coursing within the substance of the psoas muscle, is an anastomitic branch running just lateral to the vertical leaf of the ITL. The LA is tipically ventro-lateral and caudal to the exiting spinal nerve (Viswanathan, 2002). After giving off its proximal branches, the LA penetrates the horizontal leaf of the ITL along with the accompanying veins. Rich anastomoses of venous plexi are usually found in the extra-foraminal region and in the IVF (Schlesinger, 1992).

The lateral branch of the posterior primary ramus and the terminal branch of the segmental artery have been reported as useful landmarks during surgical approaches to the extra-foraminal area (Kambin, 1996). However it may be difficult to establish them as landmarks in the surgical field, while more consistent bony reference points such as the transverse process and the superior articular process can be more easily identified. (Bae, 1999).

Lumbar posterior paraspinal muscles

An imaginary plane passing through the transverse processes divides lumbar paraspinal muscles into an anterior group formed by the psoas and the quadratus lumborum and a posterior group formed by the multifidus muscle and the erector spinae complex. The erector spinae in turn is formed by the lumbar portion of the longissimus and iliocostalis muscles. The multifidus is medial to the erector spinae and both are covered by the same two-layered fascial plane, given by the thoracolumbar fascia superficially and by the erecetor spinae aponeurosis deeply.

The intertrasverse ligament, whose development ranges from a fine membrane to a thick ligamentous structure, defines three compartments: the far-lateral compartment antero-medially, the psoas muscle and the lumbar plexus within it antero-laterally and the intertrasversarii and posterior paraspinal muscles posteriorly. The thin intertransverse muscle, connecting two adjacent transverse processes, is just dorsal to the vertical leaf of the intertransverse ligament (Bogduk, 2005; Adams, 2006) (Fig 10 and 11). The posterior muscles stabilize the vertebral column and counteract the flexion effect of the abdominal muscles. (Donisch, 1972).

Such as ligaments, paraspinal muscles connect adjacent vertebrae and may extend over several segments. They are arranged in overlapping fascicles, each having a segmental neurovascular supply. Thus, surgical planes can be developed between large muscles and also between individual fascicles of a single muscle, without

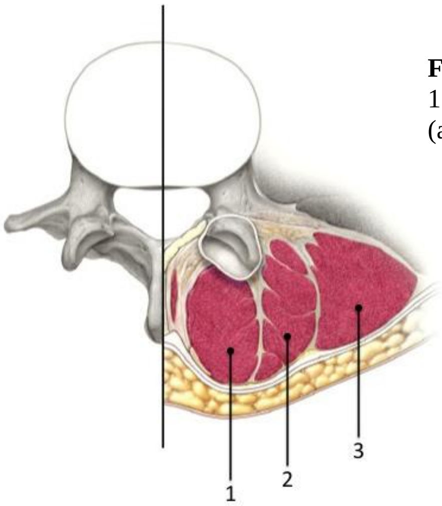

Fig. 11 Lumbar posterior paraspinal muscles. 1=multifidus m. 2=longissimus m. 3=iliocostalis m. (adapted from Hoh et al. 2010)

damaging them. Paraspinal muscle-splitting approaches, first introduced by Watkins in 1959 (Watkins, 1959), may be adopted in FLLDH surgery as well as in decompression and fixation procedures (Hoh, 2010). It is believed that preservation of the integrity of muscle groups avoids post-operative atrophy and scarring, which may lead to altered segmental motion, chronic pain and patient disability (Mayer, 1989; Sihvonen, 1993; Gejo, 1999).

Multifidus muscle

Among posterior muscles, the multifidus has the largest cross sectional area and it is the primary muscle involved in lumbosacral junction stability (Hansen, 2006). Its bulk, which is bounded medially by the spinous processes and laterally by its attachments to the superior articular process, is made up of multiple fascicles. At each lumbar level, a small subfascicle originates from the inferior edge of the spinous process and adjacent laminar margin and courses obliquely to insert on the tip of the articular process two segments caudal or on the sacrum. Longer subfascicles originate from a roboust common tendon from the inferior edge of the spinous process and insert on the articular processes at progressively more caudal levels. Below L5 these fascicles insert on the sacrum and ileum. The arrangement is such that each fascicle overlies those originating from more caudal segment, resulting in a muscle that progressively increases in bulk from cranial to caudal. This general architecture is common to longissimus and iliocostalis (Fig 12). Fascicles originating from the same spinous process share innervation and vascular supply, which is segmental and provided by the medial branch of the dorsal ramus of the nerve root and by the artery of the pars interarticularis, a distal branch of the lumbar artery (Fig 13). This neurovascular bundle supplies the multifidus originating on the spinous process immediately cranial and courses lateral to the muscle insertion in the superior articular process. Therefore, during a standard midline surgical approach, the multifidus can be detached from the spinous process and reflected laterally preserving its neurovascular supply as long as dissection does not extend lateral to the facet.

Erector spinae complex

The erector spinae complex includes the lumbar portions of the longissimus and iliocostalis muscles, which arise from the transverse processes and insert on the iliac crest at its supero-medial margin (Fig 12).

The *lumbar portion of the longissimus* is a thin muscle group formed by fascicles originating from the proximal transverse process and converging to form a common tendon which insert on the superomedial iliac crest. Laterally, this tendon also reflects ventrally separating the longissimus and iliocostalis as the *intermuscular aponeurosis*. The plane between the multifidus and the longissimus (intermuscular plane) is slightly more medial.

The *lumbar portion of the iliocostalis* is formed by fascicles originating from the tip of the transverse processes from L1 to L4 and from the adjacent portion of the medial layer of the thoracolumbar fascia. Their tendons insert on the iliac crest, lateral to the poterosuperior iliac spine. In the adult, fascicles of the longissimus and of the iliocostalis that arise from L5 become ligamentous and constitute the iliolumbar ligament. This makes opening the intermuscular planes at the L5-S1 level quite difficult (Hoh, 2010).

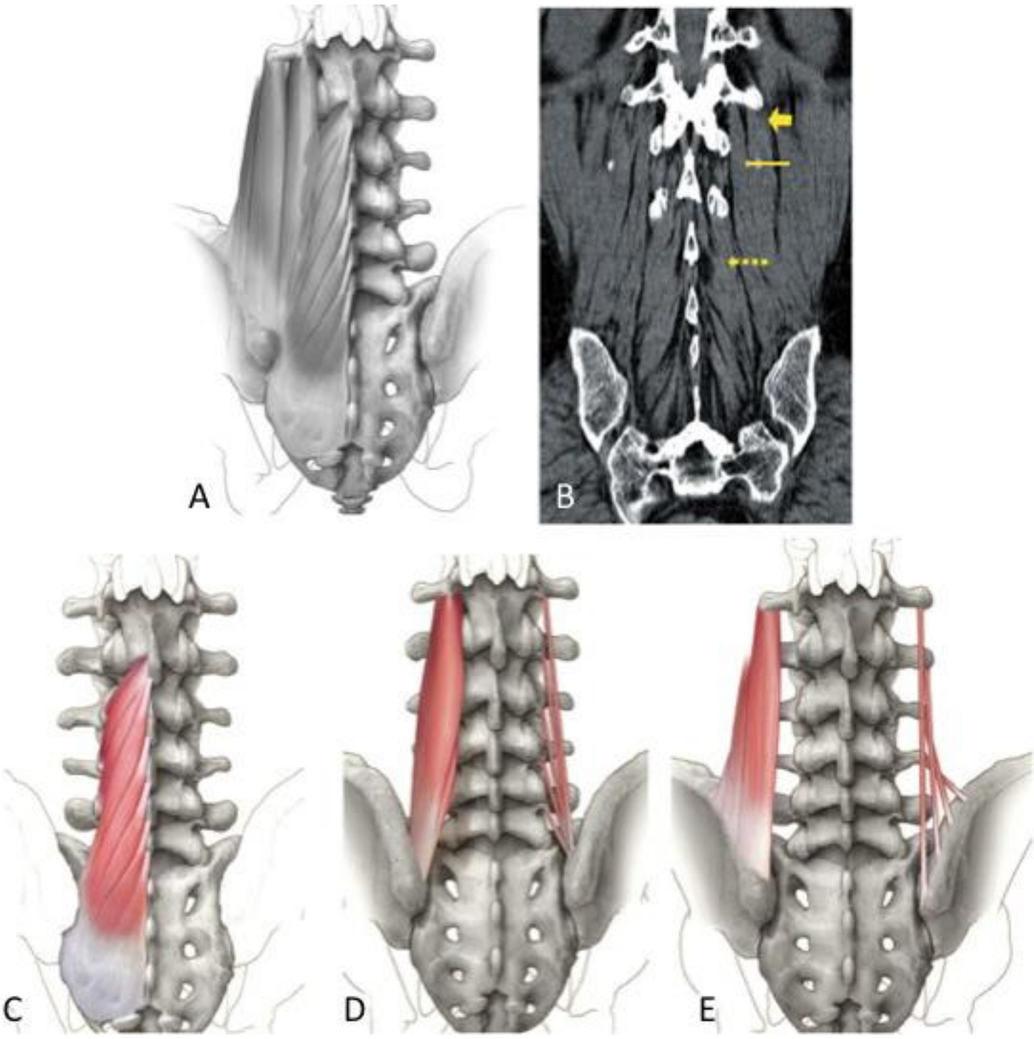

Fig. 12 Posterior paraspinal muscles illustrated (A) and as seen in a coronally reconstructed CT scan (B). The segmental arrangement of their fascicles is selectively depicted for multifidus (C), longissimus (D) and iliocostalis (E) (adapted from Hoh et al. 2010)

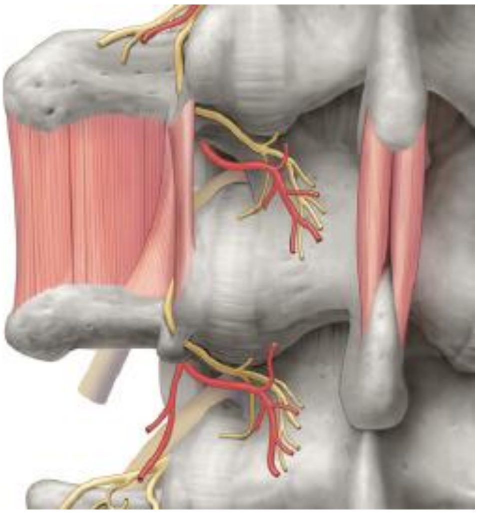

Fig. 13 Neurovascular supply to the multifidus muscle, segmentally provided by the medial branch of the dorsal ramus of the nerve root and by the artery of the pars interarticularis (dorsal view). The intertransverse muscle and the spinal nerve are also depicted (adapted from Hoh et al. 2010)

Aponeurotic layers

The *erector spinae aponeurosis* (ESA) is a tendinous sheet covering the whole posterior lumbar musculature. A cleavage plane is always found between the ESA and the underlying muscles. The ESA has a medial and a lateral portion, formed by the tendons of the thoracic part of the longissimus and of the iliocostalis respectively. The medial portion of the ESA overlies the multifidus and longissimus while the lateral part covers the iliocostalis. Discrete tendons insert on individual spinous processes, allowing the independent motion of each segment. Below S1, the tendons fuse into a continuous sheet inserting on distal sacral segments. At the midline, the tendons of the ESA fuse with the overlying lumbodorsal fascia and contribute to the supraspinous ligament, while laterally and ventrally they continue to about the lateral raphe.

The *lumbodorsal fascia* is a bilaminar connective sheet that overlies the ESA. It composed of the tendons of the latissimus dorsi muscle. These tendons course obliquely. At the midline they cross to the contralateral side and laterally to the iliocostalis they fuse with tendons from the transverse abdominis and the lumbodorsal fascia to form a lateral raphe. The arrangement of the bilaminar lumbodorsal fascia is such that its superficial layer consists of tendons arising from the ipsilateral latissimus dorsi, whereas the deep layer comprises tendons from the contralateral latissimus dorsi. A cleavage plane is found between the lumbodorsal fascia and the ESA, even if, at the lumbosacral junction, adhesions may occur (Hoh, 2010).

Intermuscular corridors

A natural cleavage plane named *intermuscular plane* is always found between the multifidus and longissimus muscles. This is followed during a transmuscular approach to the extraforaminal region. Moving from caudal to cranial, the intermuscular plane approaches the midline, following the shape of the multifidus and getting close to the spinous process at L1. According to the cadaveric study by Vialle and coworkers, a well defined fibrous partition is found in 92% of cases at the caudal part of the cleft and disappears gradually above the level of L4 transverse process. The mean distance between this cleavage plane and the midline is 4 cm (range 2,4 – 5,5 cm). (Vialle, 2005) This distance may be even more variable in patients because of variation in muscle trophism.

Small arteries and veins are found in the intermuscular plane. In particular a large division of the L3 nerve was found to be very consistent. At surgery, this nerve can be retracted laterally and preserved to avoid hypoesthesia and focal muscle denervation.

Lateral to the intermuscular plane is the *intermuscular aponeurosis*, made up by tendons of the longissimus fusing together and reflecting ventrally from the ESA. The intermuscular aponeurosis, separating the longissimus and the iliocostalis, is the surgical plane followed during an intermuscular approach to the extraforaminal region (Fig 14).

Fig. 14 Axial MR image showing the intermuscular plane (thin arrows) and the intermuscular aponeurosis (thick arrows) (adapted from Hoh et al. 2010)

SURGICAL APPROACHES

A significant subset of patients with FLLDH (30-80%) fail to respond to conservative management based on steroidal and non-steroidal anti-inflammatory medication. (Epstein, 1995; Rust, 1999).

The presence of significant neurological deficits should, however, prompt toward rapid consideration of surgical treatment.

The interlaminar microsurgical appoach to the herniated lumbar disc (Yasargil, 1977; Williams, 1978; Caspar, 1979) has become the gold standard for the treatment of common postero-lateral herniations. This well-known procedure is however ineffective in dealing with foraminal or extra-foraminal root compression as found in FLLDH.

Thus, various alternative techniques have been devised. Being the foramen hidden beneath the interapophyseal joint, whose integrity is critical to the stability of the motion segment, FLLDH surgery faces a dilemma: the exposure of the disc abnormality is directly proportional to the amount of bone removal, which, in turns, may jeopardize vertebral stability.

Surgical approaches to FLLDH include *medial approaches* in which a conventional midline subperiosteal dissection is performed to expose the spinal segment and *lateral approaches* adopting an oblique route through posterior paraspinal muscles.

Medial approaches are the interlaminar ipsilateral with full or partial artrectomy, the intertransverse (or paraisthmic) approach and the pars interarticularis fenestration. The lateral approaches are the transmuscular and the intermuscular (see Table 3).

A medial interlaminar contralateral approach has recently been proposed with promising preliminar results (Pal, 2006; Yeom, 2008; Berra, 2010). A further assessment of this new technique is the subject of the present study.

Table 3: classification of surgical approaches to far-lateral lumbar disc herniations

Medial approaches (midline subperiosteal)

- Artrectomy (or facetectomy)
  - Partial (or medial) artrectomy
  - Full artrectomy
- Intertransverse (or paraisthmic)
- Pars interarticularis fenestration
- Interlaminar contralateral

Lateral approaches (muscle-splitting)

- Transmuscular (Wilse's, also called intramuscular)
- Intermuscular (or far-lateral)

Artrectomy

Artrectomy (or facetectomy) is the oldest and more straightforward method to expose foraminal and extra-foraminal root compression (Abdullah, 1988; Lejeune 1994; Epstein, 1995). Removal of the facet joint with laminotomy or hemilaminectomy unroofs the neural foramen and provides exposure of the nerve root and ganglion.

In *partial (or medial) artrectomy* the inferior articular process of the upper vertebra (medial facet) is resected. This technique may provide sufficient access to proximal foraminal lesions, particularly

at L4-L5 and L5-S1, but rarely successes in case of more distal lesions and in the presence of coexistent degenerative changes such as spondyloarthrosis, degenerative spondylolisthesis and scoliosis.

Full artrectomy is the resection of both the superior articular process of the lower vertebra and the inferior process of the upper vertebra. It provides the best exposure of the root and ganglion throughout their course, especially in the setting of coexistent degenerative changes. Full facetectomy offers the lowest incidence of retained disc fragments, is the most familiar approach and limits inadvertent neural trauma (Fig 15).

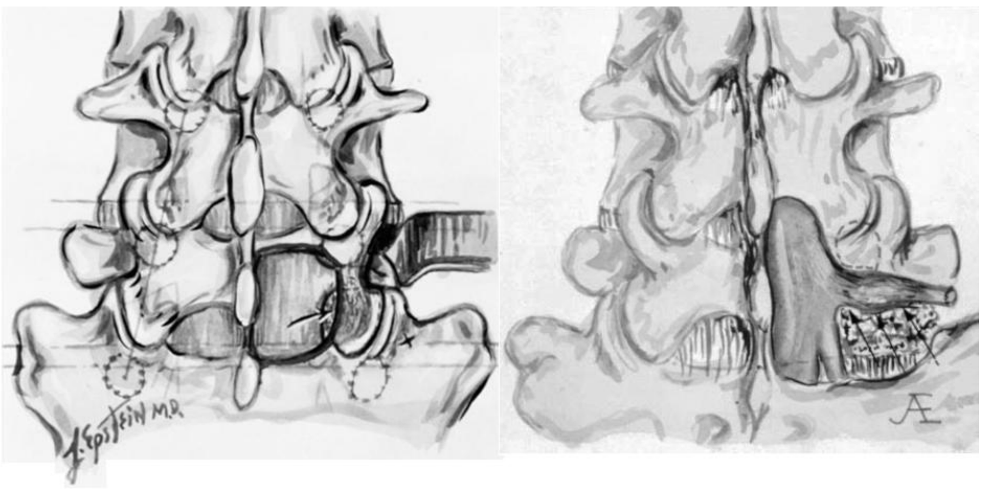

Fig. 15 Artist illustration. Partial artrectomy (left) and full artrectomy (right) exposing a left L5-S1 intraforaminal herniation (from Epstein et al. 2010)

Each of the techniques that require facet resection carries a risk of subsequent low back pain and spinal instability (Gates, 1999; Manchikanti, 2001; Lee, 2004; Ivanov, 2007). This is the reason why some authors advocated automatically fusing all patients with lateral disc herniations managed with full facetectomy (Kunogy, 1991). The true biomechanical impact of lumbar facetectomy is controversial. It has been suggested that complete facetectomy is well tolerated, with little likelihood of instability, particularly at the lowest two lumbar motion segments (Hazlett, 1982). From a clinical perspective, large series showed that only 2% to 4% of patients required subsequent fusion (Epstein, 1995; Porchet, 1997; Epstein, 1998; Epstein, 2006). In Epstein's initial series of 60 patients with far lateral disc herniations, only one required a secondary fusion (Epstein, 1990).

Garrido et al. reported the largest series of FLLDH treated by full artrectomy. 41 patients were followed up for an average of 22,4 months (range 4-60). All patients underwent follow-up dynamic lumbar spine x-ray films with flexion and extension exposures. An excellent clinical result with complete resolution of pain and return to daily and working activities was reported by the authors in 35 out of 41 patients. Only one patient suffered postoperative spinal instability and required fusion because of back pain. The authors concluded that unilateral facetectomy carries a very low risk of instability .

In summary, artrectomy offers the best exposure of both the foramen and extra-foraminal region but may result in spinal instability and chronic back pain. Even if focused studies showed that this occurrence is rarer than previously thought, facetectomy cannot be recommended as a standard (Lanzino, 1998).

Intertransverse approach

The *intertransverse* (IT) or *paraisthmic* approach has been devised to expose the extraforaminal region without disrupting the facet joint (Jane, 1990; Melvill, 1994). The procedure starts as a standard posterior midline approach with uncovering of the spinous processes, laminae and facet joints. Lateral retraction of multifidus muscle bundles allows the transverse process to be exposed (Weatherley, 2010). The dorsal root ganglion and the spinal nerve are embedded in fat and connective tissue beneath the intertransverse muscle, which is often very thin. Overhanging isthmic bone may drilled if necessary. Further access is obtained by trimming the most lateral aspect of the superior articular process of the facet without disturbing the joint itself. Bone reduction is not always needed, especially at upper levels. At L4-L5 and L5-S1 however, bone removal is almost always needed in order to gain sufficient access to the foramen. This is due to the longer course of the foraminal canal as well as to the orientation of pedicles and facets at these levels (Pfaundler, 1989). Exposure of both the cranial and caudal transverse processes is not necessary. The junction between the root of the cranial transverse process and the isthmus of the upper vertebra is a useful landmark to start the dissection toward the nerve root (Fig 16).

Using microsurgical technique, the intertransverse membrane is sectioned and the nerve is identified and retracted laterally allowing access to the disc material, which is removed with disc forceps. The remaining degenerative disc material is then cleared. Further exploration beneath the dorsal root ganglion should be attempted only at this stage, because the ganglion is no more under tension and its damage is less likely. In this way, any residual, sequestrated material can be removed with a probe (O'Hara, 1997; Wang, 1976; Hood, 1993).

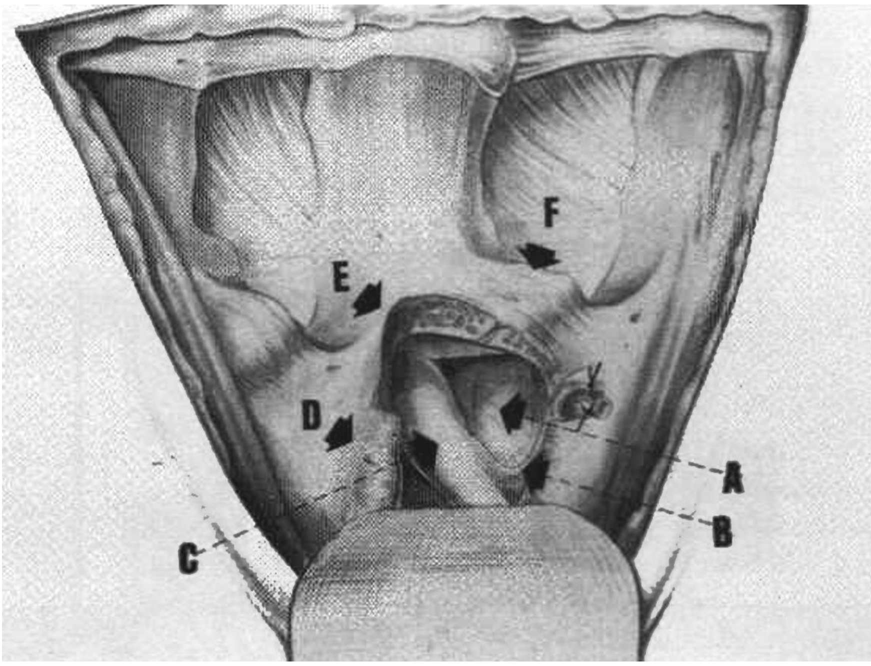

Fig. 16 Artist illustration. Left intertransverse approach. After exposure of the facet jont and the angle between the root of the transverse process and the isthmus (E), the isthmus with the lateral part of the pars interarticularis (F) have benn trmmied and the intertransverse muscle (D) opened. The nerve root (C) is compressed from below by the herniation (A), which comes into view after sectioning of the posterior logitudinal ligament (B). (from O'Hara et al, 1997)

The IT approach had long been the most popular technique in FLLDH surgery.

Epstein and coworkers did not find any significant difference in outcomes between intertrans-

verse, full facetectomy, and medial facetectomy techniques in 170 patients followed-up for an average of 5 years. Rates of good to excellent outcomes (Odom's criteria) were 79%, 70% and 68% respectively for IT, full facetectomy and partial facetectomy. Even in the absence of statistic significance, a trend toward better outcomes with the IT approach was observed. (Epstein, 1995; Epstein, 1998).

Pars interarticularis fenestration

This technique has been specifically devised for purely or mainly intraforaminal herniations. In these instances, a generous lateral facet resection would be needed during the IT approach, especially at lower levels (Di Lorenzo, 1998). The procedure involves a standard midline exposure extended laterally up to the isthmus; then, high-speed drill is used to cut a small ovoid window through the pars interarticularis , sparing several millimiters of bone on both its medial and lateral aspects and thus leaving the inferior facet connected to the pedicle and lamina (Fig 17). This bony window allows the surgeon to microsurgically access the foramen in a “keyhole” fashion and do not interfere with spinal stability.

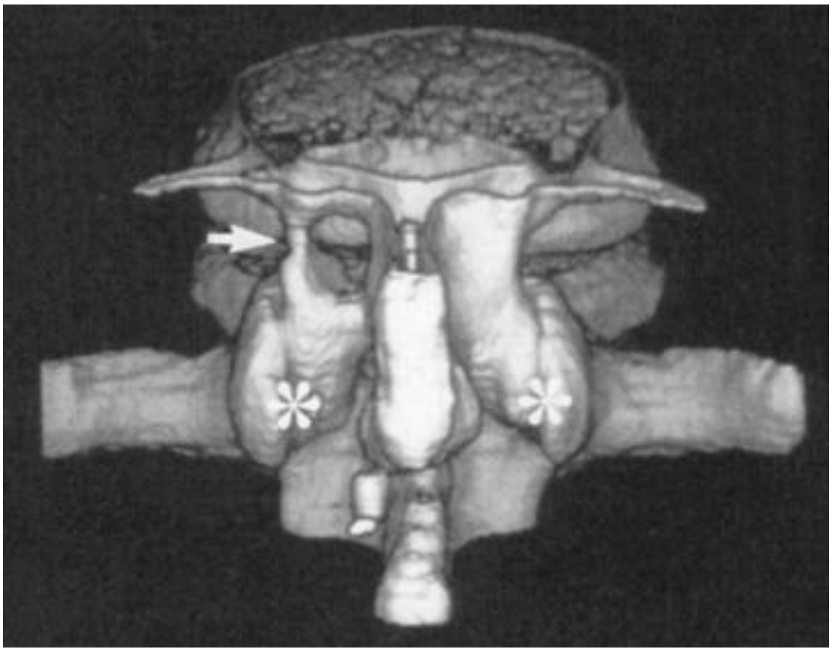

Fig. 17 Pars interarticularis fenestration. Postoperative three-dimensional CT scan. Delineation of the pars interarticularis ovoid fenestration. Arrows point to the isthmic notch and the asterisks mark the zygapophyseal joints. (from Di Lorenzo et al 1998)

This approach was introduced by Di Lorenzo and coworkers, who reported on a series of 28 cases. Remission of pain and return to previous occupations was observed in all patients within 30 days and no complication occurred. No recurrence of pain was detected during a mean follow-up of 24 months (range, 12-36 months).

Despite its elegancy, this approach has not yet gained widespread acceptance because of its limited applicability: the pars must be intrinsically wide enough to permit fenestration without compromising its integrity, the foramen must be wide enough, uninvolved by stenosis, to permit manipulation of the root and herniation. Eventually the approach cannot be modified with the addition of laminectomy to address more medial pathology (Ehni, 2004; Epstein, 1995).

Lateral muscle-splitting approaches

In 1988 Wilse and Spencer showed that FLLDH can be addressed via a lateral muscle-splitting approach (Wiltse, 1976). Advantages are the development of an oblique corridor, through which the foramen comes into view without the need of significant bone removal, and the avoidance of muscle insertions detachment, which may result in muscle ischaemia and denervation (Maroon, 1990; Faust, 1992; Schlesinger, 1992; Porchet, 1997). The *transmuscular* approach follows the plane between the multifidus medially and the longissimus laterally, while in the *intermuscular (or far-lateral)* approach the intermuscular aponeurosis between the erector spinae and the iliocostalis is used. The latter approach allows for a more oblique trajectory toward the foramen denervation (Maroon, 1990; Faust, 1992; Schlesinger, 1992; Tessitore, 2004) (Fig 14).

For the *transmuscular approach,* the skin incision is approximately 5-7 cm long and 8-10 cm from the midline. The thoracolumbar fascia and the erector spinae aponeurosis are incised along with the same line. A fibrous septum usually identifies the limit between the multifidus and longissimus. Sometimes, peripheral divisions of posterior lumbar vessels can be seen arising from this plane. If the septum cannot be identified, finger dissection between muscle fibers is also possible and in any case an avascular plane can be found. Care must be taken to keep inside this plane, to avoid bleeding and damage to the divisions of the posterior primary ramus of the spinal nerve which may result in hypoesthesia.

The plane is enlarged until the bony landmarks of the surgical exposure, i.e., the inferior border of the cranial transverse process and the lateral aspect of the isthmus, can be palpated. As one should note, bony landmarks are the same used in the intertransverse approach. Some advocate identifying and following lumbar arterial branches and spinal nerve divisions as a guide to the target area (Kambin, 1996). However, according to most authors, this can be confusing and consistent bony landmarks are always more reliable (Maroon, 1990; Tessitore, 2004). Intraoperative x-ray confirmation of the level is taken, with a spinal needle placed in the corner between the isthmus and the base of the superior transverse process. The isthmus, the base of the superior transverse process, and the lateral aspect of the facet joint are then cleaned of muscular attachments. A definitive Caspar-type retractor is inserted; the shorter blade is medially placed over the dorsal aspect of the facet joint and the longer blade is laterally placed between the longissimus muscle and the intertransverse ligament. The operative microscope is then brought into position (Fig 18A). Muscle fibers between the accessory and mamillary processes (the medial intertransverse muscle) are cut. The lumbar artery and accompanying veins may be exposed in the lower part of the surgical field. Any damage to this vascular bundle can cause troublesome bleeding, thus the exposure should be limited caudally and uncovering the articular joint and the inferior transverse process is not necessary. In this way, potential damage to the exiting spinal nerve is also avoided. Exposure of the spinal nerve in this area is not needed since it may result in damage to the dorsal primary ramus. At this stage, the use of punches to tear off soft tissue should be avoided, because of the risk of catching the dorsal primary ramus and avulsing part of the spinal nerve of the dorsal root ganglion. The use of monopolar coagulation should also be avoided. The angle between the transverse process and the isthmus is then drilled. The amount of drilling varies depending on the involved level and degenerative changes (Fig 18B). The lateral border of the ligamentum flavum and the inferior border of the pedicle are exposed and the lateral extension of the ligamentum flavum is resected with Kerrison punches. The operation then goes on as described for the intertransverse approach (Fig 18 C, D). Lateral dissection along the dorsal ganglion and spinal nerve should be avoided, because of the risk of injury to the lumbar artery and dorsal primary ramus (Maroon, 1990; Tessitore, 2004).

For an *intermuscular approach*, a more lateral incision is made exposing the intermuscular aponeurosis between the erector spinae and the iliocostalis. The procedure do not differ from that described for the transmuscular approach, but less bone removal is needed due to the very angled line of sight.

Lateral muscle-splitting approaches are usually not suitable for L5-S1 herniations because of the presence of the iliac ala and the very fibrous and tense consinstency of longissimus and iliolumbar ligaments (Schlesinger, 1992; Hoh, 2010). Other disadvantages of these approaches are the unfamiliar extraspinal anatomy and the steep learning curve, especially in the setting of degenerative changes (Ryang, 2007).

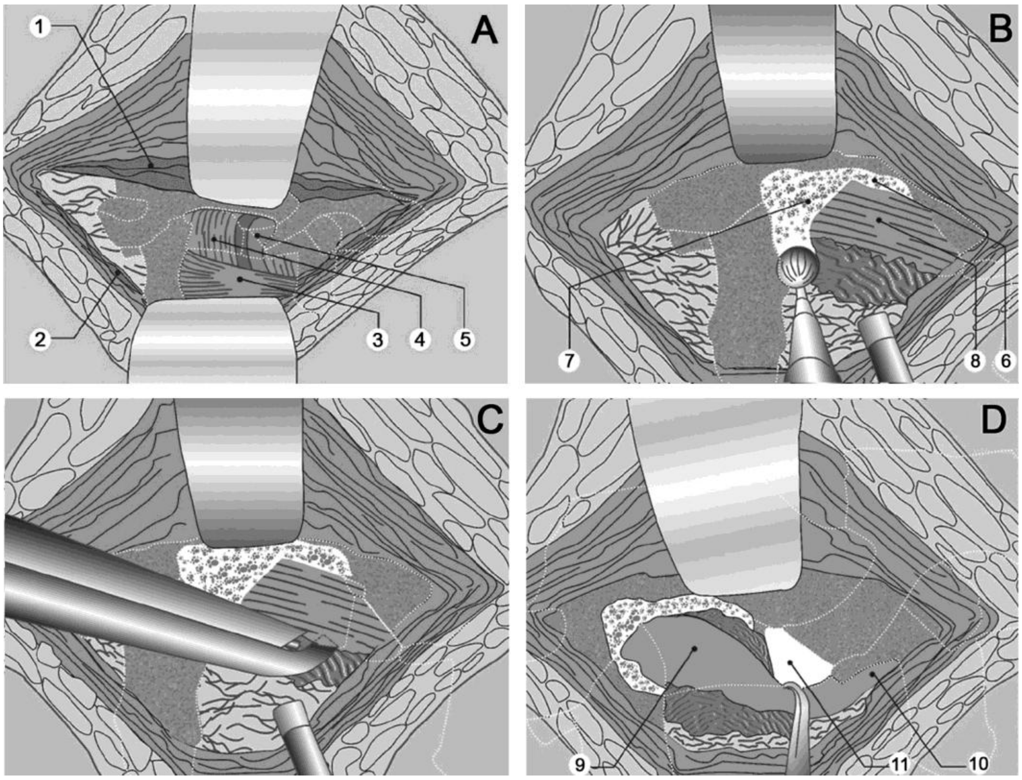

Fig. 18 Left intramuscular approach. A) The multifidus (1) is retracted medially and the longissimus (2) laterally. The intertransverse ligament with its horizontal (3) and vertical (4) leaves is exposed. The lumbar artery and veins (5) may be exposed at the caudal edge of the field. B) Drilling of the angle between the superior aspect of the isthmus (6) and the base of the cranial transverse process (7) with a high-speed drill, exposes the lateral border of the ligamentum flavum (3). Cranially, the drilling reaches the spongiosa of the pedicle. C) Resection of the outer part of the ligamentum flavum with Kerrison rongeurs, to expose the dorsal root ganglion. D) The dorsal root ganglion (9) and the spinal nerve (10) are visualized and, after displacing the nerve with a microsurgical dissector, the disc bulging (11) is exposed beneath them (from Tessitore et al 2004)

Tessitore et al. reported the results of the largest series of FLLDH surgically treated via a lateral transmuscular approach. The analysis of long-term outcomes (mean follow-up period 50 months) for 202 patients showed a decrease of incidence from 96 to 30% for back pain, from 74 to 16% for motor deficits and from 59 to 18% for sensory deficits. According to the Macnab outcome scale (Macnab, 1971), 31% of patients experienced an excellent recovery and 42% experienced a good recovery. The complication rate was 1.5%. Complications directly related to surgery were one muscular herniation, one dural tear and one superficial foreign-body granuloma. The recurrence rate was 4.5%. A recent retropective analysis by Ryang and colleagues revealed a 95% rate of excellent to good results according to Ebeling's criteria (Ebeling, 1986) in 20 patients who underwent a lateral transmuscular approach. This group compared favorably to a control group of 28 cases in which a combined interlaminar-paraisthmic approach was adopted, in terms of global outcome, incidence of new back pain and complication rate.

The authors argue that these findings are the result of the less invasive nature of the lateral approach and of the better exposure of nervous structures and disc that it provides.

Interlaminar contralateral approach

In 2006 Pal and coworkers reported one case of L4-L5 intraforaminal herniation that was successfully removed via a microsurgical interlaminar contralateral approach (Pal, 2006). The authors performed a bilateral subperiosteal dissection exposing the interlaminar spaces on both sides and then a bilateral flavectomy and interlaminotomy with resection of the interspinous ligament. From the contralateral side, after a small trimming of the medial facet, the dural sac and the herniation were identified and after retraction of the root and incision of the annulus, the disc material was removed from the foramen with a pituitary rongeur (Fig 19).

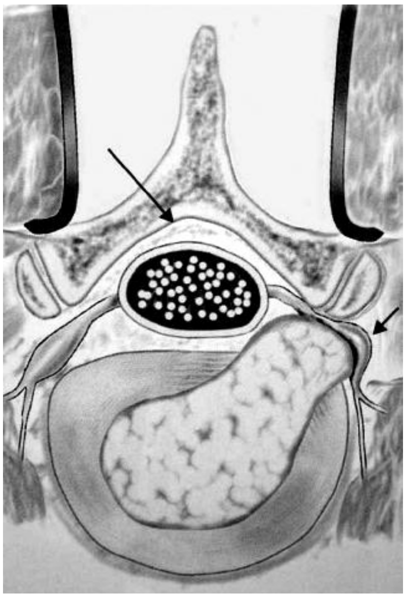

Fig. 19 Schematic drawing showing the surgical trajectory of the interlaminar contralateral appoach (from Pal et al 2006)

Two years later, Yeom and colleagues described the successful treatment of two L5-S1 intraforaminal herniations via the contralateral route (Yeom, 2008). These authors used a strictly unilateral approach from the contralateral side. Access to the canal and the contralateral foramen was achieved by resecting the caudal portion of the base of the L5 spinous process and of the L5 lamina, a small anterior portion of the interspinous ligament, the medial portion of the ligamentum flavum on both sides and the inner portion of the lateral ligamentum flavum on the side of the disc herniation. This corrodor allowed to visualize the intervertebral foramen, the root and the intraforaminal disc herniation (Fig 20). Thus the authors demonstrated the feasibility of a purely contralateral approach to intraforaminal herniations, at least for the L5-S1 level. Instead of a subperiosteal dissection, they performed a contralateral transmuscular approach using tubular retractors. The authors highlighted the usefulness of such approach at L5-S1 level, where both medial approaches (intertransverse) and lateral muscle-splitting approaches can be demanding.

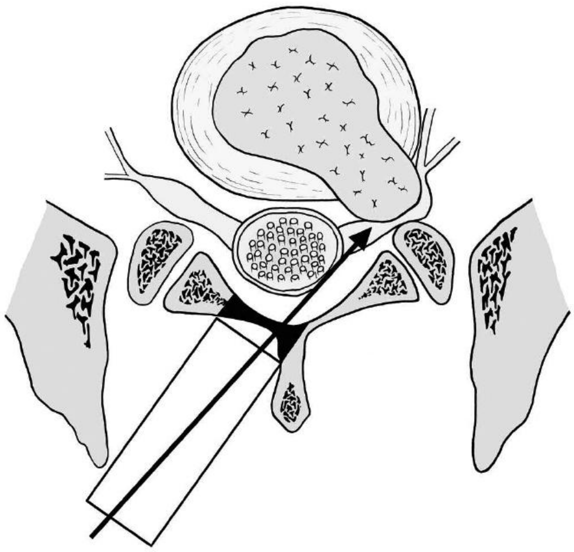

Fig. 20 L5-S1 Contralateral approach according to Yeom et al: the caudal portion of the base of the L-5 spinous process and the inferomedial portion of the L-5 lamina *(black-shaded area)* should be resected. The resection can be minimized with a caudal-to-cranial angulation of the trajectory (from Yeom et al 2008)

The contralateral technique has further been refined by Berra and coworkers, who adopted it for intraforaminal and intra-extraforaminal herniations, also at L4–L5 and L3–L4 levels, and reported on the results obtained in nine patients (Berra, 2010). According to their technique, a midline incision is used and the interlaminar space contralateral to that of the herniation is exposed subperiosteally. A self-retaining tubular Caspar retractor is inserted opening its lateral blade widely. Under microscopic view, the caudal portion of the base of the spinous process, the medial and caudal part of ipsilateral lamina and the inner portion of contralateral lamina are removed with a highspeed diamond drill (Fig 21).

Fig. 21 Contralateral approach. Representation of the bone area to be removed (base of the spinous process, the medial and caudal part of ipsilateral lamina and the inner part of the contralateral lamina) (from Berra et al 2010)

A curvilinear dissector or bended spatula is used by the assistant surgeon to protect the dural sac from the drill and enlarge the surgical corridor. As in previously described contralateral techniques, the operating surgeon stands on the side opposite to that of the disc herniation. Tilting the table toward the side of herniation improves the visualization of the foramen and allows to minimize the bone drilling. A 2-mm Kerrison punch is used to remove the ligamentum flavum on the side of the herniation and to perform the contralateral foraminotomy. The space between both superior and inferior pedicles is then visualized, and the dorsal aspect of the nerve root and ganglion exposed. The disc occupies the most caudal part of the microscopical surgical field (Fig 22). The herniated disc is exposed, separated, and removed by a micropituitary rongeur. The space underneath the root is explored with a small hook dissector and the root is mobilized.

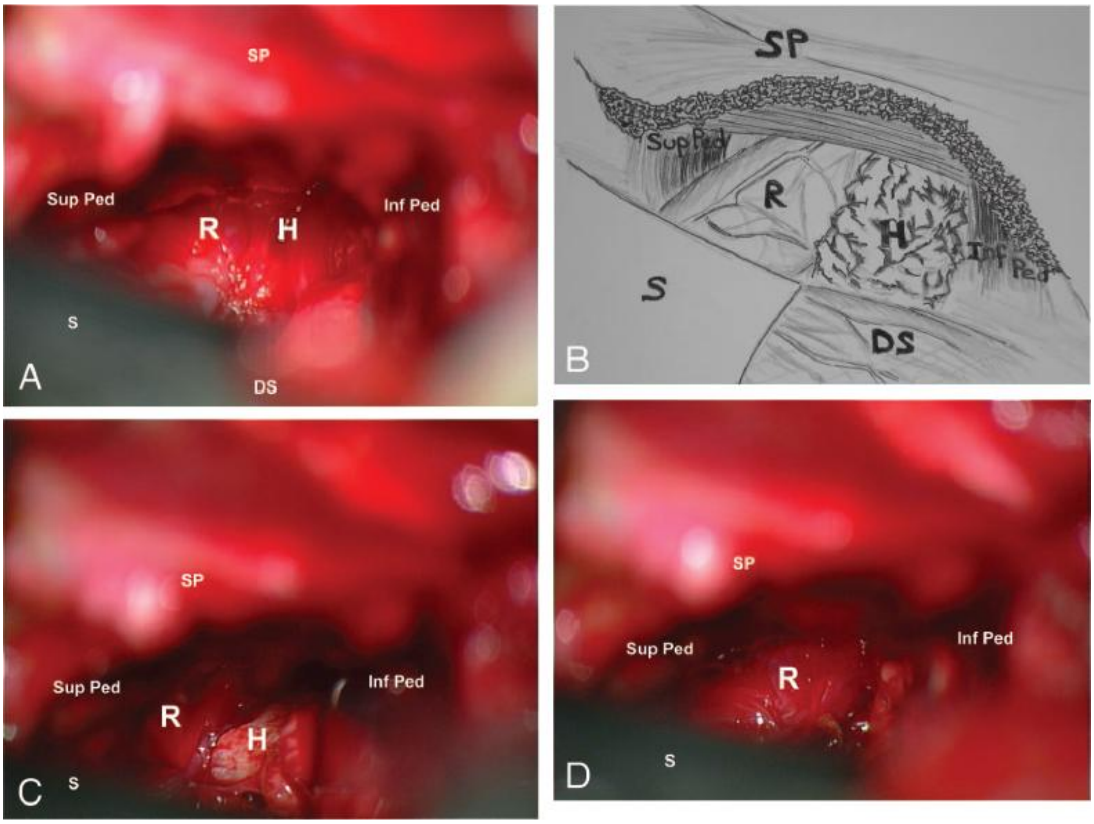

Fig. 22 Intraoperative pictures and schematic diagram of the contralateral approach to a rightsided L4 –L5 far-lateral disc herniation. **A,** The microsurgical field is centered on the neural foramen region; SP indicates spinous process; Sup Ped, superior pedicle; Inf Ped, inferior pedicle; R, spinal root; H, contained disc herniation; S, spatula; DS, dural sac. **B,** Schematic drawing of the surgical corridor. The nerve root is usually displaced upward and against the superior pedicle. **C,** disc fragments after opening of posterior ligament. **D,** expansion of the nerve root after the disc herniation removal (from Berra et al 2010)

In their nine patients, followed-up for a median of 12.7 months (range, 5–22), postoperative average ODI score improved from 44 to 14. According to Macnab's criteria (Macnab, 1971) 7 patients made an excellent recovery and 2 patients a good recovery. At discharge, 7 patients experienced complete regression of radicular pain and 2 patients reported a dramatic improvement of the symptoms. At follow-up, no patient complained of radicular pain. The incidence of back pain decreased from 5/9 patients to 2/9 patients. Preoperative motor deficits, present in 8/9 patients, improved in all cases even though at follow-up 3 patients still showed some degree of motor weakness. No patient developed postoperative complications nor recurrences.

MATERIALS AND METHODS

Population

The aim of the study was to compare the outcome of the interlaminar contralateral approach to FLLDH with that of standard techniques. For this purpose a retrospective analysis of a single-institution surgical case series was performed.

Patients operated for FLLDH at the Neurosurgical Department of the San Carlo Borromeo Hospital (Milan, Italy) between january 2010 and september 2013 were considered for the analysis.

In order to rule out possible confounding factors, we did not include patients with recurrent herniations, those with herniations due to severe scoliosis and cases in which the intervention included not only the excision of a FLLDH but also a concurrent procedure (e.g. laminectomy or fusion) at the same or another level.

The final study population consisted of 38 patients, 20 men and 18 women, whose median age was 59,5 years (range 26-77). All patients presented with radiculopathy and had a preoperative diagnosis of FLLDH confirmed by MR and/or CT. In some instances the diagnosis was supported by neurophysiological studies. 18 patients underwent a microsurgical interlaminar contralateral approach (CL group) while in the remaining 20 cases a standard approach was adopted (intertransverse in 16, transmuscular in 2, intermuscular in 2) (ST group). Several surgeons performed the operations.

Surgical technique

All the operations were performed under general anesthesia in the prone position with the aid of the operating microscope. Patients received prophylactic intravenously administered antibiotic agents before skin incision. Fluoroscopical confirmation of the level was estabilished preoperatively by means of a needle inserted in the spinous process or in the interspinous space and then repeated intraoperatively. Adopted surgical techniques are described above in the Introduction section. If deemed necessary, the disc space was entered and partially emptied but was not routinely cleared. Absorbable haemostatic gelatin sponge imbued with steroid were used to obtain epidural hemostasis and to reduce the root inflammation. A drain tube was placed for 12-24 hours and patients were routinely mobilized on the first day after surgery. In patients with residual pain at 1 month evaluation, physiotherapy was started.

Data collection

Relevant data were retrospectively collected reviewing hospital case notes, operative reports, outpatient documents and neuroradiological images. We recorded patient demographics, clinical features (level and side of herniation, duration of symptoms, presence of back pain and of sensory or motor deficits, preoperative Oswestry Disability Index (ODI) score, comorbidities) as well as post-operative complications. The ODI questionnaire (version 2.0) (Baker, 1989; Fairbank, 2000) had been administered at the time of hospital admission and at the routine 1 month post-operative outpatient visit. Neuroradiological images were reviewed and herniations categorized as intraforaminal, extraforaminal and intra-extraforaminal according to the main site of root compression. Recurrences were defined as a relapse of preoperative symptoms with neuroradiological evidence of root compression that required reoperation.

Outcome assessment

Outcome was assessed at 1 month post-operatively (short-term outcome) and at follow-up (long-term outcome). For short-term outcome, patients were categorized as improved or not improved with regard to radicular pain, back pain and motor or sensory deficit reviewing outpatient notes and ODI and Macnab's questionnaires (Macnab, 1971) administered at the time of outpatient evaluation. For long-term outcome assessment, structured telephone interviews were performed by an examiner blinded to the type of surgical procedure. Patient were asked if any further functional improvement of their motor deficit occurred since the time of discharge and ODI and Macnab's questionnaire were administered. For each patient, short-term and long-term ODI scores were registered and an improvement index, ranging from 0 to 1, was calculated as the difference between pre-operative and post-operative scores, normalized for the pre-operative score.

Statistical analysis

Data are presented as median for continuous variables and as count (percentage) for categorical variables. For intergroup comparisons, the Pearson chi-square or the Fisher exact test were used for categorical variables and the Mann-Whitney U test for independent samples for continuous variables. Relationships between baseline and outcome variables were checked with the Pearson chi-square or the Fisher exact test for categorical variables and with a linear regression analysis for continuous variables. Statistical significance was defined as a $p<0,05$. Analysis was performed with the SPSS Statistics software v.21 (IBM, USA).

RESULTS

Baseline characteristics

Demographics

The median age of the 38 patients was 59,5 years (range 26-77). 20 (52,6%) of them were males and 18 (47,4%) females. There was no statistically significant difference in age and gender distribution between the CL and the ST group.

Clinical features

All the patients presented with radicular pain either of the sciatic or of the femoral type. Back pain was a complaint in 31 out of 38 cases (81,6%). The time since the onset of symptoms varied from 1 week to 24 months (median 10 weeks). A motor deficit was present preoperatively in 18 patients (47,4%) and a sensory deficit in 22 (57,9%). Deep tendon reflexes were altered in 27 cases (71,1%) and radicular stretching tests (Lasegue or Wasserman) were positive in 29 cases (76,3%).

The median preoperative ODI score was 73/100 (range 18-96) in the whole population, 73/100 (range 32-92) in the CL group and 71/100 (range 18-96) in the ST group.

21 patients (55,3%) had relevant systemic comorbidities. Among them, diabetes and mood/anxiety disorders were separately assessed because of their known potential negative impact on outcome. The two groups were statisitcally comparable with regard to all the above-mentioned preoperative clinical features (see table 4). In 20 cases electromyography was performed preoperatively. Only in 7 cases the severity of radiculopathy was assessed (severe in 4, mild-moderate in 3).

Level, side and site of herniations

The most often involved level was L4-L5 (22 cases), followed by L3-L4 (7 cases), L5-S1 (6 cases) and L2-L3 (3 cases). Herniations at L5-S1 were more frequent in the CL group, while those at upper levels (L2-L3 and L3-L4) were more frequent in the ST group (p=,092).

Herniations were intraforaminal in 15 cases (39,5%) extraforaminal in 13 (34,2%) and intra-extraforaminal in 10 (26,3%). A statistically significant difference in the site of herniations was found between the two groups. Purely intraforaminal herniations were more frequent in the CL group (66,7%) than in the ST group (15%), on the other hand extraforaminal herniations were more frequent in the ST group (50,0%) than in the CL group (16,7%) (p=,005).

These differences between the two groups in the level and site of operated FLLDH reflect a selection bias due to a case-based choice of the approach by the attending surgeon.

With regard to the side of herniations, 17 of them were right-sided (44,7%), 21 were left-sided (55,3%) and no statistically significant difference was observed between groups.

Surgeons

Nine surgeons performed the operations. All of them did standard approaches and seven did contralateral approaches. All surgeons were already trained in FLLDH surgery via standard approaches, while six of the seven operators who took part in contralateral approaches were at their first experience with this technique. Surgeon C had alraedy carried out about 30 contralateral approaches and taught his colleagues. Surgeon A is the senior staff member. The number of procedures performed by each operator is summarized in Table 5.

Follow-up length

Median follow-up length was 21 months (range 1-47). Mean follow-up length was greater in the CL group than in the ST group but this difference did not reach statistical significance (p=,059).

Table 4. Baseline characteristics

	Population (38 patients)	CL approach group (18 patients)	ST group (20 patients)	p
Demographic characteristics				
Age (years)	median 59,5 (26-77)	median 58 (29-76)	median 63,5 (26-77)	,393
Males	20 (52,6%)	8 (44,4%)	12 (60,0%)	,338
Females	18 (47,4%)	10 (55,6%)	8 (40,0%)	
Clinical carachteristics				
Duration of symptoms (weeks)	median 10 (1-96)	median 10 (1-96)	median 10 (1-48)	,965
Back pain	31 (81,6%)	16 (88,9%)	15 (75,0%)	,410
Motor deficit	18 (47,4%)	10 (55,6%)	8 (40,0%)	,338
Sensory deficit	22 (57,9%)	11 (61,1%)	11 (55,0%)	,703
Preoperative ODI score	median 73 (18-96)	median 73 (32-92)	median 71 (18-96)	,654
Deep tendon reflexes abnormalities	27 (71,1%)	13 (72,2%)	14 (70,0%)	,880
Positive radicular stretching test	29 (76,3%)	13 (72,2%)	16 (80,0%)	,709
Lasegue	18 (47,4%)	9 (50%)	9 (45,0%)	,758
Reverse Lasegue	15 (39,5%)	5 (27,8%)	10 (50,0%)	,162
Comorbidities	21 (55,3%)	9 (50,0%)	12 (60%)	,536
Cardiovascular	17 (44,7%)	8 (44,4%)	9 (45,0%)	,937
Diabetes	3 (7,9%)	2 (11,1%)	1 (5,0%)	,595
Mood/anxiety disorders	2 (5,3%)	1 (5,6%)	1 (5,0%)	1,000
Level of herniation				
L2-L3	3 (7,9%)	0 (0,0%)	3 (15,0%)	,092
L3-L4	7 (18,4%)	4 (22,2%)	3 (15,0%)	
L4-L5	22 (57,9%)	9 (50%)	13 (65,0%)	
L5-S1	6 (15,8%)	5 (27,8%)	1 (5,0%)	

	Population (38 patients)	CL approach group (18 patients)	ST group (20 patients)	p
Side				
Right	17 (44,7%)	6 (33,3%)	11 (55,0%)	,180
Left	21 (55,3%)	12 (66,7%)	9 (45,0%)	
Site of radicular compression				
Intraforaminal	15 (39,5%)	12 (66,7%)	3 (15,0%)	,005
Extraforaminal	13 (34,2%)	3 (16,7%)	10 (50,0%)	
Intra-extraforaminal	10 (26,3%)	3 (16,7%)	7 (35,0%)	
Follow-up length (months)	21 (1-47)	median 25 (3-47)	median 14 (1-46)	,059

Table 5. Number of procedures performed by each surgeon

	Number of procedures		
	All operations	**Contralateral approaches**	**Standard approaches**
Surgeons			
A	10	3	7
B	6	4	2
C	5	4	1
D	4	0	4
E	3	2	1
F	3	2	1
G	3	2	1
H	3	1	2
I	1	0	1
Total	38	18	20

Intergroup comparison

Short-term outcome

Short term-outcome was assessed at the time of the routine 1 month post-operative outpatient visit. Median ODI score decreased from 73/100 to 18/100 (range 0-84). In the CL group the median short-term score was 22/100 while in the ST group it was 12/100. The mean ODI score at 1 month evaluation was significantly lower in the ST group than in the CL group (p=,028). Also the ODI improvement index was higher in the ST group but this difference did not reach statistical significance (p=,067).

Overall rate of improvement was 88,9% for leg pain, 62,5% for back pain and 80,0% for motor deficits. No statistically significant difference was found between groups.

According to Macnab's criteria, an excellent/good result was achieved in 71,1%, a fair result in 13,2% and a poor result in 15,8%. Even if the percentage of excellent/good results was higher in the ST group (80,0%) than in the CL group (61,1%), this difference did not reach statistical significance (p=,157).

Long-term outcome

At follow-up, the median ODI score had decreased from 73/100 to 6/100 (range 0-76). Intergroup comparison did not show statistically significant differences neither in absolute ODI score nor in ODI improvement index, even if the mean improvement index was higher in the CL group than in the ST group (p=,182). Thus a change in the trend in favor of the CL approach was observed at long-term compared to short-term evaluation.

According to Macnab's criteria, results were deemed excellent/good in 76,5%, fair in 14,7% and poor in 8,8%. As for short-term outcome, the percentage of excellent/good results was higher in the ST group (82,4%) than in the CL group (70,6%) but, again, intergroup comparison did not show statistical significance. Moreover the p value of this comparison was much greater at long-term than at short-term evaluation (,709 instead of ,157). Comparing short-term and long-term assessments, the relative incidence of excellent/good, fair and poor results did not change in the ST group, while in the CL group the percentage of excellent/good results raised from 61,1% to 70,6% and that of poor results decreased from 27,8% to 11,8%.

These data suggest a trend toward a better functional outcome in patients operated with standard approaches at 1 month evaluation but, on the other hand, a trend toward better long-term functional results in patients treated with the contralateral technique.

Complications

Only one complication was recorded (incidence 2,6%). During one operation via the contralateral route a dural tear occurred and was directly repaired without sequelae. No complications were detected in the ST group.

Recurrences

During the follow-up period, four patients (10,5%) required reoperation because of symptomatic recurrence of the herniation. The incidence of recurrences was greater in the ST group (15,0%) than in the CL group (5,6%). This difference did not reach statistical significance (p=0,606).

Reoperation consisted in a second herniation removal with interlaminar extension in one case and in unilateral transforaminal interbody fusion in three cases.

The time between first surgery and reoperation ranged from 2 to 20 months (median 14 months).

Relationships between baseline and outcome variables

The existence of relationships between long-term outcome variables (ODI score, ODI improvement index, percentage of good/excellent results and recurrences) and baseline characteristics was checked by means of crosstabs with association tests and by linear regression analysis.

Gender, presence of motor or sensory deficits, level, side, site of the herniations and presence of comorbidities did not correlate with long-term outcome.

Young age correlated with recurrence (p=,046). According to regression analysis, the time since the onset of symptoms correlated positively with follow-up ODI score even if this association was not statistically significant (p=,053). Symptoms duration also correlated negatively with ODI improvement index and in this instance the association was statistically significant (p=,001).

Preoperative ODI score correlated weakly with follow-up ODI score (p=,184) but not with the ODI improvement index (p=,532). This finding supports the usefulness of the ODI improvement index in obtaining an outcome assessment that is not influenced by the degree of preoperative functional impairment. The presence of both diabetes and mood/anxiety disorders significantly correlated with a high follow-up ODI score (p=,013) and with a low ODI improvement index (p=,049).

The analysis of relationships between variables was also applied to look for operator-dependent influences on outcome. Outcome variables did not correlate with the operating surgeon neither in the whole population nor into single groups. In the whole population the performance of the operation by the senior surgeon (A) did not correlate with outcome. In the CL group the performance of the operation by the surgeon with the largest experience with this approach (C) did not correlate with outcome. With respect to the number of procedures performed by each operator, no correlation was found between the total number of operated cases and outcome variables in the whole population. Moreover, the same analysis conducted separately on the two groups failed to show any correlation.

Thus in our population the long-term outcome was operator-indipendent and did not show any correlation with the number of intervention performed by each surgeon.

Table 6. Short-term outcome

	Population (38 patients)	**CL approach group (18 patients)**	**Standard approaches group (20 patients)**	**p**
ODI score (median, range)	18 (0-84)	22 (2-84)	12 (0-64)	,028
ODI improvement index (median, range)	0,73 (-0,40-1)	0,64 (-0,40-0,97)	0,78 (0,29-1)	,067
Macnab's criteria				
Excellent/Good	27/38 (71,1%)	11/18 (61,1%)	16/20 (80,0%)	,157
Fair	5/38 (13,2%)	2/18 (11,1%)	3/20 (15,0%)	
Poor	6/38 (15,8%)	5/18 (27,8%)	1/20 (5,0%)	
Leg pain improvement	35/38 (92,1%)	15/18 (83,3%)	19/20 (95,0%)	,263
Back pain improvement	23/31(74,2%)	10/16 (62,5%)	13/15 (86,7%)	,220
Motor deficit improvement	14/18 (77,8%)	8/10 (80,0%)	6/8 (75,0%)	1,000

Table 7 Long-term outcome

	Population (38 patients)	CL approach group (18 patients)	Standard approaches group (20 patients)	p
ODI score (median, range)	6 (0-76)	20 (0-76)	6 (0-52)	,028
ODI improvement index (median, range)	0,88 (0-1)	0,73 (0-1)	0,20 (0,39-1)	,067
Macnab's criteria				
Excellent/Good	26/34 (76,5%)	12/17 (70,6%)	14/17 (82,4%)	,709
Fair	5/34 (14,7%)	3/17 (17,6%)	2/17 (11,8%)	
Poor	3/34 (8,8%)	2/17 (11,8%)	1/17 (5,9%)	
Motor deficit improvement (follow-up)	2/4 (50%)	1/2 (50%)	1/2 (50%)	1,000

Table 8. Complications

	Population (38 patients)	CL approach group (18 patients)	Standard approaches group (20 patients)	p
Complications	1/38 (2,6%)	1/18 (5,6%)	0/20 (0%)	,474

Table 9. Recurrences

	Population (38 patients)	CL approach group (18 patients)	Standard approaches group (20 patients)	p
Recurrence-reoperation	4/38 (10,5%)	1/18 (5,6%)	3/20 (15,0%)	,606

DISCUSSION

Since the first comprehensive description of FLLDH and the associated clinical syndrome by Abdullah et al. in 1974 (Abdullah, 1974), various surgical techniques have been devised to address this pathology and the results of several case series have been reported. Table 10 summarizes the relevant literature on FLLDH surgery. Different outcome measures have been used by the authors and this prevent an effective comparison between studies.

Artrectomy, either full or partial, was the first adopted technique. It is an extension of the routine interlaminar approach that allows for a very good visualization of the foramen and its contents. This approach was adopted by Abdullah at al. who first published a large case series in 1988 (Abdullah, 1988). As known, resection of the zygapophyseal joint carries a substantial risk of postoperative instability and chronic low back pain. Overt radiological instability is estimated to occur in 2% to 4% of patients, but a more subtle biomechanical impairment, often referred to as micro-instability, may develop and lead to chronic pain. Therefore artrectomy has gradually been replaced by new and less demolitive approaches (Epstein, 1990; Garrido, 1991; Epstein, 1995; Porchet, 1999; Epstein 2006).

The intertransverse approach was introduced to address extra-foraminal and foraminal herniations without destabilizing the facet joint (Jane, 1990; Siebner, 1990; Melvill, 1994; Hodges, 1999). In the large comparative study by Epstein et al. 1995 the intertransverese approach yielded nearly comparable results with respect to full and medial facetectomy, but did not cause instabilty (Epstein, 1995).

Donaldson et al. reported a 72% rate of excellent or good outcome in 29 patients treated with this technique (Donaldson, 1993). Similar satisfactory results were reported by Hodges et al. and by Montinaro et al. (Hodges, 1999; Montinaro, 2004). The main advantages of the intertransverse route are the familiar surgical anatomy and the opportunity to extend the exposure more medially, if needed, with an interlaminotomy. However the intertransverse approach may be unsuitable in addressing purely intraforaminal herniations, especially at lower lumbar levels, because of its tangential rather than oblique angle of sight in relation to the foramen.

The pars interarticularis fenestration approach, specifically devised for intra-foraminal herniations (Di Lorenzo, 1998) has not yet gained widespread acceptance due to its limited applicability. The fenestration allows for an effective management of the intraforaminal herniation only if the pars and the foramen are intrinsically wide (Epstein, 1995; Ehni, 2004).

Lateral muscle-splitting approaches allow for an oblique, direct view of the foramen without significant bone removal. The transmuscular approach between the multifidus and longissimus muscles was firstly introduced by Wiltse in 1988 (Wiltse, 1976) and many reports on its results have been published so far. Excellent or good outcomes have been reported in 73% to 94,3% of cases (Darden, 1995; O'Hara, 1997; Porchet, 1999; Gioia, 1999; Quaglietta, 2005; Marquardt, 2012). In a study on 202 patients by Porchet et al., the prevalence of motor and sensory deficits decreased from 74% to 16% and from 59% to 18% respectively, while the prevalence of back pain decreased from 96% to 30% (Porchet, 1999). The main risk factor for a poor outcome seems to be a long time between the onset of symptoms and surgery (O'Hara, 1997). The complications rate is around 2%. Minor wound-related complications and less frequently dural tears are the most frequent. The recurrence rate has been accurately extimated by Marquardt et al. with an ultra long-term follow-up spanning an average of 10 years. The incidence of early recurrences (i.e. manifesting during hospital stay) was 5,8%, and that of late recurrences was 8%.

The intermuscular approach between the longissimus and the iliocostalis has been less frequently reported. In a study by Epimenio et al. good or excellent results according to the Roland-Morris criteria were achieved in all the 46 studied patients.

Ryiang et al. conducted a retrospective study on a total of 48 patients comparing the lateral transmuscular and a combined intertransverse and interlaminar approach. In patients operated with a transmuscular approach the rate of excellent or good outcome was significantly higher and the rate of new low back pain was significantly lower. These findings may be attributable to the lesser invasiveness of the lateral transmuscular approach (Ryiang, 2007).

Together with the previous study by Epstein, in which facetectomy and the intertransverse approach were compared, the work by Ryiang et al is the only analysis aiming to a direct comparison between different techniques. The main bias of their analysis is the presence of two independent consecutive series with different planned follow-up periods (18 months for combined approaches and 36 months for transmuscular approaches).

Lateral muscle-splitting approaches have recently incorporated new minimally invasive techniques, such as microsurgery through tubular dilating retractors and endoscopy. This trend attests a search for new solutions, having as goals the reduction of operative time, blood loss, hospital stay and damage to paraspinal muscles vasculature and innervation, which may lead to post-operative altered segmental motion, chronic pain and patient disability.

Results of both microsurgery with the use of tubular retractors (Ryiang, 2007; Kotil, 2007; Pirris, 2008; Fuentes, 2009; Salame, 2010; Voyadzis, 2010) and endoscopy (Foley, 1999; Lew, 2001; Jang, 2006; Choi, 2007; Sasani, 2007; Lubbers, 2012) seem to approximate those of open microsurgery. For endoscopic procedures, a not negligible rate of failure (4,9 – 9,1%) with the need for subsequent open surgery has been reported.

The microsurgical interlaminar contralateral approach, firstly reported by Pal (2006) and Yeom (2008) and then refined and systematically adopted by Berra (2010), combines the advantage of the familiar anatomy of a midline interlaminar approach to that of an oblique angle of sight toward the foramen, without the need of facet resection. Berra et al reported a good or excellent outcome according to Macnab's criteria and no complications in nine consecutive patients at a mean follow-up of 12,7 months. However, a more extensive assessment of this new technique and a comparison with standard approaches is currently lacking.

Table 10. Literature review

Author	n	Approach	Follow up	Results	Complications	Recurrences
Abdullah (1988)	138	Artrectomy (mostly partial)	median >10 y	No complaint at 3 months in 113/138		2
Garrido (1992)	41	Full artrectomy	av 22,4 m	Excellent in 35/41		1 (subsequent fusion)
Donaldson (1993)	29	Intertransverse		72% excellent/good results 71% motor improvement		
Hodges (1999)	25	Intertransverse		av ODI 50,7 to 34,7 av VAS 7,7 to 4,2		
Montinaro (2004)	15	Intertransverse		Prompt recovery in 15/15		
Ozveren (2004)	18	Intertransverse + interlaminar	5 - 8 y	Excellent outcome in all patients		
Postacchini (1998)	43	Interlaminar	2y	Excellent-good results in 90% No instability		
Maroon (1990)	25	Transmuscular				
Darden (1995)	25	Transmuscular	>2 y	Excellent/good results in 80%		
O'Hara (1997)	20	Transmuscular	6 m - 4 y	Excellent/good results in 90% 2 patients not improved (long pre-op. symptoms duration)		
Porchet (1999)	202	Transmuscular	av 50 m	Excellent/good results in 73% Back pain 96% to 30% Motor deficits 74% to 16% Sensory deficits 59% to 18%	3 surgical minor complications 7 general complications	11 (5,4%)
Gioia (1999)	13	Transmuscular	av 14 m	13/13 leg pain improvement 8/9 motor improvement	2 wound seromas	
Quaglietta (2005)	42	Transmuscular	av 32,5 m	Excellent/good results in 91%	28,6% transient radicular pain	

Author	n	Approach	Follow up	Results	Complications	Recurrences
Marquardt (2012)	138	Transmuscular	av 12 y	Excellent/good results in 95,4% Complete relief 56,3% minor ailments 16,1% residual sympt 27,6%	3 (2,2%) 1 seroma 1 hematoma 1 wound healing disorder	Early 5,8% Late 8%
Epimenio (2003)	46	Intermuscular	av 3,5 y	Excellent 82%, good 18% (Roland-Morris)		
Ryiang (2007)	15	TMI		Excellent/good results 14/15		
Kotil (2007)	14	TMI	av 29 m			
Pirris (2008)	4	TMI	3-11 w	All improved		
Fuentes (2009)	26	TMI	av 2 y	av VAS 7 to 2		
Salame (2010)	31	TMI	av 25,16 mo	av VAS 8,6 to 0,6 (radicular) av VAS 5,8 to 0,7 (back pain) SF-36 pain score 6,71 to 79,53 (at 6 m) SF-36 functional score 9,68 to 76,33 (at 6 mo)	2 dural tears 1 residual fragment (reoparation)	
Voyadzis (2010)	20	TMI				
Berra (2010)	9	Contralateral	av 12,7 mo	av ODI 44 to 14 Excellent results in 7 Good results in 2 Back pain incidence 5/9 to 2/9 Motor deficit improved in 8/8		
Foley (1999)	11	Endoscopic	12 - 27 mo	Excellent 10 Good 1 motor improvement 6/6		
Lew (2001)	47	Endoscopic	av 18 mo	Excellent/good results in 85% 5 pt (11%) subs open surgery	Subsequent open surgery: 5 (11%)	

Author	n	Approach	Follow up	Results	Complications	Recurrences
Jang (2006)	36	Endoscopic	median 18 m	Excellent/good results 85,7%	Subsequent open surgery: 3 (8,6%)	
Sasani (2007)	66	Endoscopic	6-12 m	Excellent/good results 80%	Subsequent open surgery: 5 (7,5%)	
Choi (2007)	41	Endoscopic	av 34,1 m	av VAS 8.6 to 1.9 92% satisfactory outcome.	Subsequent open surgery: 2 (4,9%)	
Lubbers 2012	22	Endoscopic		Excellent/good results 81,8% mean ODI 67.3 to 26.7	Subsequent open surgery: 2 (9,1%)	
Comparative studies						
Author	**n**	**Approach**	**Follow up**	**Results**	**Complications**	**Recurrences**
Epstein (1995)	170	Full artrectomy (73) Partial artrectomy (39) Intertransverse (58)	av 5 y	Excellent/good results (Odom's criteria): 79% of intertransverse 70% of full artrectomy 68% of partial artrectomy	4/170 required fusion	25/170 second surgery
Ryiang (2004)	48	Combined Intertransverse + interlaminar (28) Transmuscular (20)	19-37 m	In transmuscular group: - More excellent/good outcomes ($p<0,004$) - Higher rate of radicular pain and sensorymotor deficit improvement ($p>0,05$) - Lower incidence of new back pain ($p<0,01$) - Lower complication rate ($p>0,05$)	2 pars interarticularis fractures and 1 dural tear (in combined group)	1 recurrent herniations 3 symptomatic scar tissue growth

Legend: av. = average; ODI=oswestry disability index; VAS= sual analogue scale; m=months; y=years; TM lar minimally invasive approach

In the present study we sought to determine the outcome of the interlaminar contralateral approach and to compare it with standard techniques. For this purpose a retrospective analysis of a 4-years consecutive series of 38 patients with a median follow up of 21 months was accomplished. 18 patients underwent a contralateral approach and 20 a standard approach. Among standard approaches, the intertransverse was far more frequently adopted (16 cases) than lateral muscle-splitting ones (4 cases) and thus their separate analysis would not have been statistically meaningful. This was a multi-surgeon series. The impact of this potential confounding factor has been tested with a correlation analysis which did not show any relationship between long-term outcome and the operating surgeon. We chose as main outcome measures the ODI score - a rather analytical functional scale - and Macnab's criteria - a synthetic assessment of patient's satisfaction. A combination of the two is largely being used in the pertinent literature. Moreover, we introduced a normalized ODI score improvement index which according to regression analysis proved to be useful in taking the assessment of post-operative improvement independent of the baseline functional impairment. Groups were statistically comparable for preoperative demographic and clinical features. However the level and site of herniation differed between groups with intraforaminal and lower level herniations being more common in the contralateral approach group and extraforaminal and upper level herniations being more common in the standard approach group. This reflects a selection bias due to a case-based choice of the technique which in turns was dictated by widely accepted anatomical criteria. In our study population the median ODI score decreased from the preoperative value of 73/100 to 18/100 1-month post-operatively and then to 6/100 at the final follow-up. The median ODI improvement index was 0,73 at 1 month and 0,88 at follow-up. The percentage of excellent or good results approximated 80%. The overall rate of motor improvement was 88,8% and that of back pain improvement 74,2 %. The only observed surgical complication was one dural tear (incidence 2,6%). The incidence of recurrence/reoperation was 10,5%.

As we stated above, a comparison between the results from different studies on FLLDH surgery is prevented by a dishomogeneity in outcome assessment methods. Given this limit, we can state that in our study population the overall results were roughly comparable to those of the previous studies on the intertransverse and the transmuscular approaches.

According to our correlation analyses, a long time since the onset of symptoms and the presence of diabetes or psychiatric comorbidities correlated with an unsatisfactory outcome. The 4 patients who did not suffer recurrences but nevertheless had a poor final outcome had all been suffering from their radicular symptoms at least for 12 months before operation, and had all diabetes and/or mood or anxiety disorders in their past medical history. Moreover, some correlation between young age and recurrence was found and this can be explained with the less dehydrated state of the disc in young people.

The comparison of outcome variables between the two groups did not show univocal and statistically significant differences. This may be due to the rather small size of the study population. However, intergroup comparison of the ODI score and the ODI improvement index yielded different results in short-term and long term assessment. At 1 month post-operatively, in the standard approach group absolute ODI score was lower ($p<0,05$) and the ODI improvement index higher ($p>0,05$) as compared to the contralateral approach group. An opposite scenario was observed at long- term follow-up, with almost comparable absolute ODI scores and a better ODI improvement index observed in the contralateral approach group (p=0,067).

One or more factors intervening in the early post-operative period might explain such time-dependent change in results. Postoperative transient dysesthesia lasting 4-6 weeks has been described after FLLDH surgery (Hodges, 1999; Quaglietta, 2005) and it is believed that surgical manipulation of the dorsal root ganglion causes this symptom. We can hypothesize that the surgical trauma to the ganglion is greater during a contralateral approach because of the narrow surgical space and that this may predispose patients to a transient worsening of their radicular symptoms. Moreover some differences in the incidence and severity of back-pain might be considered. In the contralateral approach the degree of facet trimming is usually smaller than in standard approaches and thus incidence and severity of chronic back pain are expected to be lower at follow-up. At short-term evaluation this result may be hindered by transient post-operative pain. Larger studies with longer follow-up are necessary to test these hypotheses.

Recurrences were more frequent within the standard approaches group (3/20, 15%) than in contralateral approach group (1/18, 5,6%). This difference was not satistically significant (p=0,606). If a trend toward a lower risk of recurrences with contralateral approach has to be supposed, a better surgical exploration of the intervertebral foramen with this technique may be considered as a possible explanation.

Only one complication was observed: a dural tear which was directly repaired without sequelae. This occurred during a contralateral approach performed by one surgeon who was at his first experience with this approach. However, correlation analysis showed that outcome was operator-independent in both groups and that in the contralateral group neither the number of procedures performed by each surgeon nor the performance of the operation by the surgeon who had a large previous experience influeneced outcome.

Together with the studies by Epstein and Ryiang (Epstein, 1995; Ryiang, 2005) this is one of the few studies comparing different surgical approaches in FLLDH surgery and is the first in which the interlaminar contralateral approach has been assessed in relation to standard ones.

Some limitations of the present study have to be stated. First, this is not a randomized study and thus it is inevitably affected by selection bias. Second, this is a multi-surgeon series and this introduces possible confounding factors; however a correlation analysis did not show a statistical significant association between operators and outcome, at least in our population. Third, follow up is relatively short if compared to some previous studies and this prevents a consistent assessment of long-term outcome.

CONCLUSIONS

Far-lateral lumbar disc herniations, either intra-foraminal or extra-foraminal, usually lead to severe radicular pain, unresponsive to conservative management. The goal of surgical treatment is the excision of herniated disc material with complete decompression of nerve root and ganglion, along with preservation of the facet joint, whose damage may compromise stability. The choice of the surgical approach should be dictated by the site and level of the herniation. Although current standard procedures such as the intertransverse and the lateral muscle-splitting approaches allow for satisfactory outcomes, surgery of far-lateral lumbar disc herniations may still be challenging, especially in case of purely intra-foraminal herniations and at lower lumbar levels. In such instances, a consistent amount of bone removal may be needed.

The newly introduced interlaminar contralateral approach nicely exposes the whole foramen with minimal or no bone resection and, unlike classical approaches, it is easier to perform at lower levels where the interlaminar window is wider. In our study, we showed that the interlaminar contralateral approach yields satisfactory results with minimal morbidity and that it favourably compares to standard techniques. Moreover, in our series the contralateral route was associated with better long-term outcomes, although this did not reach statistical significance. Outcome was also independent of the experience of the operating surgeon, suggesting a not very steep learning curve.

In conclusion, the interlaminar contralateral approach should be regarded as a valuable alternative in far-lateral lumbar disc herniation surgery, especially for intra-foraminal herniations and at lower levels. Further research, including larger randomized studies, should better define the role of this technique in the management of far-lateral herniations.

REFERENCES

Abdullah AF, Ditto EW, Byrd E, Williams R. Extreme – lateral lumbar disc herniations. Clinical syndrome and special problems of diagnosis. J Neurosurg 1974; 41:229-234

Abdullah AF, Wolber PG, Warfield JR, Gunadi IK. Surgical management of extreme lateral lumbar disc herniations: review of 138 cases. Neurosurgery. 1988 Apr;22(4):648-53.

Adams M, Bogduk N, Burton K, Dolan P. Muscles and fascia of the lumbar spine, in Adams M, Bogduk N, Burton K, Dolan P (eds): The Biomechanics of Back Pain. Edinburgh, Churchill-Livingstone, 2006, pp 29-42.

An HS, Vaccaro A, Simeone FA. Herniated lumbar disc in patients over the age of fifty. *J Spinal Disord (US)* 1990; 3(2): 143-146.

Arslan M, Comert A, Acar HI, Ozdemir M, Elhan A, Tekdemir I, Tubbs RS, Ugur HC. Surgical view of the lumbar arteries and their branches: an anatomical study. Neurosurgery. 2011 Mar;68(1 Suppl Operative):16-22

Bae HG, Choi SK, Joo KS, Kim BT, Doh JW, Lee KS, Shin WH, Yun IG, Byun BJ.Morphometric aspects of extraforaminal lumbar nerve roots. Neurosurgery. 1999;44(4):841-6

Baker D, Pynsent p, Fairbank J The Oswestry Disability Index revisited. In: Rroland M, Jenner J, eds. Back pain: New Approaches to Rehabilitation and Education. Manchester: Manchester University Press, 1989. 174-186

Berra LV, Foti D, Ampollini A, Faraca G, Zullo N, Musso C. Contralateral Approach for Far Lateral Lumbar Disc Herniations: A Modified Technique and Outcome Analysis of Nine Patients. Spine (Phila Pa 1976). 2010 Feb 26. [Epub ahead of print]

Bogduk N: Clinical Anatomy of the Lumbar Spine and Sacrum. Edinburgh, Churchill- Livingstone, 2005, ed 4.

Bose K, Balasubramaniam P. Nerve root canals of the lumbar spine. Spine (Phila Pa 1976). 1984;9(1):16-8.

Breathnach AS: Frazer's Anatomy of the Human Skeleton. Boston, Little, Brown, 1965, ed 6.

Chen CY, Chuang YL, Yao MS, Chiu WT, Chen CL, Chan WP. Posterior epidural migration of a sequestrated lumbar disk fragment: MR imaging findings. AJNR Am J Neuroradiol. 2006 Aug;27(7):1592-4.

Campbell, W.W., Vasconcelos, O. & Laine, F.J. Focal atrophy of the multifidus muscle in lumbosacral radiculopathy. Muscle & nerve. 1998 21, 1350-3, 1998)

Caspar W, Iwa H. A microsurgical technique for herniated lumbar disc operations. Neurol Surg (Tokyo) 1979; 6:657-662,

Chaudhry, V. & Cornblath, D.R. Wallerian degeneration in human nerves: serial electrophysiological studies. Muscle & nerve 1992; 15, 687-93

Choi G, Lee SH, Bhanot A, Raiturker PP, Chae YS. Percutaneous endoscopic discectomy for extraforaminal lumbar disc herniations: extraforaminal targeted fragmentectomy technique using working channel endoscope. Spine (Phila Pa 1976). 2007 Jan 15;32(2):E93-9.

Darden BV 2nd, Wade JF, Alexander R, Wood KE, Rhyne AL 3rd, Hicks JR. Far lateral disc herniations treated by microscopic fragment excision. Techniques and results. Spine (Phila Pa 1976). 1995 Jul 1;20(13):1500-5.

Daube Jasper R. & Rubin Devon I. Clinical Neurophysiology . (Oxford University Press, USA: 2009).

Demondion X, Manelfe C, Prere J, Francke J Lumbar lateral recess and intervertebral foramen. Radio-anatomical study. J Radiol 2000; 81: 734-45

Di Lorenzo N, Porta F, Onnis G, Cannas A, Arbau G, Maleci A. Pars interarticularis fenestration in the treatment of foraminal lumbar disc herniation: a further surgical approach. Neurosurgery. 1998 Jan;42(1):87-9.

Dommisse GF. Morphological aspects of the lumbar spine and lumbosacral region. Orthop Clin North Am. 1975 Jan;6(1):163-75.

Donaldson WF 3rd, Star MJ, Thorne RP. Spine Surgical treatment for the far lateral herniated lumbar disc. (Phila Pa 1976). 1993 Aug;18(10):1263-7.

Donisch EW, Basmajian JV. Electromyography of deep back muscles in man. Am J Anat. 1972;133(1):25-36.

Dubs Beitrag zur Anatomic der Lumbosacralregion unter besonderer Beriicksichtigung der Discushernie. Fortschr Neurol Psychiatr 1950 18:69-85

Ebeling U, Reichenberg W, Reulen HJ. Results of microsurgical lumbar discectomy. Review on 485 patients. Acta Neurochir (Wien). 1986;81(1-2):45-52.

Ebeling U, Reulen HJ. Are there typical localization of lumbar disc herniations? A prospective study. *Acta Neurochir (Wien Austria)* 1992; 117(3-4): 143-148.

Ebraheim NA, Xu R, Huntoon M, et al. Location of extraforaminal lumbar nerve roots: An anatomic study. Clin Orthop Relat Res 1997;1(340):230–5.

Ehni BL, Benzel EC, Biscup RS. Lumbar discectomy. In: Benzel ED, ed. Spine surgery. Techniques, complication avoidance and management. 2nd ed. Churhill Livingstone; 2004:601–618.

Epimenio RO, Giancarlo D, Giuseppe T, Raffaelino R, Luigi F. Extraforaminal lumbar herniation: "far lateral" microinvasive approach retrospective study. J Spinal Disord Tech. 2003 Dec;16(6):534-8.

Epstein NE, Epstein JA, Carras R,Hyman R. Far lateral lumbar disc herniations and associated structural abnormalities. An evaluation in 60 patients of the comparative value of CT, MRI, and myelo-CT in diagnosis and management. *Spine (US)* 1990; 15(6):534-539.

Epstein NE, Epstein JA. Far lateral lumbar disc herniations: diagnosis and management. In: Schmidek HH, Roberts DW, eds. Schmidek and Sweet’s Operative Neurosurgical Techniques. Indications, Methods, and Results. Saunders Elsevier; 2006:2073–86.

Epstein NE. Decompression in the surgical management of degenerative spondylolisthesis: advantages of a conservative approach in 290 patients. *J Spinal Disord* 1998; 11(2): 116-122.

Epstein NE. Evaluation of various surgical approaches used in the management of 170 far-lateral lumbar disc herniations: indications and results. *J Neurosurg* 1995;83:648–56.

Epstein NE. Review article: Different surgical approaches to far lateral lumbar disc herniations. *J Spinal Disord* 1995; 8(5): 383-394.

Fairbank JC, Pynsent PB. The Oswestry Disability Index.Spine (Phila Pa 1976). 2000 Nov 15;25(22):2940-52.

Fankhauser H, de Tribolet N. Extreme lateral lumbar disc herniation. Br J Neurosurg. 1987;1(1):111-29.

Faust SE, Ducker TB, VanHassent JA. Lateral lumbar disc herniations. J Spinal Disord Tech 5:97-103, 1992.

Fisher, M.A. The contemporary role of F-wave studies. F-wave studies: clinical utility. Muscle & nerve. 1998; 21, 1098-101.

Foley KT, Smith MM, Rampersaud YR. Microendoscopic approach to far-lateral lumbar disc herniation. Neurosurg Focus. 1999 Nov 15;7(5).

Fuentes S, Métellus P, Acosta-Diaz U, Pech-Gourg G, Dufour H, Grisoli F. Minimally invasive transmuscular approach for the treatment of lumbar far lateral disc herniation. Neurochirurgie. 2009 Feb;55(1):70-4.

Fujiwara A, An HS, Lim TH, Haughton VM. Morphologic changes in the lumbar intervertebral foramen due to flexion-extension, lateral bending, and axial rotation: an in vitro anatomic and biomechanical study. Spine (Phila Pa 1976). 2001 Apr 15;26(8):876-82.

Garrido E, Connaughton PN. Unilateral facetectomy approach for lateral lumbar disc herniation. J Neurosurg. 1991 May;74(5):754-6.

Gates GF, McDonald RJ. Bone SPECT of the back after lumbar surgery. Clin Nucl Med 1999;24:395–403.

Gejo R, Matsui H, Kawaguchi Y, Ishihara H, Tsuji H. Serial changes in trunk muscle performance after posterior lumbar surgery. Spine. 1999;24(10):1023-1028.

Gioia G, Mandelli D, Capaccioni B, Randelli F, Tessari L. Surgical treatment of far lateral lumbar disc herniation. Identification of compressed root and discectomy by lateral approach. Spine (Phila Pa 1976). 1999 Sep 15;24(18):1952-7.

Grimes PF, Massie JB, Garfin SH. Anatomic and biomechanical analysis of the lower lumbar foraminal ligaments. Spine 2000; 25(16): 2009 - 2014.

Gu Y, Xu R, Ebraheim NA, et al. The quantitative study of the lateral region to the lumbar pedicle. Surg Neurol 1999;52:353–6

Güvençer M, Naderi S, Kiray A, Yilmaz HS, Tetik S. The relation between the lumbar vertebrae and the spinal nerves for far lateral lumbar spinal approaches. J Clin Neurosci. 2008 Feb;15(2):192-7. Epub 2007 Nov 7.

Hansen L, de Zee M, Rasmussen J, Andersen TB, Wong C, Simonsen EB. Anatomy and biomechanics of the back muscles in the lumbar spine with reference to biomechanical modeling. Spine. 2006;31(17):1888-1899.

Hazlett JW, Kinnard P. Lumbar apophyseal process excision and spinal instability. Spine (Phila Pa 1976). 1982 Mar-Apr;7(2):171-6.

Hodges SD, Humphreys SC, Eck JC, Covington LA. The surgical treatment of far lateral L3-L4 and L4-L5 disc herniations. A modified technique and outcomes analysis of 25 patients. Spine (Phila Pa 1976). 1999 Jun 15;24(12):1243-6.

Hoh DJ, Wang MY, Ritland SL. Anatomic features of the paramedian muscle-splitting approaches to the lumbar spine.
Neurosurgery. 2010;66 (3 Suppl Operative):13-24

Hood RS: Far lateral lumbar disc herniations. *Neurosurg Clin N Am* 1993; 4:117-124.

Huber P, Reulen HJ. CT-observations of the intra- and extracanalicular disc herniation. Acta Neurochir (Wien). 1989;100(1-2):3-11.

In Sook Lee, Hak Jin Kim et al. Extraforaminal with or Without foraminal disk herniation: reliable MRI findings. American Journal of roentgenology. 2009; 192 no. 5: 1392-1396

Ivanov AA, Faizan A, Ebraheim NA, et al. The effect of removing the lateral part of the pars interarticularis on stress distribution at the neural arch in lumbar foraminal microdecompression at L3–L4 and L4–L5; anatomic and finite element investigations. Spine 2007;32:2462–6.

Jane JA, Haworth CS, Broaddus WC, Lee JH, Malik J. A neurosurgical approach to far-lateral disc herniation. Technical note. J Neurosurg. 1990 Jan;72(1):143-4.

Jang JS, An SH, Lee SH. Transforaminal percutaneous endoscopic discectomy in the treatment of foraminal and extraforaminal lumbar disc herniations. J Spinal Disord Tech. 2006 Jul;19(5):338-43.

Kambin P, Casey K, O'Brien E, Zhou L .Transforaminal arthroscopic decompression of lateral recess stenosis. J Neurosurg. 1996 Mar;84(3):462-7.

Kimura Jun Electrodiagnosis in diseases of nerve and muscle: principles and practice. (Oxford University Press: 2001).

Kirkaldy-Willis WH, HeithoffKB, Tchang S, Bowen CVA, Cassidy UD, Shannon R (1984) Lumbar spondylosis and stenosis. Correlation of pathological anatomy with high-resolution computed tomographic scanning, Chapter 32. In: Donovan-Post MJ (ed) Computed tomography of the spine. Williams and Wilkins, Baltimore, pp 546-553

Kotil K, Akcetin M, Bilge T. A minimally invasive transmuscular approach to far-lateral L5-S1 level disc herniations: a prospective study. J Spinal Disord Tech. 2007 Apr;20(2):132-8.

Kunogi J, Hause M. Diagnosis and operative treatment of intraforaminal and extraforaminal nerve root compression. Spine 1991;16:1312–20.

Lanzino G, Shaffrey CI, Jane JA: Surgical treatment of lateral lumbar herniated discs. In Rengachary SS, Wilkins RH (eds): Neurosurgical Operative Atlas, vol 8. Park Ridge, IL, American Association of Neurological Surgeons, 1998. pp 243-251.

Lee KK, Teo EC, Qiu TX, et al. Effect of facetectomy on lumbar spinal stability under sagittal plane loadings. Spine 2004;29:1624–31.

Lejeune JP, Hladky JP, Cotten A, Vinchon M, Christiaens JL. Foraminal lumbar disc herniation. Experience with 83 patients. Spine (Phila Pa 1976). 1994 Sep 1;19(17):1905-8.

Lew SM, Mehalic TF, Fagone KL. Transforaminal percutaneous endoscopic discectomy in the treatment of far-lateral and foraminal lumbar disc herniations. J Neurosurg. 2001 Apr;94(2 Suppl):216-20.

Lübbers T, Abuamona R, Elsharkawy AE. Percutaneous endoscopic treatment of foraminal and extraforaminal disc herniation at the L5-S1 level. Acta Neurochir (Wien). 2012 Oct;154(10):1789-95.

Macnab I. Negative disc exploration. An analysis of the causes of nerve-root involvement in sixty-eight patients. J Bone Joint Surg Am. 1971 Jul;53(5):891-903.

Manchikanti L, Pampati V, Baha AG, et al. Contribution of facet joints to chronic low back pain in postlumbar laminectomy syndrome: a controlled comparative prevalence evaluation. Pain Physician 2001;4:175–80.

Maroon JC, Kopitnik TA, Schulhof LA, Abla A, Wilberger JE. Diagnosis and microsurgical approach to far-lateral disc herniation in the lumbar spine. J Neurosurg. 1990; 72(3):378-382

Marquardt G, Bruder M, Theuss S, Setzer M, Seifert V. Ultra-long-term outcome of surgically treated far-lateral, extraforaminal lumbar disc herniations: a single-center series. Eur Spine J. 2012 Apr;21(4):660-5.

Mayer TG, Vanharanta H, Gatchel RJ, et al. Comparison of CT scan muscle measurements and isokinetic trunk strength in postoperative patients. Spine. 1989;14 (1):33-36.

Melvill RL, Baxter BL.Spine (Phila Pa 1976). The intertransverse approach to extraforaminal disc protrusion in the lumbar spine. 1994 Dec 1;19(23):2707-14.

Montinaro A. The microsurgical approach to extraforaminal lumbar disc herniations. An analysis of 15 cases. J Neurosurg Sci. 2004 Mar;48(1):23-8.

Nardin, R.A., Patel, M.R., Gudas, T.F., Rutkove, S.B. & Raynor, E.M. Electromyography and magnetic resonance imaging in the evaluation of radiculopathy. Muscle & nerve 22, 151-5 (1999).

O'Hara LJ, Marshall RW; Far lateral lumbar disc herniation. The key to the intertransverse approach; J Bone Joint Surg Br. 1997 Nov;79(6):943-7

Osborn AG, Hood RS et al. CT/MR Spectrum of far lateral and anterior Lumboscral disk herniations. AJNR 1988; 9: 775-778.

Ozveren MF, Bilge T, Barut S, Eras M. Combined approach for far-lateral lumbar disc herniation. Neurol Med Chir (Tokyo). 2004 Mar;44(3):118-22.

Pal D, Tyagi AK. Interlaminar approach for excision of lateral lumbar disc herniation: technical note. Spine (Phila Pa 1976). 2006 Feb 15;31(4):E114-6.

Panjabi MM, Takata K, Goel VK. Kinematics of lumbar intervertebral foramen. Spine (Phila Pa 1976). 1983; 8(4):348-57.

Pedersen HE, Blunck CFJ, Gardner E. The anatomy of lumbosacral posterior rami and meningeal branches of spinal nerves (sinu-vertebral nerves). J Bone Joint Surg. 1956; 38 A: 377-391

Pfaundler S, Ebeling U, Reulen HJ. Pedicle origin and intervertebral compartment in the lumbar and upper sacral spine. A biometric study. Acta Neurochir (Wien). 1989;97(3-4):158-65.

Pirris SM, Dhall S, Mummaneni PV, Kanter AS. Minimally invasive approach to extraforaminal disc herniations at the lumbosacral junction using an operating microscope: case series and review of the literature. Neurosurg Focus. 2008;25(2).

Porchet F, Chollet-Bornard A, de Tribolet N. Long-term follow-up of patients surgically treated by the far-lateral approach for foraminal and extraforaminal lumbar disc herniations. *J Neurosurg Spine* 1999;90:59– 66.

Porchet F, Fankhauser H, de Tribolet N: The far lateral approach to lumbar disc herniations, in Cohadon F (ed): Advances and Technical Standards in Neurosurgery. New York, Springer-Verlag, 1997, vol 23, pp 249–274.

Postacchini F, Cinotti G, Gumina S. Microsurgical excision of lateral lumbar disc herniation through an interlaminar approach. J Bone Joint Surg Br. 1998 Mar;80(2):201-7.

Pradhan, S. Tibialis anterior R-1 response: physiological behaviour, normative data and clinical utility in L4-L5 radicular compression. Electroencephalography and clinical neurophysiology 89, 10-21 (1993).

Quaglietta P, Cassitto D, Corriero AS, Corriero G. Paraspinal approach to the far lateral disc herniations: retrospective study on 42 cases. Acta Neurochir Suppl. 2005;92:115-9.

Reulen HJ, Müller A, Ebeling U. Microsurgical anatomy of the lateral approach to extraforaminal lumbar disc herniations. Neurosurgery. 1996;39(2):345-50;

Rust MS, Olivero WC. Far-lateral disc herniations: the results of conservative management. J Spinal Disord. 1999 Apr;12(2):138-40.

Ryang YM, Oertel MF, Mayfrank L, Gilsbach JM, Rohde V. Transmuscular trocar technique - minimal access spine surgery for far lateral lumbar disc herniations. Minim Invasive Neurosurg. 2007 Oct;50(5):304-7.

Ryang YM, Rohde I, Ince A, Oertel MF, Gilsbach JM, Rohde V. Lateral transmuscular or combined interalaminar/paraisthmic approach to lateral lumbar disc herniation? A comparative clinical series of 48 patients. J Neurol Neurosurg Psychiatry 2005;76:971-976

Salame K, Lidar Z. Minimally invasive approach to far lateral lumbar disc herniation: technique and clinical results. Acta Neurochir (Wien). 2010 Apr;152(4):663-8.

Sasani M, Ozer AF, Oktenoglu T, Canbulat N, Sarioglu AC. Percutaneous endoscopic discectomy for far lateral lumbar disc herniations: prospective study and outcome of 66 patients. Minim Invasive Neurosurg. 2007 Apr;50(2):91-7.

Schlesinger SM, Fankhauser H, de Tribolet N. Microsurgical anatomy and operative technique for extreme lateral lumbar disc herniations. Acta Neurochir (Wien). 1992;118(3-4):117-29.

Siebner HR, Faulhauer K. Frequency and specifc surgical management of far lateral lumbar disc herniations. *Acta Neurochir (Wien Austria)* 1990; 105(3-4):124-131.

Siebner HR, Faulhauer K. Frequency and specific surgical management of far lateral lumbar disc herniations. Acta Neurochir (Wien). 1990;105(3-4):124-31.

Sihvonen T, Herno A, Paljärvi L, Airaksinen O, Partanen J, Tapaninaho A. Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. Spine. 1993;18(5):575-581.

Smith GA, Aspden RM, Porter RW. Mesurement of vertebral foraminal dimensions using three-dimensional computerized tomography. Spine 18(5): 629-636, 1993

Tessitore E, de Tribolet N. Far lateral lumbar disc herniation: the microsurgical transmuscular approach. Neurosurgery. 2004; 54(4):939-942

Tibrewal SB, Pearcy MJ. Lumbar intervertebral disc heights in normal subjects and patients with disc herniation. Spine (Phila Pa 1976). 1985;10(5):452-4.

Torun F, Dolgun H, Tuna H, Attar A, Uz A, Erdem A Morphometric analysis of the roots and neural foramina of the lumbar vertebrae Surg Neurol 66: 148-151, 2006

Van Rijn JC, Klernesto N et al. Observer variation in the evaluation of lumbar herniated discs and root compression: spiral CT compared with MRI. British Journal of Radiology 2006; 79: 372-377.

Vialle R, Court C, Khouri N, Olivier E, Miladi L, Tassin JL, Defives T, Dubousset J. Anatomical study of the paraspinal approach to the lumbar spine. Eur Spine J. 2005 May;14(4):366-71. Epub 2004 Nov 19

Viswanathan R, Swamy NK, Tobler WD, Greiner AL, Keller JT, Dunsker SB. Extraforaminal lumbar disc herniations: microsurgical anatomy and surgical approach. J Neurosurg. 2002 Mar;96(2 Suppl):206-11.

Voyadzis JM, Gala VC, Sandhu FA, Fessler RG. Minimally invasive approach for far lateral disc herniations: results from 20 patients. Minim Invasive Neurosurg. 2010 Jun;53(3):122-6.
Wang QP, Lee NS, Zhang Y, Liu J, Zhu JY; Intertransverse approach for extraforaminal herniations; Spine (Phila Pa 1976). 1997 Mar 15;22(6):701-5

Watkins MB. Posterolateral bonegrafting for fusion of the lumbar and lumbosacral spine. J Bone Joint Surg Am. 1959;41-A(3):388-396.

Weatherley CR, Emran IM, Newell RL; A modification of the standard midline posterior approach to the intertransverse area of the lumbar spine; Ann R Coll Surg Engl. 2010 Jan;92(1):19-22

Wilbourne, A.J. & Aminoff, M.J. AAEM MINIMONOGRAPH 32: The electrodiagnostic examination in patients with radiculopathies. Muscle & nerve 21, 1612-1631 (1998).

Williams RW. Microlumbar discectomy: a conservative surgical approach to the virgin herniated lumbar disc. Spine (Phila Pa 1976). 1978 Jun;3(2):175-82.

Wiltse LL, Spencer CW. New uses and refinements of the paraspinal approach to the lumbar spine. Spine (Phila Pa 1976). 1988 Jun;13(6):696-706.

Yasargil MG. Microsurgical operation of the herniated lumbar disc. Adv Neurosurg 1977; 4:81-81.

Yeom JS, Kim KH, Hong SW, Park KW, Chang BS, Lee CK, Buchowski JM. A minimally invasive technique for L5-S1 intraforaminal disc herniations: microdiscectomy with a tubular retractor via a contralateral approach. J Neurosurg Spine. 2008 Feb;8(2):193-8.