Anatomic Features of the Paramedian Muscle-Splitting Approaches to the Lumbar Spine

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BACKGROUND: Intermuscular approaches can expose the lumbar spine and minimize muscular trauma and injury. The segmental anatomy of the posterior lumbar musculature allows surgical access through separation of muscle groups and fascicles and provides one to develop intermuscular working channels while preserving the integrity of the muscles and their function. In addition, preservation of the accompanying neurovascular bundles minimizes blood loss, tissue atrophy, and pain. With these approaches, a variety of procedures for decompression, discectomy, interbody fusion, or pedicle screw fixation can be achieved for single or multiple levels without subperiosteal stripping or muscle transection.

OBJECTIVE: A detailed description of the relevant surgical anatomy for the muscle-sparing approach to the lumbar spine.

KEY WORDS: Intermuscular approach, Minimally invasive surgery, Muscle-sparing approach, Paraspinal approach, Surgical anatomy, Surgical technique, Wiltse approach

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The typical surgical approach to the dorsal thoracolumbar spine involves subperiosteal stripping and retraction of the soft tissues to access the vertebrae and neural elements. This commonly used method is safe and effective, and it requires little knowledge of the anatomy of the soft tissues. However, this approach leads to unintended disruption of the neurovasculature of the soft tissues and facet joints, contributing to muscular devitalization and atrophy.

More elegant muscle-sparing techniques have been developed to minimize trauma to the soft tissues. After Watkins'[1] first description of the paraspinal approach for posterolateral lumbar fusion in 1959, techniques and methods were developed to use the natural planes between or through large muscle groups to access the dorsal lumbar spine. Wiltse and Hutchinson[2] and Wiltse and Spencer[3] later described use of the natural plane between the multifidus and longissimus muscles for posterior lumbosacral arthrodesis. The evolution of microsurgical techniques for lumbar discectomy in the 1970s led the way in minimizing superficial soft tissue disruption during access to the spinal canal.[4] More recently, the development of tubular and expandable retractors has provided an alternative "minimally invasive" approach to the spine.[5] Enthusiasm for these techniques has been driven by the desire to achieve the same surgical objectives as conventional open midline exposures but preserve lumbar muscle function and improve clinical outcomes. In contrast to subperiosteal or intramuscular approaches, intermuscular techniques create working corridors for performing various decompression, instrumentation, and fusion procedures while minimizing muscle dissection and preserving neurovascular and tendon integrity.

ABBREVIATIONS: ESA, erector spinae aponeurosis

Exploration of the anatomy of the posterior lumbar musculature reveals a complex architecture of muscle fascicles and associated neurovascular elements. Appreciation of the 3-dimensional anatomy of these muscle groups and individual fascicles defines the boundaries of the working corridor without compromising necessary access. Various procedures including central and foraminal decompression, discectomy, interbody fusion, and screw fixation can be performed by use of techniques that fully preserve muscle fibers and their tendinous attachments. This technical report reviews the relevant surgical anatomy of the posterior lumbar musculature as it pertains to intermuscular approaches and describes muscle-sparing techniques for gaining surgical access. This report also highlights the neurovascular structures and tendinous attachments at risk for disruption during operations in the area of the transverse and articular processes.

SURGICAL ANATOMY

Description of the complete anatomy of the lumbar musculature, its tendinous attachments, and its primary actions is beyond the scope of this article. We provide a focused description of the surgical anatomy of the posterior lumbar muscles with respect to natural cleavage planes and anatomic constraints for surgical exposure. For a thorough description of lumbar anatomy, including the biomechanics of specific muscle groups, authoritative chapters by Bogduk[6] and Adams et al[7] are available. The basic anatomy section of this article incorporates work that has been published in these chapters combined with the authors' observations and experience with the use of microsurgical techniques for lumbar spine surgery.

The major muscle groups of the lumbar spine can be divided into anterior and posterior groups based on an imaginary coronal plane that passes through the transverse processes. The muscle group anterior to the transverse processes consists of the psoas major and quadratus lumborum muscles. The psoas major arises from the transverse processes and the vertebral body near the disc space, combining to form a large tendon that inserts in the lesser trochanter of the femur. The quadratus lumborum is a sheet of muscle that extends from the ilium and iliolumbar ligament to the 12th rib. These fibers are joined by additional fibers from the anterior surface of each lumbar transverse process, which also extend rostrally to attach to the 12th rib.

The posterior musculature comprises 2 major muscle groups: the multifidus medially and the erector spinae complex laterally (Fig. 1). The multifidus is a complex arrangement of fibers with multiple attachments and insertions. They arise from each spinous process and adjacent lamina and radiate caudally to insert on the superior articular processes. The erector spinae complex includes the lumbar portion of the longissimus and iliocostalis muscles, which arise from the accessory and transverse processes, respectively, radiating to insert on the superomedial margin of the iliac crest. The neurovascular structures similarly demonstrate segmental anatomy, coursing along their corresponding transverse processes and superior facets. This provides a natural plane of separation between the muscle groups, which allows exposure to the lateral aspect of the facet joint and the transverse process from L1 to the sacrum while preserving muscle and neurovascular integrity. Of note, several small monosegmental muscles may be physiologically and anatomically significant, but they do not directly constrain the surgical approach to the posterior lumbar spine. These muscles include the interspinales and the intertransversarii (mediales, lateral dorsales, and lateral ventrales).

Multifidus

The multifidus is the medial posterior muscle group. It is highly complex in its structure and demonstrates the largest cross sectional area of the posterior lumbar muscles (Fig. 2). The bulk of the multifidus is confined medially by the spinous processes and laterally by its attachments to the superior articular process. The arrangement is such that each segment originates from a spinous process and has multiple subdivisions that insert distally on either the superior articular processes, beginning 2 levels caudally, or the sacrum. Bogduk[6] describes 4 subdivisions for each segment (Fig. 3). A small fascicle 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 2 segments caudal (excepting L5). Longer fascicles originate from a robust common tendon from the inferior edge of the spinous process of the same level to insert on articular processes at progressively more caudal levels. Below L5, these subfascicles insert on the ilium and sacrum. Each segment overlies those originat-

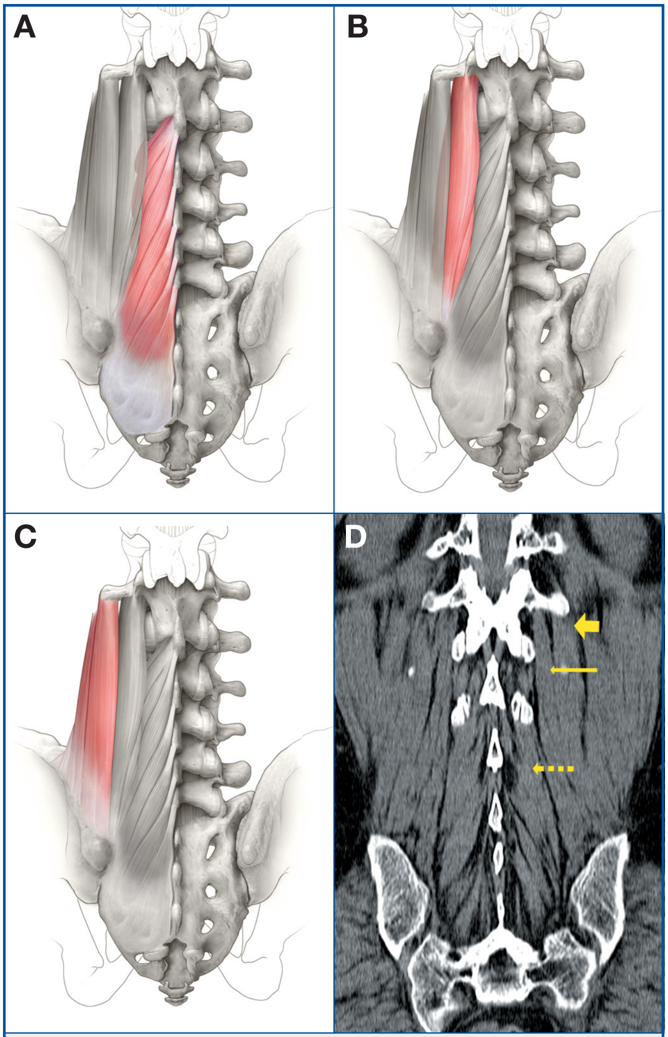

FIGURE 1. **A–C**, *illustrations of the organization of the posterior lumbar musculature showing the multifidus* (**A**), *the longissimus* (**B**), *and the iliocostalis* (**C**). **D**, *computed tomographic coronal reconstruction showing the arrangement of the posterior lumbar musculature: multifidus (dotted arrow), longissimus (thin arrow), and iliocostalis (thick arrow).*

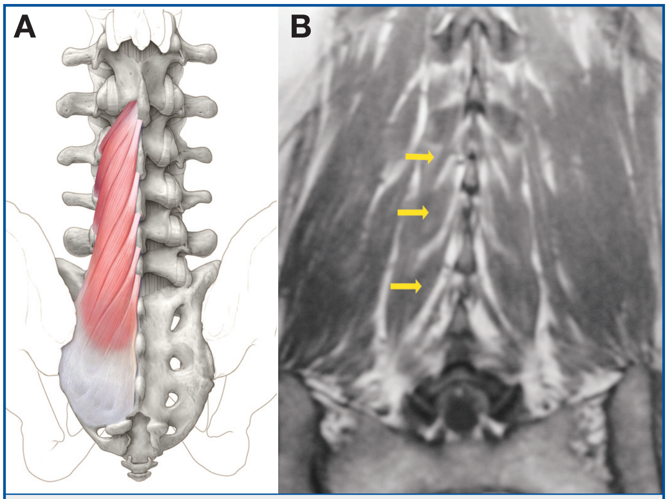

FIGURE 2. **A**, *illustration showing the combined arrangement of the L1–L5 multifidus segments.* **B**, *coronal T2-weighted magnetic resonance imaging (MRI) scan showing the multifidus, situated medially, and the segmental arrangement of the multifidus and its attachments (arrows).*

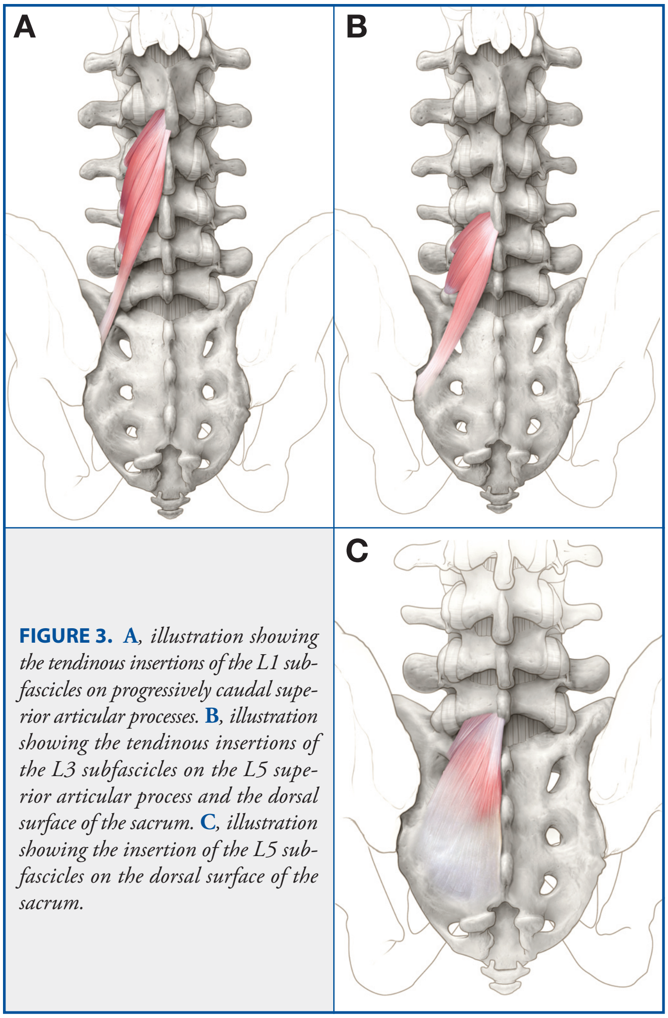

FIGURE 3. **A**, *illustration showing the tendinous insertions of the L1 subfascicles on progressively caudal superior articular processes.* **B**, *illustration showing the tendinous insertions of the L3 subfascicles on the L5 superior articular process and the dorsal surface of the sacrum.* **C**, *illustration showing the insertion of the L5 subfascicles on the dorsal surface of the sacrum.*

ing from more caudal segments, resulting in a muscle that increases in bulk as it approaches the sacrum.

This arrangement makes the muscle unique, in that each multifidus complex arises from 1 vertebra but attaches to multiple other vertebrae. This allows for complex coordinated movements in lumbar extension, rotation, and lateral bending. Thus, the multifidus complex serves as an important dynamic stabilizer of the thoracolumbar spine.

Each muscle fascicle has a discrete neurovascular supply. The medial branch of the dorsal ramus of the nerve root courses dorsally and caudally over the medial transverse process before it wraps around the base of the articular process. The nerve then traverses the mammilloaccessory notch to join the artery of the pars interarticularis, supplying the multifidus originating on the spinous process immediately rostral (Fig. 4). The artery of the pars interarticularis passes just medial to the intertransversarius medialis, a small muscle connecting the superior articular process to the adjacent mammillary and accessory processes, and joins the nerve as it exits the mammilloaccessory notch. Together, the nerve and artery then invest the traversing multifidus segment. Therefore, fascicles that have a common spinous process of origin also share the same segmental innervation and vascular supply.

The multifidus defines a medial compartment, which is bounded medially by the spinous processes, ventrally by the lamina, and dorsally by the erector spinae aponeurosis (ESA) and constrained laterally by its insertions in the superior articular processes. The neurovascular supply to the multifidus courses lateral to the muscle's insertion in the superior articular process. As such, during a conventional midline surgical exposure, 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. Further retraction of the multifidus for more lateral exposure of the facet and transverse process can disrupt the insertion of the multifidus on the superior articular process and place the neurovascular bundle at risk. In traditional subperiosteal exposures, this neurovascular supply is typically disrupted to expose the transverse processes for posterolateral fusion of pedicle screw insertion sites. Although the effects of this action remain uncertain, devitalization of the facet joint complex may result in impaired joint function and may contribute to adjacent segment degeneration at the ends of the exposure.

As an alternative, an intermuscular approach between muscle planes and around tendon insertions allows for lateral access to the facet and transverse process without disturbing muscle integrity or its neurovascular supply. These techniques are described in the Surgical Exposure section.

Longissimus Thoracis

The longissimus muscle is composed of 2 portions. The lumbar portion (pars lumborum) comprises the intermediate group of the posterior lumbar musculature, which is situated lateral to the

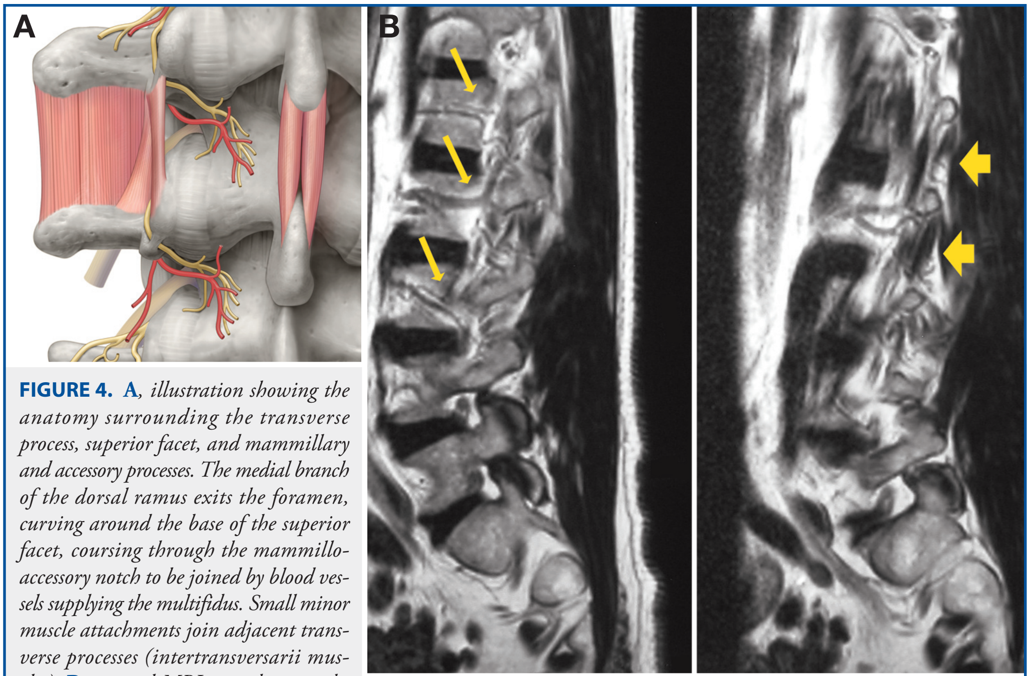

FIGURE 4. **A**, *illustration showing the anatomy surrounding the transverse process, superior facet, and mammillary and accessory processes. The medial branch of the dorsal ramus exits the foramen, curving around the base of the superior facet, coursing through the mammillo-accessory notch to be joined by blood vessels supplying the multifidus. Small minor muscle attachments join adjacent transverse processes (intertransversarii muscles).* **B**, *sagittal MRI scan showing the segmental arrangement of the neurovascular bundle (thin arrows) and the attachments (thick arrows) of the intertransversarii muscles.*

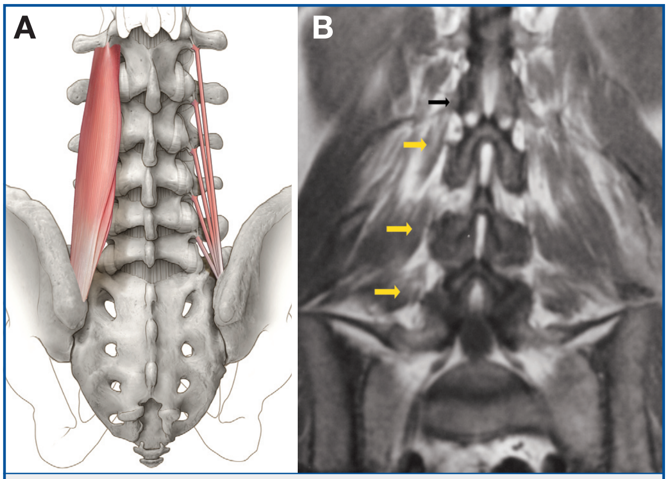

FIGURE 5. **A**, *illustration showing the segmental anatomy of the L1–L5 longissimus (left) and a schematic of its attachments (right).* **B**, *coronal MRI scan showing the segmental arrangement of the longissimus (yellow arrows) and the tendinous attachment of the longissimus to the accessory process (black arrow).*

multifidus and medial to the iliocostalis (Fig. 5). The thoracic portion (pars thoracis) has muscle bellies that overlie the posterior thoracic spine and ribs. In the lumbar region, the longissimus pars thoracis transitions to a tendon complex that lies superficial to the multifidus and longissimus pars lumborum. This forms the medial part of the ESA, which is discussed separately.

The pars lumborum is a slender muscle group lying between the multifidus and iliocostalis. Individual fascicles of the longissimus arise from the accessory processes from L1 to L4 via a fairly robust tendon. The origins may extend to both the adjacent transverse process and the mammilloaccessory ligament and mammillary process. The corresponding fascicle from L5 typically extends along the transverse process and over the accessory process to the mammillary process. The L1–L4 fascicles are joined by the fascicle arising from the posterior surface of the L5 transverse process, converging to form a common tendon of insertion, known as the lumbar intermuscular aponeurosis. The intermuscular aponeurosis can be appreciated as the lumbar contribution to the longissimus tendon complex, and it continues ventrally from the ESA between the longissimus and iliocostalis pars lumborum.

On axial images, the location of the intermuscular aponeurosis frequently is identified by a slight depression in the ESA over the lumbar muscles approaching the iliac crest. This depression commonly represents the division between the iliocostalis and longissimus, not the intermuscular plane between the multifidus and the longissimus. The plane between the multifidus and the longissimus is slightly more medial to this depression. It trends closer to the midline at upper lumbar levels, with entry into this plane essentially along the spinous process at the L1 level.

Iliocostalis Lumborum

The iliocostalis is also composed of thoracic (pars thoracis) and lumbar (pars lumborum) portions. The iliocostalis pars lumborum comprises the lateral group of the posterior lumbar musculature and is situated lateral to the longissimus (Fig. 6, A and B). The iliocostalis pars thoracis has muscle bellies that originate from the thoracic ribs. In the lumbar region, the tendon complex of the iliocostalis pars thoracis forms the lateral portion of the ESA, which overlies the iliocostalis pars lumborum.

The fascicles of the iliocostalis pars lumborum originate from the tips of the transverse processes and adjacent portion of the medial layer of the thoracolumbar fascia. The tendons insert on the iliac crest lateral to the posterosuperior iliac spine, with the insertions extending laterally to abut the medial insertion of the lateral raphe. The transverse process of L5 does not provide iliocostalis muscle fibers but rather contributes to the iliolumbar lig-

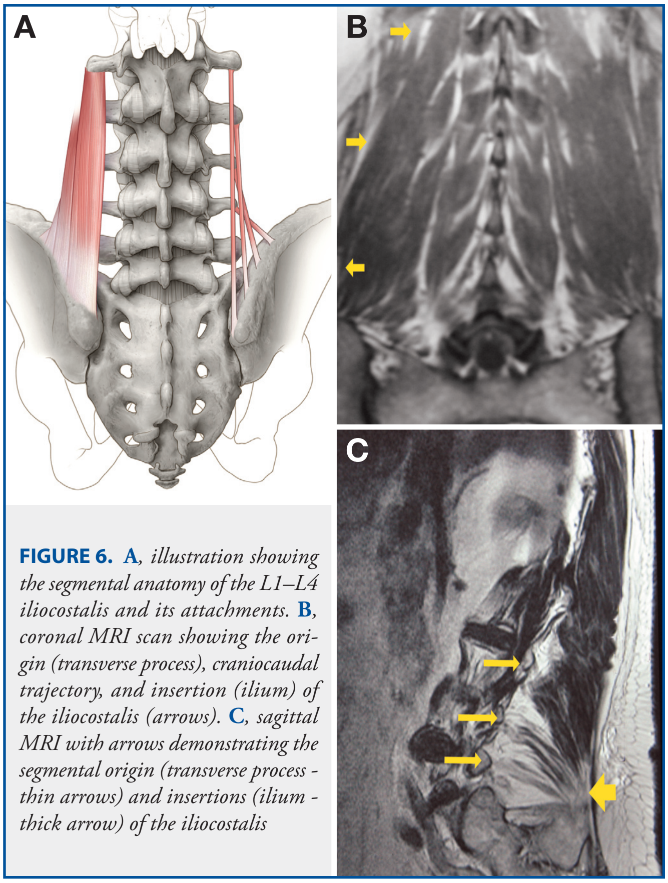

FIGURE 6. **A**, *illustration showing the segmental anatomy of the L1–L4 iliocostalis and its attachments.* **B**, *coronal MRI scan showing the origin (transverse process), craniocaudal trajectory, and insertion (ilium) of the iliocostalis (arrows).* **C**, *sagittal MRI with arrows demonstrating the segmental origin (transverse process - thin arrows) and insertions (ilium - thick arrow) of the iliocostalis*

ament. The fascicles of the iliocostalis are arranged such that rostral segments lie superficial to more caudal segments.

The L5 fascicle of the iliocostalis pars lumborum is unique from those originating at more rostral levels. In children, the L5 fascicle is muscular in nature; however, it eventually develops into a portion of the iliolumbar ligament with maturity. Likewise, the L5 fascicle of the longissimus crosses a relatively short, immobile segment and is frequently appreciated surgically in adults as a fibrous band from L5 to the medial ilium. The tense fibrous nature of the L5 longissimus and iliolumbar ligament contributes to the commonly observed difficulty opening the distal intermuscular plane between L5 and S1.

ESA

The ESA is a broad, flat, tendinous sheath that lies superficial to the posterior lumbar musculature (Fig. 7). The ESA is composed of medial and lateral portions. The medial portion extends from the muscle bellies of the longissimus pars thoracis. The longissimus pars thoracis muscle fibers originate from the transverse processes of the thoracic spine and terminate in a tendon complex that extends caudally to insert on lumbar spinous processes and the sacrum. The tendons begin inserting on about the L2 spinous process, with more caudal muscles inserting to progressively more distal lumbar segments. The medial portion of the medial ESA is appreciated as a series of discrete flat tendons with insertions to individual lumbar processes and the S1 spinous processes, allowing for independent motion of the spinous processes. At S1, the tendons merge into a continuous sheet inserting to distal sacral segments and continuing ventrally as the intermuscular aponeurosis inserting to the superomedial iliac crest. The broad, flat portion of the tendon forms the medial ESA and covers the multifidus and longissimus pars lumborum muscles.

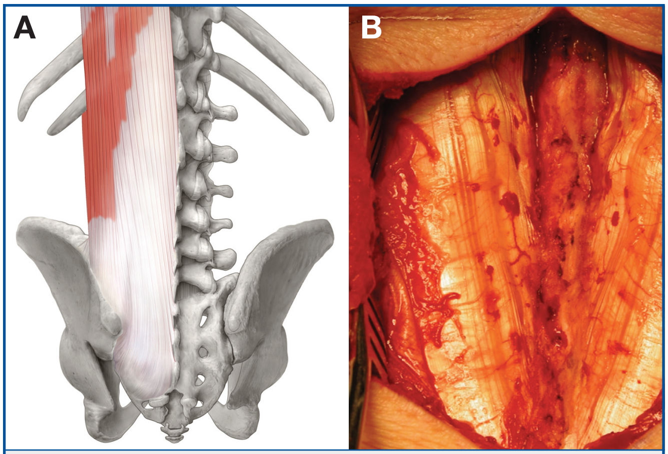

FIGURE 7. **A**, *illustration showing the vertical banding pattern of the medial and lateral erector spinae aponeuroses.* **B**, *intraoperative photograph showing the direction of the fibers of the erector spinae aponeuroses.*

The lateral portion of the ESA is derived from a tendinous sheath that extends from the muscle bellies of the iliocostalis pars thoracis. The iliocostalis pars thoracis muscle fibers originate from the lower 8 thoracic ribs and give rise to tendons that extend caudally to insert on the iliac crest. The composite of these tendons form a sheet that lies superficial to the iliocostalis pars lumborum and constitutes the lateral portion of the ESA. The tendons of the pars lumborum continue laterally and ventrally to abut the lateral raphe.

The attachment of the ESA to the spinous processes begins at the rostral tip of the spinous process and continues slightly along the dorsolateral margin of the spinous process with a relatively thick tendon. On its opposite surface, the tendons of the ESA fuse with the overlying lumbodorsal fascia, where its fibers cross over the spinous process and interdigitate with fibers from the contralateral side.

Both medial and lateral portions of the ESA are independent of the underlying multifidus, longissimus, and iliocostalis muscle fibers. As a result, there is a natural cleavage plane between the ESA and the posterior lumbar muscles, allowing separation between the ESA and underlying muscles.

Lumbodorsal Fascia

The lumbodorsal fascia is the connective tissue layer that lies superficial to the ESA. This fascia layer is a bilaminar sheath composed of the aponeuroses of the latissimi dorsi (Fig. 8). The latissimus dorsi from each side sends tendons caudally in an oblique manner, such that they cross the midline to the contralateral side.

At the spinous processes, these crossing tendons interlace and contribute to the supraspinous ligament. The tendons are arranged such that the superficial layer of the lumbodorsal fascia consists of tendons arising from the ipsilateral latissimus dorsi, whereas the deep layer comprises tendons from the contralateral latissimus dorsi. Lateral to the iliocostalis pars lumborum, the lumbodorsal fascia fuses with tendinous fibers from the transverse abdominus and the medial layer of the lumbodorsal fascia arising from the tips of the transverse process and intertransverse ligament to form a lateral raphe. Above the lumbosacral junction, the lumbodorsal fascia is distinct from the ESA, creating a natural cleavage plane; however, at the lumbosacral junction, adhesions between the ESA and lumbodorsal fascia can occur, making surgical separation of these layers difficult.

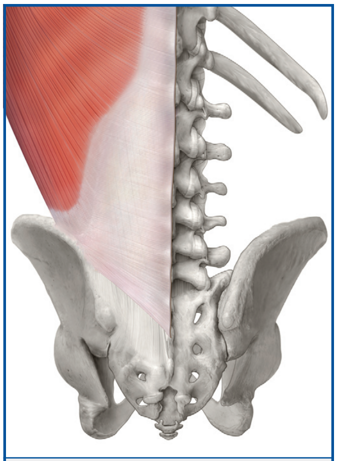

FIGURE 8. *Illustration showing the crossing oblique fibers of the bilaminar lumbodorsal fascia.*

SURGICAL EXPOSURE

An anatomic intermuscular approach maintains the integrity and function of the back muscles. The segmental anatomy and inherent cleavage planes of the posterior lumbar musculature create natural corridors for surgical access to the posterior lumbar spine. With careful blunt dissection using a finger, Penfield no. 1 dissector, or speculum, the neurosurgeon can place bladed retractors to open between segmental muscles. If the muscles are considered as discrete segments with a degree of elasticity, a bladed retractor can be opened between muscle fascicles for adequate exposure without disrupting the muscle or its tendinous insertions. In turn, the tensile characteristic of the muscle fibers and tendons creates natural constraints that help define the boundaries of the working channel and position the retractor.

By use of an anatomic intermuscular approach, surgical access can be performed for various procedures including spinal decompression, discectomy, interbody fusion, and pedicle screw instrumentation. An anatomic approach preserves the integrity of the muscles by creating working channels between muscle elements while respecting the neurovascular supply and tendinous insertions. The retractor is bounded by muscle fascicles or subfascicles and constrained on the spine by muscle insertions.

The intermuscular technique is composed of 2 basic approaches, which are determined by the surgical target and clinical objectives. The medial approach, which creates a natural corridor between segments of the multifidus, allows for exposure over the lamina for decompression of the canal and access to the disc space for discectomy or interbody fusion. The lateral approach, which gains access to an intermuscular plane bounded by the superior articular process and multifidus medially and segments of the longissimus laterally, provides exposure over the transverse process for pedicle screw instrumentation or far-lateral approaches to the disc space or canal. Disconnection of muscle attachments over the superior articular process merges the 2 approaches if broader access is required.

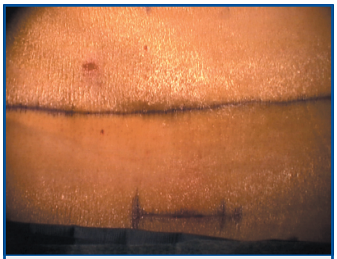

FIGURE 9. *Intraoperative photograph showing a 2-cm skin incision approximately 2 to 2[1/2] finger breadths off the midline.*

A single skin incision provides comfortable access for either medial or lateral exposure (Fig. 9). If the incision is positioned farther off midline, for example to provide a more lateralized trajectory for pedicle screw insertion, usually the neurosurgeon still can mobilize the superficial soft tissue layers for medial access to the canal and disc space. Although it is reasonable to make a longer midline skin incision, particularly for access across multiple segments, shorter bilateral incisions may provide easier access to achieve the trajectory needed for screw insertion or sublaminar decompression, particularly in the lumbosacral region.

In performing these approaches, the operating microscope provides invaluable visualization of the pertinent anatomy. Commitment to preserving muscle fibers, their tendinous attachments, and neurovascular supply requires an understanding of local anatomy. Although structures may be small and difficult to visualize directly, awareness of their location allows for dissection in safe zones that provide passive protection of muscle integrity and avoid specific areas in which these structures may be at risk. Particularly in obese patients, in whom the depth of the working channel may be lengthy, optimized illumination greatly facilitates the surgical view. In addition, use of an assistant to aid with retraction may, in some cases, be preferable to use of a self-retaining retractor to enable optimal visualization.

Superficial Exposure

The patient is positioned prone on the operating table, with fluoroscopic guidance used to determine the spinal level of interest. For 1- or 2-level procedures, a 2- to 3-cm paramedian skin incision is made overlying the appropriate level and side. For multilevel exposure, the incision is extended rostrocaudally as needed. At the L5–S1 disc space, an approach just medial to the iliac crest provides access down the medial aspect of the intermuscular aponeurosis and longissimus to the L5 and S1 facet joint. At more rostral levels, the intermuscular plane between the multifidus and the longissimus approaches the midline. In some cases, an approach through fascicles of the longissimus allows entry to the intermuscular plane closer to the facet joint along a more appropriate trajectory for screw insertion. Preoperative axial magnetic resonance imaging or computed tomography usually demonstrates the loca-

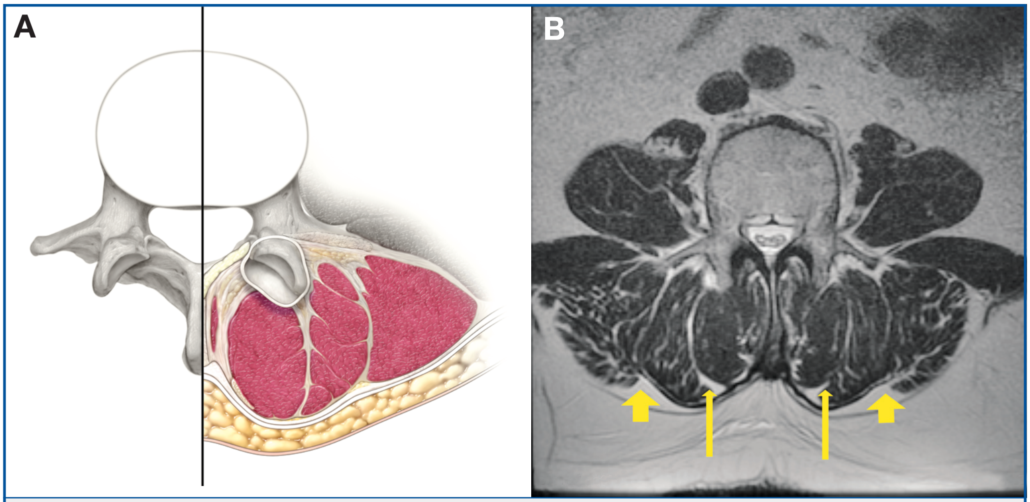

FIGURE 10. **A**, *illustration showing the axial cross sectional anatomy of the posterior lumbar musculature.* **B**, *axial MRI scan showing the lumbar cross sectional anatomy, the intermuscular plane (thin arrows) between the multifidus (medial) and the longissimus (intermediate), and the plane (thick arrows) between the longissimus (intermediate) and iliocostalis (lateral).*

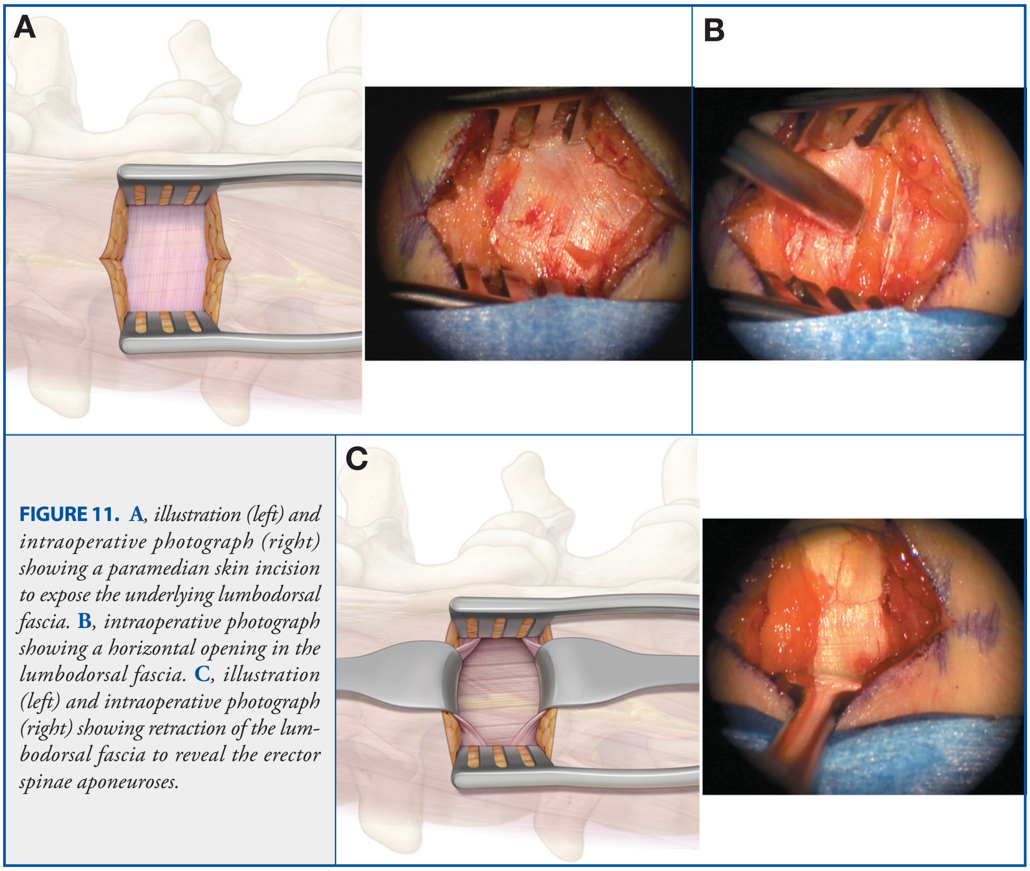

FIGURE 11. **A**, *illustration (left) and intraoperative photograph (right) showing a paramedian skin incision to expose the underlying lumbodorsal fascia.* **B**, *intraoperative photograph showing a horizontal opening in the lumbodorsal fascia.* **C**, *illustration (left) and intraoperative photograph (right) showing retraction of the lumbodorsal fascia to reveal the erector spinae aponeuroses.*

tion of the intermuscular plane and facilitates determination of the most appropriate position for the paramedian incision (Fig. 10). In situations that warrant bilateral exposure of the canal or disc space, or for pedicle screw instrumentation, paired incisions equidistant from the midline are made. As an alternative, a single midline incision can be made, for example, in revision surgery after a previous midline exposure. Mobilizing the skin over the fascia or disconnecting and reflecting the lumbodorsal fascia at the spinous process allows for an appropriate intermuscular approach from a midline incision. At the L5–S1 level, however, the approach along the multifidus is quite lateral and may be more easily accomplished with a paramedian incision.

For a limited exposure (1 or 2 levels), the lumbodorsal fascia may be divided horizontally, potentially from the midline to the lateral raphe (Fig. 11, A and B). This provides a comfortable lateralized trajectory in the intermuscular plane for pedicle screw placement yet allows access for instrumentation spanning 2 or sometimes 3 levels. The nearly horizontal orientation of the fascial fibers is such that they tend to fall closed when split medial to lateral for a natural closure. A horizontal opening also provides simultaneous medial and lateral access to the intermuscular planes, for example, when both an interbody fusion (medial) and pedicle screw instrumentation (lateral) are performed. A paramedian vertical opening in the lumbodorsal fascia can also be created; however, the closure is less secure, as sutures tend to pull through the fascia. At the midline, where the crossing fibers interdigitate and fuse with the underlying supraspinous complex, the fascia tends to be slightly more robust and allows for a more secure vertical closure. Opening of the lumbodorsal fascia exposes the underlying ESA (Fig. 11C).

At the sacrum, there is a loss of relative motion between the lumbodorsal fascia and the underlying ESA. Adhesions frequently occur between these 2 layers, so the neurosurgeon can make a simple opening along the course of the fibers of the ESA. If the patient has undergone previous surgery and has significant scar formation, opening the lumbodorsal fascia over the underlying approach may be appropriate.

Medial Approach

Access to Spinal Canal and Disc Space

To gain access to the canal or disc space, a medial intermuscular approach through the multifidus is necessary. The ESA is entered bluntly by dividing between vertical bands with either the flat end of a Penfield no. 1 dissector or the closed tips of Metzenbaum scissors. An opening a few millimeters off the midline preserves the tendinous insertion of the ESA on the spinous processes. Although a single opening through the ESA is frequently convenient for closure, the neurosurgeon can make more than 1 opening in the ESA for multilevel procedures. Lifting the divided edge of the ESA allows the neurosurgeon to free it from the underlying multifidus and to approach the rostral spinous process of the interspace or disc space being addressed. After the spinous process is reached, a speculum is slid down the bony surface of the spinous process to the lamina and inferior facet (Fig. 12A). This separates the fascicle arising from the rostral spinous process along with its neurovascular supply from the underlying bone. Dissection along the spinous process and lamina retracts the traversing multifidus segments laterally.

After the speculum is deeply seated against the dorsal surface of the lamina, it is turned 90 degrees and opened. Opening the speculum allows the caudal blade to separate the traversing multifidus from the fascicle arising from the adjacent spinous process (Fig. 12B). The opened speculum then guides insertion of a bladed retractor along the speculum to dock on the lamina, such that the medial blade apposes the spinous process and the lateral blade is positioned over the lateral aspect of the inferior facet (Fig. 12C). Therefore, the medial blade is constrained by the spinous process, and the lateral blade is bounded by the tendon inserting on the superior articular process and the multifidus traversing to more caudal levels. The rostral edge of the blade actually engages the deep fascicle of the multifidus crossing from the rostral spinous process and laminar margin to the superior articular process at the operated segment. The speculum is removed, and the bladed retractor is immobilized with an articulated arm locked to the operating table.

The multifidus only has attachments at its originating spinous process and adjacent laminar margin and to the superior articular processes. Therefore, opening the speculum separates the traversing multifidus and its accompanying neurovascular bundle from the directly underlying spinous process and lamina along a natural cleavage plane. When retraction is accomplished over the lamina and inferior facet, the nerve and vessel are just rostral to the joint in a location safe from injury during segmental access to the canal. Extending the exposure rostral or caudal to an additional segment increases the risk of neurovascular compromise, unless the multifidus is released medially from the spinous process and reflected laterally. Therefore, full preservation of muscle integrity via an intermuscular approach limits access through the multifidus to either a monosegmental approach or a combination of multiple separate approaches.

The opened retractor blades are naturally constrained medially by the spinous process and laterally by the multifidus insertions to the superior articular process at and caudal to the operative segment. The end result is a working channel with a surgical field over the lamina and inferior facet (Fig. 12D). The medial boundary is defined by the retractor blade against the spinous process. The lateral boundary is the retractor blade constrained by the multifidus insertion in the caudal superior articular process and traversing multifidus. The superior border is created by the tendinous origin of the traversing multifidus as its muscle fibers are retracted laterally. The inferior margin is formed by the deep multifidus fascicle that originates from the spinous process and adjacent laminar margin at the level being exposed.

With this working channel, the spinous process, lamina, and inferior facet are adequately exposed for either a central canal or foraminal decompression, or access to the disc space for discectomy or interbody fusion (Fig. 12E). For a hemilaminotomy, the laminar portion of the deep multifidus fascicle may need to be partially disconnected to open into the canal. To gain access to the contralateral side, the spinous process portion of the deep multifidus fascicle may need to be partially detached, and a sublaminar decompression can be performed out to the opposite lateral recess and foramen. To do so, the medial retractor blade needs to be slightly higher on the side of the spinous process to line up with the lamina on the contralateral side. Placing the retractor obliquely through the fascicles of the multifidus to the inferior facet provides adequate trajectory for approach to the canal, disc space, and removal of the tip of the superior facet for a transforaminal interbody fusion (Fig. 12, F and G). A facet fusion can be performed by partially separating the multifidus attachment to the superior articular process and retracting laterally. The facet capsule is then completely exposed and can be prepared for arthrodesis.

Lateral Approach

Access for Pedicle Screw Instrumentation and Posterolateral Fusion

To gain access for placement of pedicle screw instrumentation, a lateral intermuscular approach between the multifidus and longissimus is performed. After opening of the lumbodorsal fascia, the ESA is again divided between vertical bands of fibers overlying the junction of the multifidus and the longissimus. With the ESA divided and retracted, a Penfield no. 1 dissector can be used to identify the intermuscular plane bluntly along the lateral border of the multifidus. After the plane between the multifidus (medial) and the longissimus (lateral) is open, finger dissection can be used to extend rostrocaudally as necessary and identify the superior facets segmentally. Opening this plane at the lumbosacral junc-

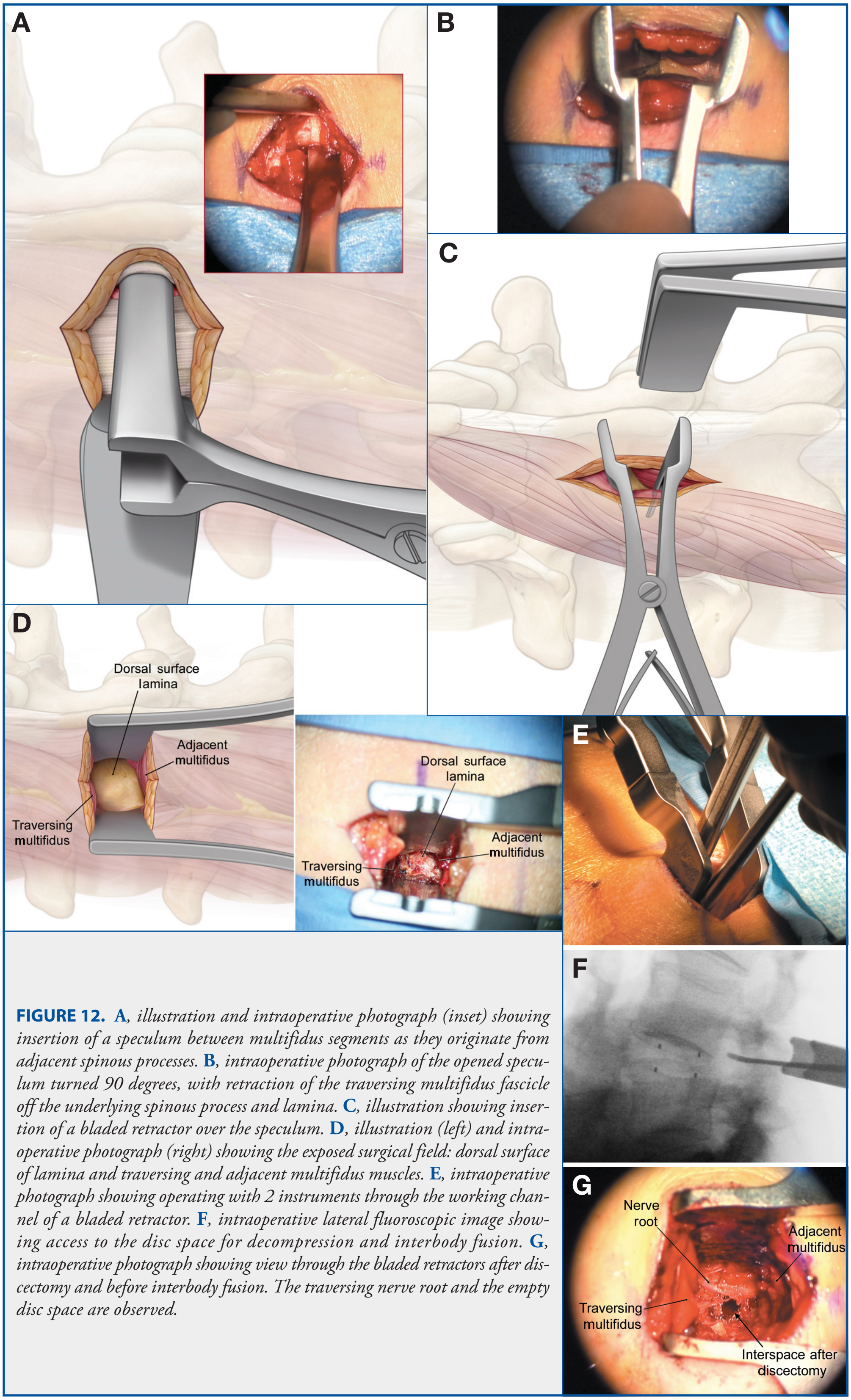

FIGURE 12. **A**, *illustration and intraoperative photograph (inset) showing insertion of a speculum between multifidus segments as they originate from adjacent spinous processes.* **B**, *intraoperative photograph of the opened speculum turned 90 degrees, with retraction of the traversing multifidus fascicle off the underlying spinous process and lamina.* **C**, *illustration showing insertion of a bladed retractor over the speculum.* **D**, *illustration (left) and intraoperative photograph (right) showing the exposed surgical field: dorsal surface of lamina and traversing and adjacent multifidus muscles.* **E**, *intraoperative photograph showing operating with 2 instruments through the working channel of a bladed retractor.* **F**, *intraoperative lateral fluoroscopic image showing access to the disc space for decompression and interbody fusion.* **G**, *intraoperative photograph showing view through the bladed retractors after discectomy and before interbody fusion. The traversing nerve root and the empty disc space are observed.*

tion can be challenging. The cross sectional area of the multifidus is greatest at L5 and often fills the compartment between the sacral spinous processes and the ilium. In addition, the longissimus that arises from L5 is short and frequently tendinous, creating an inelastic band between the transverse process and the ilium, which prevents the intermuscular plane from opening laterally. There is a similar fibrous band to the sacral articular process. If necessary, detaching the most medial origin of the L5 longissimus and the ligament to the sacrum relaxes the exposure and provides for pedicle screw placement with the least amount of muscle compromise.

Lateral retraction of the longissimus originating from the rostral accessory process uncovers the superior facet and adjacent transverse process (Fig. 13A). Exposure of the transverse process reveals that the rostrodorsal surface of the transverse process and the lateral aspect of the facet are free of any muscle attachments. The multifidus inserts in the superior facet and is constrained medially by this tendinous attachment. The longissimus arising at the exposed level originates from the accessory process and defines the caudal margin of the mammillary process and transverse process (Fig. 13B). Minor small muscle attachments join adjacent transverse processes by their rostral and caudal edges (intertransversarii laterals).

The natural cleavage plane between the traversing longissimus of the immediately rostral level and the dorsal surface of the transverse process allows clean separation and retraction laterally of this muscle segment. An L-shaped retractor engaged to the superior facet and transverse process may be placed to retract the traversing longissimus (Fig. 13C). This facilitates direct visu-

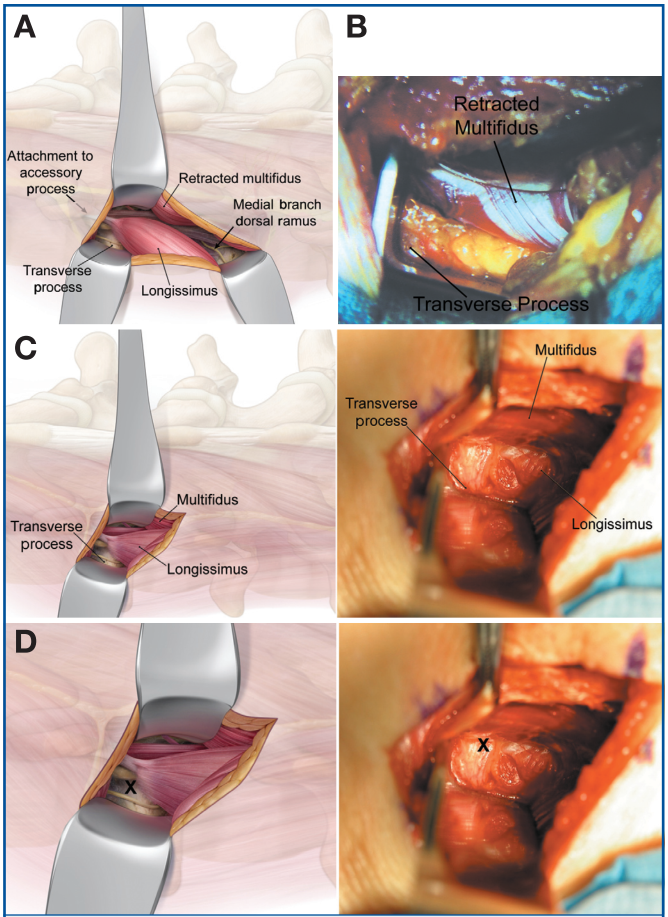

FIGURE 13. **A**, *illustration showing arrangement of the multifidus and longissimus around the lateral facet and transverse process. The attachment of the longissimus to the accessory process is observed.* **B**, *intraoperative photograph showing retraction of the multifidus muscle medially with the longissimus muscle visualized deep within the field.* **C**, *illustration (left) and intraoperative photograph (right) showing a hand-held L-shaped retractor in the intermuscular plane between the multifidus and longissimus. The blade is retracting the traversing longissimus segment laterally, exposing the transverse process-superior facet junction.* **D**, *illustration of the idealized pedicle screw entry point (X) at the junction of the transverse process-superior facet junction. The entry point is on the rostrodorsal surface of the transverse process, which is free of muscle attachments. The medial branch of the dorsal ramus courses around the screw entry point.*

alization of the mammillary and accessory processes for any necessary bony remodeling or soft tissue dissection necessary to make an adequate screw entry point. An optimal screw entry point usually is close to the rostral margin of the accessory process and just lateral to the mammilloaccessory notch (Fig. 13D). Insertion of a pedicle screw from this trajectory reduces the risk of facet joint compromise and muscle insertions. In addition, placement of the screw entry point at the rostral margin of the accessory process and slightly lateral to the mammillary process minimizes the risk of disrupting the medial branch of the dorsal ramus of the nerve as it traverses the mammilloaccessory notch. For screw fixation of the sacrum, the sacral ala can be palpated just lateral to the joint, and it provides localization for an entry point into the sacral pedicle.

After the intermuscular plane is opened, screw placement may be performed conventionally with a pedicle seeker, tap, and direct screw insertion. When the plane is opened to the superior facet and transverse process, the bony surface and anatomy may be palpated with a tap or pedicle seeker for indirect visualization of the screw entry point. As an alternative, use of a Jamshidi needle for pedicle identification and cannulated screw placement over a K-wire can be performed. Opening the intermuscular plane over the full extent of the instrumented levels places the screw-rod construct in a natural plane rather than bluntly guiding the rod through muscle.

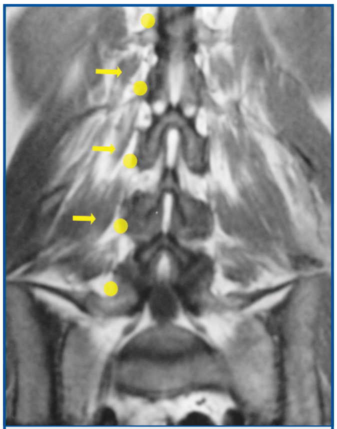

FIGURE 14. *Coronal MRI scan showing access points (circles) for segmental pedicle screw placement in an intermuscular plane bounded by the longissimus laterally (arrows).*

Intermuscular screw placement can be performed at several levels (from L1 to S1) for multisegment pedicle screw fixation (Fig. 14). A rod is placed along the screw heads such that the rod lies in the intermuscular plane. Specifically, the rod is situated lateral to the multifidus, medial to the muscle bellies of the longissimus, and dorsal to the tendinous attachments of the longissimus to the accessory processes (Fig. 15). The longissimus muscle tendon is observed between screws at adjacent levels and is situated ventral to the connecting rod. At lower lumbar levels, extension of the longissimus tendon to the mammillary process occasionally obstructs rod placement, which necessitates partial disconnection of the medial-most portion of the tendon to allow proper seating of the rod.

DISCUSSION

Muscle-splitting approaches to the spine were introduced by Watkins[1] in 1959. Watkins described a paraspinal approach, in which the fascial plane between the lateral border of the sacrospinalis (longissimus, multifidus) and the quadratus lumborum is developed to expose the transverse processes for posterolateral fusion. Wiltse and Hutchinson[2] later reported a modified transmuscular approach, in which the plane between the multifidus and longissimus is separated to allow bone grafting across L5–S1 for patients with isthmic spondylolisthesis. This same intermuscular plane between the multifidus and longissimus has been adapted to gain access for removal of far-lateral lumbar disc herniations[8,9] and for placement of pedicle screw instrumentation.[3,10] Caspar[4] introduced a muscle-splitting, slightly paramedian approach for lum-

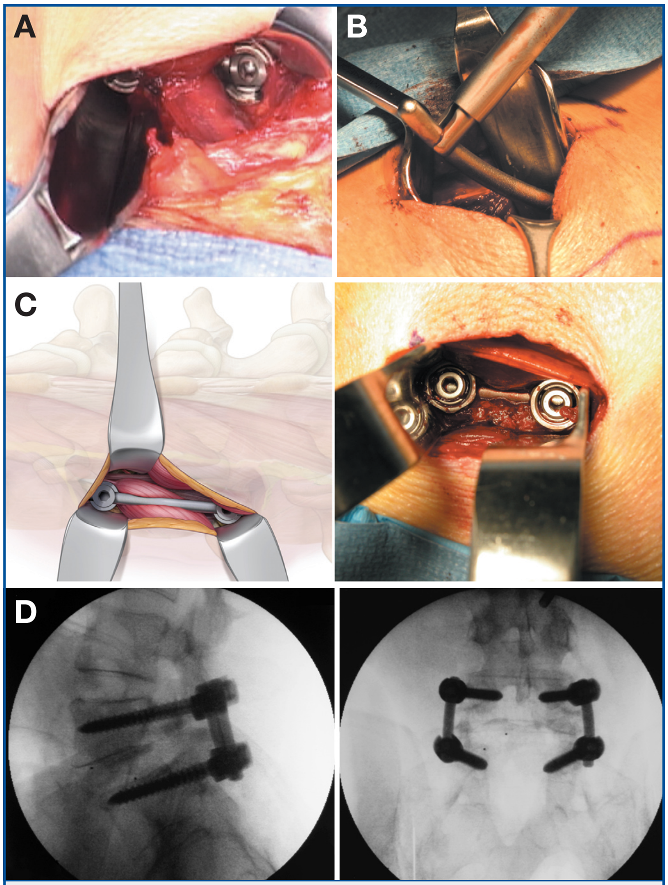

FIGURE 15. **A**, *intraoperative photograph showing screws placed within the intermuscular plane.* **B**, *intraoperative photograph showing rod insertion in the intermuscular plane.* **C**, *illustration (left) and intraoperative photograph (right) showing a final screw-rod construct situated in the intermuscular plane.* **D**, *lateral (left) and anteroposterior (right) fluoroscopic images showing single-level intermuscular screw-rod construct.*

bar microdiscectomy as a muscle-sparing technique for treatment of lumbar disc herniation.

Further elaboration of these techniques involves identifying the microsurgical anatomy of the posterior lumbar musculature, particularly as it relates to individual muscle segments and their tendinous attachments. Intermuscular planes exist between large muscle groups (e.g., multifidus and longissimus); they also can be developed between individual fascicles of a single muscle group. The discrete segmental anatomy and neurovascular supply of the fascicles allows the neurosurgeon to create a natural working channel between intact muscle segments without disturbing their fibers or tendons. As a result, at a given level, the traversing multifidus can be retracted laterally as an individual segment to expose the underlying spinous process, lamina, and inferior facet. Various procedures for central or foraminal decompression, discectomy, or interbody fusion can be performed via this exposure without disrupting the multifidus insertions on the spinous process or superior facet.

Lateral exposure via the intermuscular plane between the multifidus and longissimus provides access to the junction of the transverse process and superior facet. Retracting the traversing longissimus laterally exposes the rostrodorsal surface of the transverse process, which is free of muscle attachments. This creates an ideal pedicle screw entry point that preserves the insertions of the multifidus and longissimus on the superior articular and accessory processes, respectively. Screw placement from this lateralized trajectory eliminates risk of facet joint compromise. The neurovascular bundle is also protected as it courses through the mammilloaccessory notch. Seating the implants in a natural longitudinal cleavage plane prevents the need to force the rod bluntly through muscle tissue to connect across screws, which can occur with percutaneous screw-rod systems. The combination of a segmental approach to the spinal canal and an intermuscular approach for instrumentation allows multilevel approaches to decompression and fusion, without disrupting the major lumbar musculature and with minimal bleeding, in contrast to subperiosteal midline stripping to expose the transverse processes.

Tubular dilators have been introduced recently for minimally invasive transmuscular exposure.[5,11] Insertion of dilating tubes may also provide surgical access without disrupting muscle fibers. However, appreciation of the microsurgical detail of individual fascicles and their attachments may be lost in part by the tunnel-like view through smaller tubes. Larger-diameter tubes may result in encroachment of muscle under the deep edge of the tube, requiring resection of these tissues with electrocautery to expose the underlying spine. Gaining broader exposure by adjusting the trajectory of the tube often requires "sweeping" across the dorsal elements or expanding on the surface of the spine, which may bluntly damage muscles or disrupt their attachments. We have found that a simple bladed retractor placed between intact muscle segments allows a broader surgical view without the necessity to divide muscle fibers. As an alternative, anatomically based microdissection to the spine and then placement of a tubular retractor down this corridor uses the best features of both approaches.

The goal of preserving muscle fibers and their attachments is to maintain muscle function. The posterior muscles serve to stabilize the lumbar vertebral column[12,13] and counteract the flexion effect of the abdominal muscles.[6,13] The multifidus specifically is the primary muscle group responsible for stabilizing the lumbosacral junction.[13] Conventional surgical approaches that completely detach the multifidus from the midline disrupt the function of the muscle group. Further compromise of the neurovascular supply results in muscle denervation and devascularization, with subsequent atrophy and scar formation.[14-16] Loss of biomechanical stabilization and disturbed segmental motion may contribute to patient disability and chronic pain.[16] Preservation of muscle function and the potential for improved clinical outcomes with muscle-sparing approaches, however, must be determined via comparison studies with conventional open procedures. Nevertheless, until it is demonstrated that compromising these structures is relatively benign or equivalent to muscle-sparing approaches, it is reasonable to attempt to preserve the integrity of these muscle groups.

Intermuscular techniques may provide benefits other than sparing of muscle function. In patients with previous midline exposure, revision surgery via an intermuscular approach usually results in planes that are relatively free of scar tissue or adhesions. Temporary internal fixation to treat unstable spinal fractures can be inserted and then removed after bony healing, with fewer complications than a long midline exposure and without disrupting the posterior tension band. Incorporation of muscle-sparing techniques may reduce the morbidity associated with large surgical procedures for correction of lumbar deformity. Pedicle screw-based posterior dynamic stabilization devices may prove to work better in conjunction with preserved posterior lumbar muscle function.

CONCLUSIONS

Posterior lumbar anatomy exhibits a complex segmental arrangement of muscles, tendons, and neurovascular elements. Understanding this anatomy provides a basis to approach the spine in planes that spare these muscles without compromising essential surgical access. When necessary, the neurosurgeon can disconnect muscle attachments partially for better exposure while preserving the primary function of the muscle. It is important to balance muscle, neurovascular, and facet joint integrity against sufficient exposure to achieve the clinical objective. Use of this microsurgical anatomy in lumbar surgery to preserve muscles and their attachments may maintain muscle function and optimize patient outcomes.

Disclosure

A portion of the anatomic work presented in this manuscript was performed using cadaveric specimens provided by Depuy Spine (Raynham, MA, USA). Otherwise, the authors have no personal financial or institutional interest in the drugs, materials, or devices described in this article.

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COMMENTS

Hoh et al present a detailed report of lumbosacral paraspinal muscle anatomy including methods of surgical exposure that minimize disruption of muscular, tendinous, neural, and vascular structures. This report is timely given the increasing popularity of paramedian transmuscular spinal approaches. The anatomic information is thorough and detailed and the operative strategies are practical. Specifically, we echo the authors' emphasis on the natural cleavage plane between the longissimus and multifudus muscle groups when using an approach to the lateral facet and intertransverse area. Though our preference is to use an expandable tubular retractor we first use blunt dissection to enter this cleavage plane and reach the intertransverse area. The retractor is then placed without any sequential muscle dilation and holds the natural plane open. There appears to be less creeping muscle when this plane is used compared to muscle splitting and sequential dilation.

We wholeheartedly agree that muscle sparing has many theoretical benefits and should be performed whenever reasonably possible. However, this must be balanced against inadequate exposure of important structures. For example, good exposure of the superior articular process is important in determining the optimal lumbar pedicle screw entry point when there are large, degenerative facet joints. In these situations it would be difficult to visualize the superior articular process without disconnecting a portion of the multifudus insertion. In addition, we release portions of the multifudus and longissimus muscles often in order to increase the bony surface area for intertransverse arthrodesis. In summary, this report provides useful and relevant anatomical information and will assist spinal surgeons in preserving normal anatomy whenever possible.

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Boston, Massachusetts

In this well conducted and comprehensively written article, Hoh et al give a detailed report of the gross and microsurgical anatomy of the posterior lumbar musculature, particularly as it relates to performing minimally invasive spinal surgery. They make the case that, as opposed to subperiosteal or intramuscular approaches, intermuscular techniques create working corridors for surgical intervention that minimize muscle dissection and preserve neurovascular and tendon integrity. Preserving muscle fibers and their attachments maintains muscle function; preserving the neurovascular supply may minimize muscle denervation and devascularization. In addition to providing a sound anatomical description of relevant surgical anatomy, the authors describe in detail 2 muscle-sparing techniques: a medial approach that allows access to the spinal canal and disc space and a lateral approach that allow for access for pedicle screw instrumentation and posterolateral fusion.

With the expansion of minimal access surgery, knowledge of relevant 3-dimensional musculoskeletal and neurovascular anatomy will allow surgeons to define operative boundaries without compromising necessary access to critical structures. The authors also postulate that these techniques may be used in various circumstances, including revision surgery, temporary internal fixation, and potentially deformity correction.

Does preservation of muscle function with muscle-sparing approaches result in clinical improvement? The authors recognize that well-designed comparison studies with conventional open surgery are currently lacking. Until then, it seems reasonable to consider this approach as an accepted alternative under appropriately selected cases. Hoh et al should be commended for their thorough investigation.

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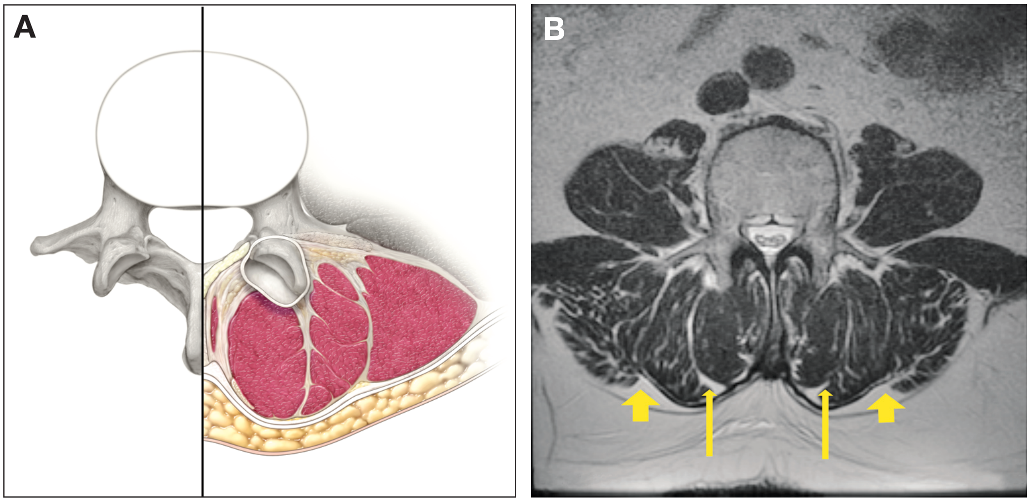
Hoh et al have provided a masterpiece. Their illustrated dissertation on the anatomy of the paramedian dorsal lumbar spine is well done. The illustrations alone are well worth the “price of admission.” They have provided a “must read” for all surgeons utilizing dorsal paramedian muscle splitting approaches, as well as for those who desire to simply “brush up” on their anatomy. The authors are to be heartily congratulated.

Edward C. Benzel
Cleveland, Ohio



A, illustration showing the axial cross sectional anatomy of the posterior lumbar musculature. **B**, axial MRI scan showing the lumbar cross sectional anatomy, the intermuscular plane (thin arrows) between the multifidus (medial) and the longissimus (intermediate), and the plane (thick arrows) between the longissimus (intermediate) and iliocostalis (lateral). See Figure 10, page 19.