Minimally invasive Wiltse approach posterolateral fusion

POSTERIOR INTERMUSCULAR APPROACHES TO FIXATION AND FUSION

WILTSE APPROACH AND POSTERIOR INTERMUSCULAR APPROACHES TO FUSION

Introduction

MISS approaches to the spine minimize requisite exposure to reduce morbidity associated with surgery, striving for that balance between minimizing anatomic compromise and optimizing surgical outcome. This chapter deals with a subset of approaches constrained by the posterior segmental muscles, with specific regard to their neurovascular supply. The local anatomy of the back supports an anatomic approach medial or lateral to the neurovascular and tendinous constraints about the superior articular process. Initial discussion addresses the fixed constraints about the articular complex in the back with subsequent attention to the more superficial elements constraining the approach.

Wiltse (1964) described and popularized an intermuscular approach between the multifidus and erector spinae complex for posterior fusion. Approach along the multifidus and lateral to the mammillary process to the level of the transverse process avoids the tendons and fixed neurovascular elements essential to the integrity of the back muscles. Use of microsurgical technique and an understanding of the periarticular anatomy facilitate preservation of muscle integrity with segmental fixation and posterior fusion.

A segmental approach along the lateral surface of the spinous process and over the lamina, constrained by the tendons inserting to the superior articular process, similarly respects the tensile and neurovascular integrity of the back muscles. Medializing the screw construct allows for a decompression and or fusion with a construct that underlies the segmental back muscles without compromise to the anatomic integrity of the muscles. Extending the approach with takedown of midline tendons and removal of bony elements may allow for better decompression and correction of deformity while still preserving the neurovascular integrity of the muscles.

Posterior and lateral fusion is variably anatomic. A robust facet fusion may be performed from a medial or lateral approach with no compromise of muscles. Extending to a posterolateral fusion incurs a variable cost in muscle attachments but may still be accomplished with no extension to adjacent segments. The decision to remove bone or muscle connections is then based on optimizing decompression, deformity correction, and the requisite bony exposure for adequate fusion.

I will review an intermuscular approach for fixation with a segmental approach to the facet joint for a muscle sparing posterior fusion. I will then consider a medialized screw placement which provides an equally anatomic segmental approach, between fascicles of multifidus, for fixation and fusion. This provides the option of a facet fusion or decompression with an interbody fusion using an approach constrained by the tendons inserting to the superior articular process and respecting the associated segmental neurovascular supply.

Intermuscular approach

Approach down the lateral aspect of the multifidus complex opens the intermuscular plane between longissimus laterally and the multifidus and lateral aspect of the superior articular process. Entry into the plane moves from adjacent to the spinous process at L1 laterally as the more distal multifidus fascicles are included in the medial muscle mass. The multifidus incorporates a common tendon of insertion to the superior articular process at each level, visible on the lateral aspect of the muscle complex. The lateral aspect of the articular process and the transition to the dorsum of the transverse process is free of attachments. The tendon of longissimus originates at each level on the accessory process. The tendon thins dorsally, and may continue to the mammilloaccessory ligament and mammillary process. At progressively lower segments the projection of tendons transitions from primarily caudal to a more dorsal trajectory consistent with the common tendon of the longissimus complex inserting to the iliac crest.

Figures 1 and 2 open the intermuscular plane and illustrate the muscle and neurovascular constraints about the mammillary process. This plane provides an elegant intermuscular placement of a fixation construct. Division of the segmental neurovascular supply occurs at or deep to the transverse process, allowing one to open between the multifidus and erector spinae complex with no compromise to the neurovascular supply to the back muscles. The medial branch of the dorsal ramus runs along the lateral articular process to turn medial through the mammilloaccessory notch while the associated artery of the pars interarticularis, which supplies the corresponding muscle fascicle, runs medial to the intertransversarius medialis adjacent to the lateral aspect of the pars before turning over the laminar surface deep to the segmental multifidus. The lateral branch of the dorsal ramus and associated vessels enter the deep surface of the erector spinae fascicles. The lateral branch of the ramus, and vessels are at risk with significant retraction over the transverse process.

A retractor engaging the lateral articular process retracts the longissimus traversing the transverse process and exposes bone for direct placement of a pedicle screw, with limited retraction of the longissimus. A screw entry point at the cephalad margin of the accessory process and 2 to 3 mm lateral to the lateral aspect of the mammillary process generally provides pedicle screw placement that respects the facet joint and mammilloaccessory notch.

Realizing that the spirit of MISS involves approaches preserving the anatomy rather than being defined by a skin incision, the illustrations reflect an anatomic approach opening intermuscular planes. This approach works for 1 or multiple segments and becomes easier with a multisegmental approach. While it is illustrated with a retractor engaging the articular process with limited retraction of the longissimus traversing from above, an awareness of the anatomy facilitates placement of a variety of retractors while taking advantage of an intermuscular construct placement. While the Wiltse approach has been used historically with decortication over the transverse process and articular complex, preservation of the back muscles is relatively straightforward. In a MISS situation, it may be appropriate to just decorticate inside the joint or extend the bony exposure along the lateral mass avoiding unnecessary neurovascular disruption.

It is my experience and impression that screw placement may respect the medial branch of the dorsal ramus most of the time. While it is difficult to visualize the nerve intraoperatively, an understanding of its course allows an entry generally sparing the mammilloaccessory notch and medial branch. There are certainly cases where maintaining an appropriate trajectory through the pedicle puts the nerve at risk, particularly in the upper lumbar spine, where divergence of the pedicles and articular complex necessitates encroaching to the region of the mammilloaccessory notch to avoid lateral compromise of the pedicle. With direct visualization and screw placement, it is appropriate to minimize Bovie use to preserve the nerve. Use of a cannulated screw with needle and wire to assist placement may also minimize risk to the nerve.

The erector spinae aponeurosis (ESA) is the tendon complex of the thoracic fascicles of longissimus and Iliocostalis. This overlies the local back muscles with a medial trajectory to insertions on the dorsum of the spinous processes and across the distal sacrum and ilium. These tendons cross the intermuscular plane obliquely. Dividing the fibers over the underlying intermuscular plane generally allows easy exposure of 3 or 4 segments. A second parallel opening generally allows exposure of the entire lumbar spine with minimal difficulty encountered working under the preserved intervening tendons.

The dorsolumbar fascia is the aponeurosis of the latissimus dorsi. Reflecting this from adjacent to the spinous process provides a generous exposure for opening between the tendons of the ESA. A mediolateral opening along its fibers opens up the plane over the ESA and provides easy exposure for 1 or 2 segments. Exposing the entire lumbar intermuscular plane generally requires 3 or more openings in the dorsolumbar fascia if one wishes to avoid reflecting and reclosing this layer.

The skin incision is less critical in minimizing morbidity to lumbar muscles. At L3 and above mobilizing a midline incision for intermuscular approach is generally straightforward. When the dorsolumbar fascia is mobilized along the spinous process retraction occurs over the ESA, avoiding a potential space for fluid collection or seroma superficial to the fascia. At L5-S1 and to a lesser extent at L4-5 mobilizing a short midline incision is more difficult because of the relatively lateral entry to the intermuscular plane, and short paramedian incisions are simpler for a short segment construct.

Facet fusion

The multifidus has a common tendon of insertion to each superior articular process. Figure 3 illustrates approach at the dorsal margin of the common tendon over the mammillary process allows retraction of muscle traversing the lamina and facet capsule to caudal insertions. Opening the capsule of the joint allows decortication of the articular surfaces, with direct graft placement. This provides a robust facet fusion with no compromise of segmental muscle integrity. Extending decortication from the articular process to the lateral pars and base of the pedicle above, or to the laminar surface below, increases fusion, area with limited muscle disruption. For many years I have used a facet fusion only, when the articular processes have not been compromised and interbody grafting has been deemed unnecessary.

Retraction is generally straightforward and I continue to use a variety of retractors to maintain visualization in the intermuscular plane. A malleable brain retractor may be bent slightly to engage the rod and folded at the skin to open the plane. An appropriate handheld retractor such a Langenbeck may then be used to retract muscle over the facet capsule for appropriate decortication and fusion in the joint.

While a facet fusion is adequately robust much of the time (figure 4), it is straightforward to extend through the inferior articular process to a transforaminal fusion. This may be done from the same opening used for the joint, or approach through the multifidus or down the lateral margin of the spinous process may provide a more medial, segmental approach while still preserving the muscles over the articular process.

Medialized segmental approach to fixation

A medial approach constrained by the muscle insertions to the superior articular process provides a complementary and equally anatomic approach to fixation and fusion. It is a segmental approach, rather than exposing the length of the lumbar spine, when the multifidus origins are preserved.   In many cases, correction of deformity dictates osteotomies removing portions of spinous process or inferior articular process. Intervention is variably muscle sparing, however, and midline muscle disconnection optimizes exposure. In this situation the neurovascular integrity of the muscle is still preserved and fixation across multiple segments is facilitated without exposure extending lateral to the superior articular process.

At each segment the multifidus arises from a common tendon of origin along the lateral caudal margin of the spinous process, with a deep subfascicle coming off of the deep spinous process and medial laminar margin to insert on the superior articular process 2 segments caudal (i.e., L2 spinous process to L4 superior articular process). Figure 5 illustrates opening the plane along the spinous process and engaging the segmental multifidus. This exposes the lamina, inferior articular process and facet capsule. Figure 6 illustrates the deep subfascicle of multifidus inserting to the superior articular process. The retractor can engage the tendon inserting to the adjacent SAP and muscle traversing to lower levels without disrupting or compromising the segmental neurovascular supply.   When a speculum is used to open this plane for retractor placement, the cephalad blade is constrained by the tendon arising from the spinous process above and the caudal blade elevates the multifidus complex from the fascicle arising on the process adjacent. A retractor blade contoured to follow the facet surface and with projections to engage the tendon to the SAP and the muscle traversing to caudal segments minimizes risk of compromise to muscle integrity. With a symmetric exposure, mild divergence of the blades provides secure retractor positioning without a mechanical support arm being required. Figures 7 and 8 illustrate operative approach with retention of tendon layers and exposure over the lamina.

There are considerations for detaching midline muscles. These include access for better decompression of neural elements, bone removal or osteotomies for better correction of deformity and harvesting bone for grafting. While this may interrupt the tensile integrity of the muscle, it does not devitalize the muscle and is relatively anatomic compared to conventional and some expanding tube approaches which sacrifice anatomy about the articular complex. This makes the approach particularly useful in multisegment exposure for deformity correction.

Medialized screw fixation

Medializing screw placement allows fixation respecting the neurovascular and tendon constraints along the superior articular process. Exposure and retraction constrained at the SAP allows for a comfortable screw fixation respecting the neurovascular integrity of the back muscles.

Richard Hynes pioneered use of medially placed screws with a relatively cortical trajectory traversing the pars interarticularis, and was involved in investigating the biomechanics of medial fixation. Lab testing demonstrated comparable strength comparing a traditional pedicle trajectory with a medialized, relatively more cortical trajectory for screw placement (Santoni et al. , 2009) Experience in more than 1000 cases over the past 14 years has demonstrated clinical efficacy (Richard Hynes, personal communication).

For a single segment fusion, there are slightly different constraints for a cephalad or caudal screw respecting the local anatomy. While a medialized placement may be made from a range of cephalad to caudal trajectories, preservation of segmental neurovascular integrity constrains placement further. The cephalad screw may be placed deep and medial to the multifidus with an entry point on the dorsum of the pars interarticularis must below the joint for the segment above. For the caudal screw, if the muscle origins on the adjacent spinous process are preserved, placing a screw entry point at the inferior margin of the articular surface of the SAP avoids transecting the medial branch of the dorsal ramus and the artery supplying the corresponding multifidus.

When preserving the muscles from the segment above, there is limited exposure of very reliable surface anatomy to assist in screw placement (figure 9). There is an arcuate fossa between the lateral margin of the pars and the accessory process that I find critical for anatomic placement of screws. Richard Hynes has used it to assist in his screw placement and for reasons of description and history I consider it Rick's fossa. The fossa defines the inferior dorsum of the pedicle, with a transition to the accessory process and longissimus lateral, and transition to the pars interarticularis and lamina medial. Approach over the surface of the lamina to the edge of the pars elevates the overlying muscle and neurovascular supply. Identifying the lateral margin of the pars defines a screw entry slightly medial that maintains the course of the screw in bone while accessing a relatively cortical trajectory to traverse the pars into the pedicle. Palpating over the margin of the pars into Rick's fossa defines the plane of transition from pars to pedicle, with relatively certain definition of craniocaudal placement of the screw entry point to avoid an inferior breach of the screw on the pedicle to pars transition.

I use a high speed burr to make the initial entry through the pars and convert to a tap once the burr reaches the cancellous bone in the pedicle. I feel the margin of the pars and into Rick's fossa to define the trajectory of the screw in the sagittal plane, and then rotate the trajectory to place the screw entry on the dorsum of the pars for a much stronger and more cortical screw placement than starting in the fossa would provide. The trajectory approximates 25 degrees cranial and 15 degrees lateral to the axial and sagittal plane respectively (figure 10). Full dimension tapping is important to avoid fracturing out the cortical pars with an oversized screw. A cortical thread screw of 4.5 to 5.5 mm diameter optimizes thread pitch and minor diameter to most effectively engage the bone and maximize screw strength. Screw length is typically 25 to 35 mm.

In advanced degenerative cases a combination of factors may obscure surface anatomy. Settling of the disk brings the superior articular process into contact with the inferior margin of the pedicle and Rick's fossa. Hypertrophic arthropathy with capsular and bony overgrowth of the joint further obscures the keel of lamina and pars. Opening the facet joint allows one to follow the inferior articular process to the keel of the pars and Rick's fossa.

The caudal screw presents slightly different limitations. With a short exposure, I use a medialized trajectory entering through the articular surface. The capsule of the facet provides some protection to the segmental nerve and vessel just inferior to the joint, supplying the adjacent multifidus. I enter typically at the base of the articular surface between middle and lateral third, with an AP or slightly lateral trajectory that allows the screw to engage the vertebral endplate and lateral body junction for maximal security (figure 11). If the canal has been decompressed, direct confirmation of the medial pedicle confirms anatomy. If the muscle has been detached for exposure, placement analogous to the cephalad screw is straightforward but requires a slightly longer incision to achieve the desired trajectory.

L5 is unique in that the pars interarticularis is foreshortened relative to cephalad levels, with a less well developed cortical portion than levels above, and with a transition to the pedicle and body providing somewhat less margin to inferomedial pedicle compromise. In surgery it is frequently not easy to directly palpate the lateral pars and into Rick's fossa directly. Opening the sacral facet joint allows one to follow the inferior articular process of L5 to the fossa and inferior pedicle and define screw entry.

Sacrum presents a different issue. An analogous trajectory lacks the same cortical development seen at levels above, which relates to the stresses across the lamina and pars associated with the dynamics of the motion segment disk complex. I frequently place a pedicle screw directly, or through the muscle with a medial trajectory, to optimize placement in the better bone under the sacral endplate and to engage the sacral apex anteriorly. A short side connector facilitates lining up with the cephalad construct, if necessary. A sacral alar screw provides an elegant and secure solution in many cases, and places the head of the screw in relatively better alignment with a medial construct.

With 2 or 3 segments, it is possible to pass the rod under or through the segmental multifidus, however detachment of the midline muscles may facilitate and optimize surgery while still preserving the neurovascular integrity of the muscles (figure 12).

Discussion

Anatomic approach about the muscles of the back provides a muscle sparing, naturally minimal approach to the back. Historically, many approaches simply disconnected muscles of the spine for exposure as desired. Caspar (1977) introduced the use of the operating microscope to lumbar discectomy, with a slightly paramedian approach through the ESA, and retraction of the multifidus from the cephalad segment to avoid local muscle compromise. Ritland (2000, 2002) described a microsurgical intermuscular fusion or micro-TLIF, working about the muscle constraints with an intermuscular approach to construct placement, and a segmented intermuscular approach to the lamina for decompression and interbody fusion. Foley (2003) initiated a parallel approach to MISS with percutaneous screw fixation and a transmuscular approach to the spine. This provided a limited approach, but one frequently extraanatomic in regards to the tendon and neurovascular elements in the back.

To the extent that MISS involves not just the skin incision, but preservation of the muscular integrity of the back, there is a compelling argument for approaches that respect the integrity of the back muscles and work about rather than through muscle fascicles. Engaging and respecting the segmental muscles in the back has the potential to preserve muscle integrity at risk with transmuscular or expanding retraction. In the situation of deformity and multisegmental correction, an intermuscular approach provides a muscle sparing approach to placing fixation and seats the construct between the major back muscles. Combined with a segmented approach to facet or interbody fusion, it is possible to fully preserve the back muscle integrity. It places the construct between muscle groups with minimal impact on segmental muscle function. A midline approach for fixation with medialized screw placement is similarly anatomic. Midline muscle detachment may provide a more generous approach to the spine and spinal canal, while still preserving the neurovascular integrity of the midline back muscles.

An understanding of the segmental muscles of the back enables and facilitates anatomic approaches to the back which preserve or minimally impact the functional integrity of the back. It is reasonable to consider approaches which detach muscles only as required to optimize deformity correction, neurologic decompression or as necessitated for fusion.

Acknowledgements

The artwork has been developed with Scott Bodell over a period of years. It is meant to illustrate the most relevant surgical anatomy. For purposes of illustration and clarity, some details such as interspinales and intertransversarii have been variably omitted. It expands on work previously published with Hoh (2010). I reference Bogduk (2005) for anatomic nomenclature.

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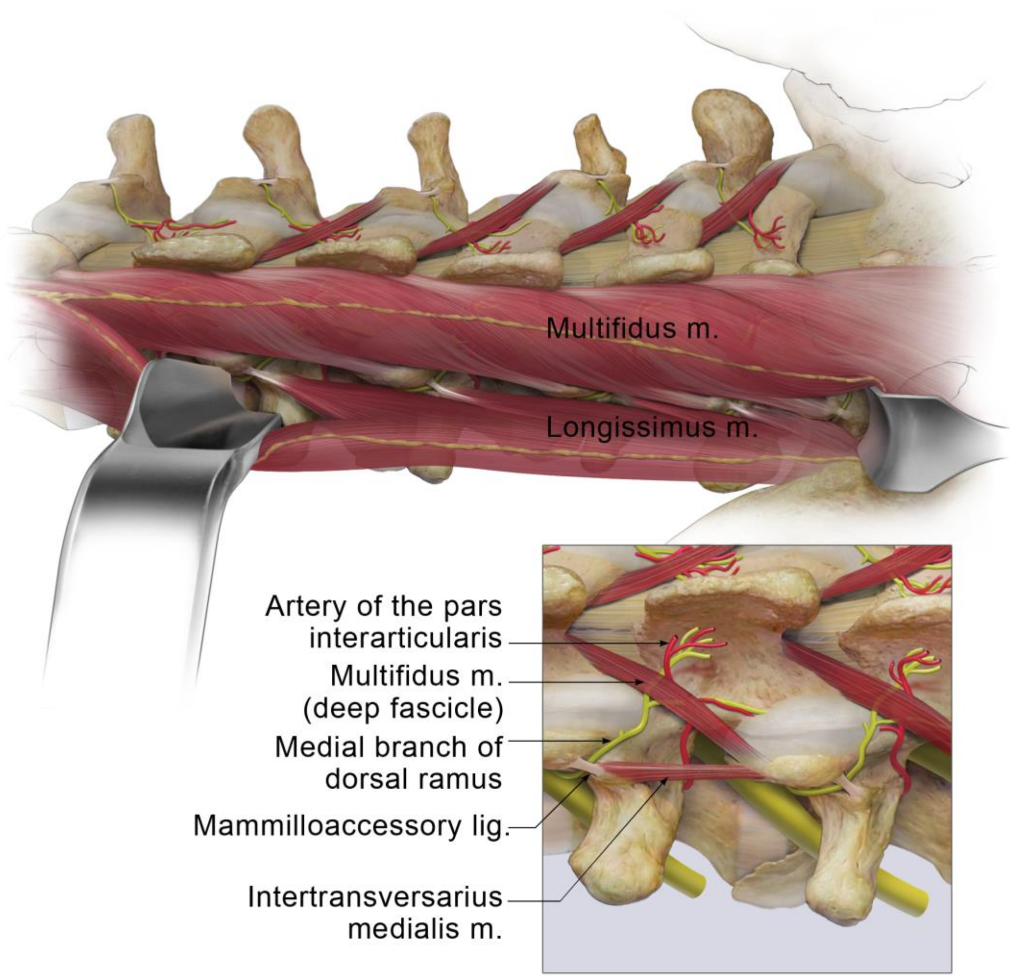
Figure 1

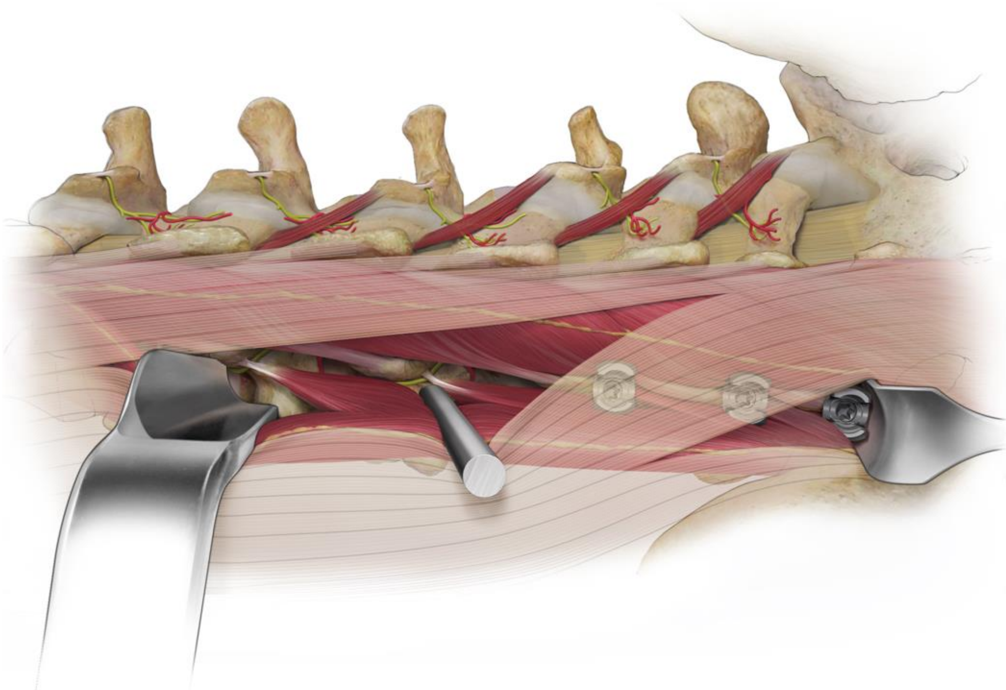
A

The intermuscular plane is opened from L2 through sacrum. The common tendon of multifidus is seen inserting to the superior articular process at each segment. The longissimus fascicle arising from each accessory process is seen projecting towards a common tendon of insertion to the medial superior iliac spine. A bit of fat typically defines the dorsum of the intermuscular plane, with the entry adjacent to the spinous process at L1 and just medial to the iliac crest at the sacrum. The inset shows anatomy important to consider during screw placement and fusion. It is generally possible to place a screw just caudal and lateral to the medial branch of the nerve by being aware fo the anatomy.



B

A right angle retractor may be used to engage the lateral articular process and retract the longissimus arising from the cephalad segment. The entry point for screw placement is seen on L2 just inferior to and lateral to the mammilloaccesssory notch and nerve, and at the upper margin of the tendon arising on the accessory process. Tap placement is seen at L3, with screw placement L4 to sacrum. The erector spinae aponeurosis is opened and retracted as necessary.



C

Screws are placed L2 through sacrum. The tendon and proximal longissimus lie between screw heads, and may at times require a bit of division of the most dorsal portion of the tendon extending from the accessory process onto the mammilloaccessory ligament, to allow the rod to seat fully without unduly stretching the muscle and tendon. The assembled construct lies lateral to the multifidus complex with minimal impingement against back muscles.

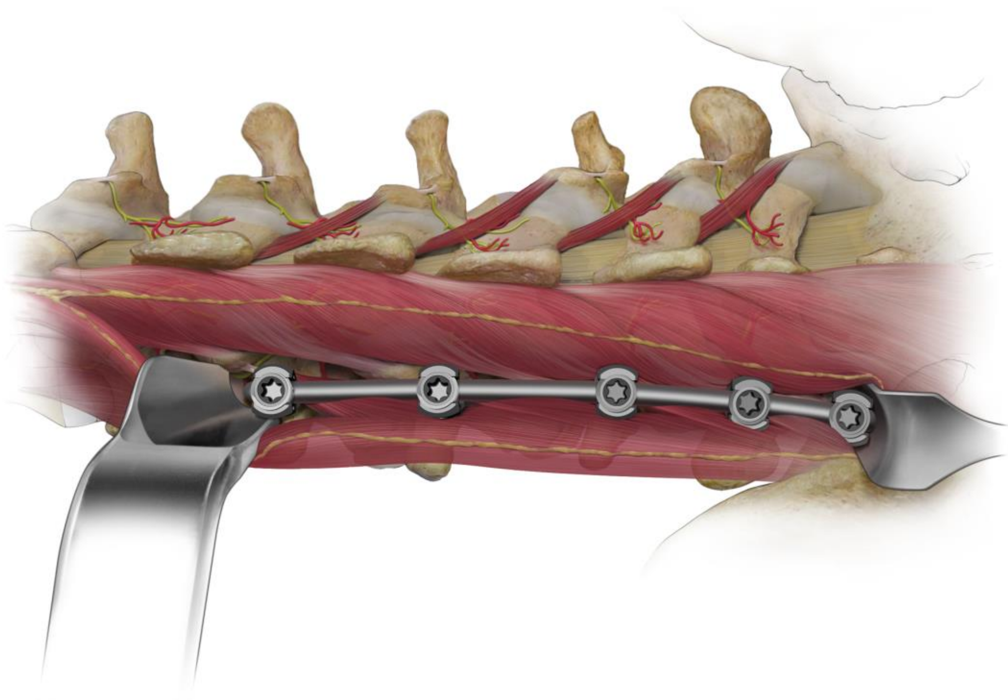
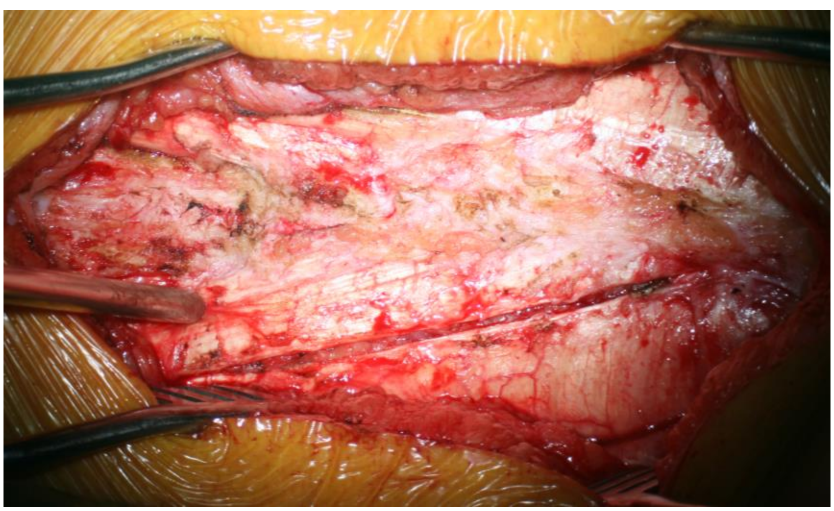


Figure 2

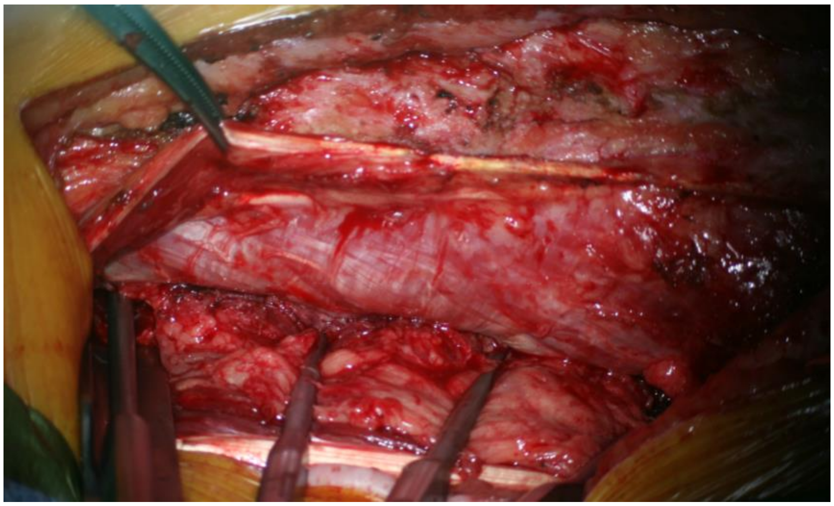
A

A midline skin incision has been made, with the dorsolumbar fascia reflected from L1 to the sacrum. The tendons of the ESA are seen projecting caudally to insertions on the dorsum of the spinous processes.The opening of the ESA is seen between tendons inserting to L4 and L5.



B

The upper medial ESA is reflected medially. The intermuscular plane is seen with the upper opening occurring near spinous process, adjacent to the spinous process. The tendons of the multifidus are seen forming on the lateral aspect of the multifidus to insert to the superior articular process (SAP). The retractor is seen engaged against the L1 SAP. Taps are in place in the pedicles L1 through L4. A bit of fat is appreciated in the deep plane between fascicles of longissimus.



C

The final construct is in place. Screws are seen in L1 through L3. The L4 screw underlies intervening ESA. The L5 and S1 screws are seen through a second opening in the ESA.

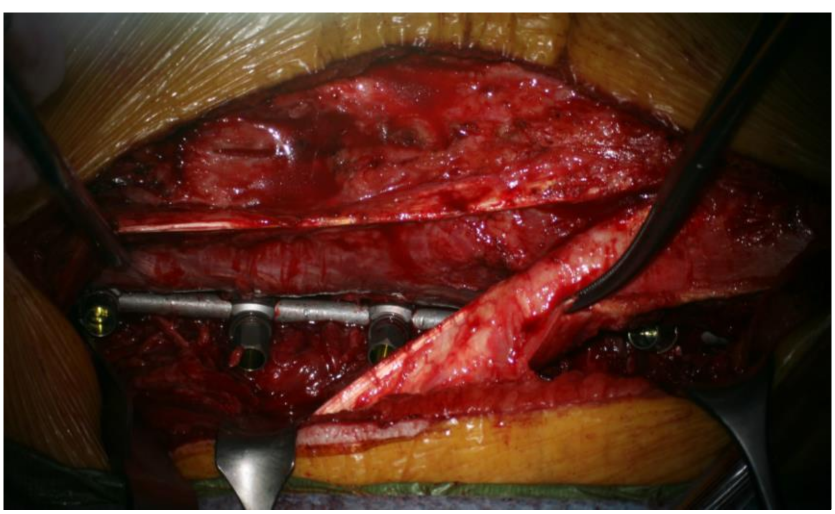
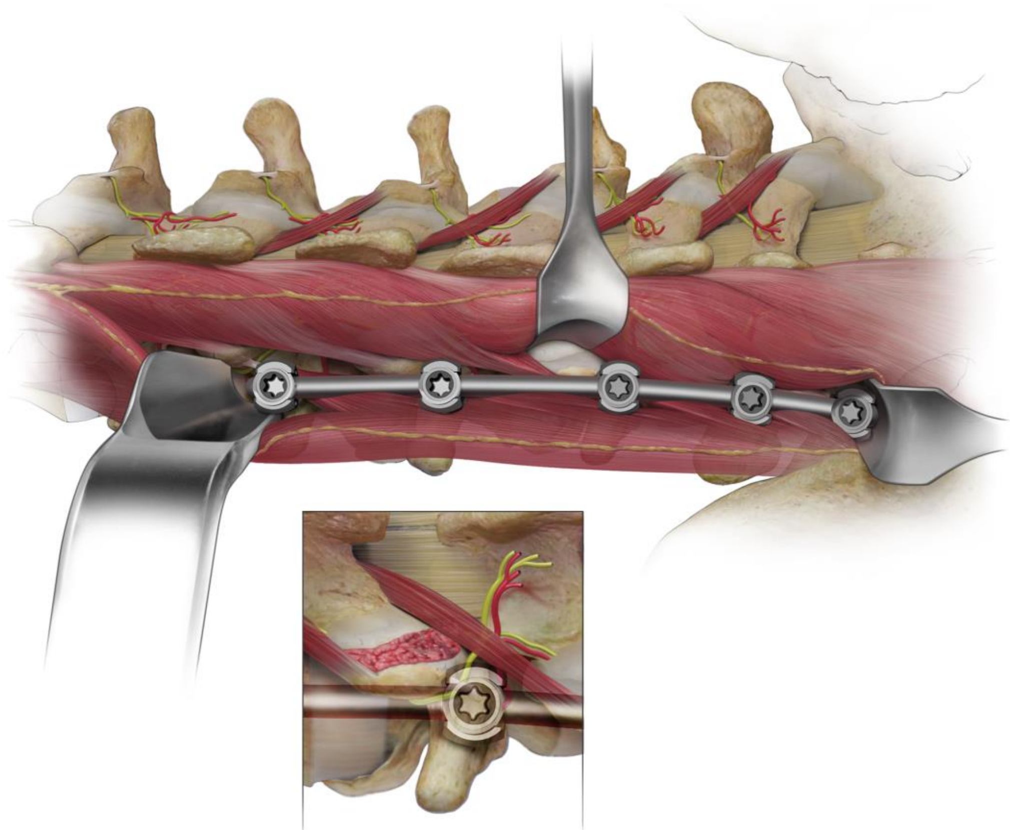


Figure 3

A

Approach at the caudal margin of the common tendon inserting to the SAP allows retraction of multifidus complex traversing to caudal levels. The retractor exposes the capsule of the facet joint and the lateral margin of the lamina and inferior articular process. The capsule of the facet joint is opened. This allows decorticating the facet joint with preservation of the integrity of the articular processes. The trajectory from the intermuscular plane allows optimal preparation of the joint for grafting. Bone graft is packed into the prepared joint before releasing the overlying muscle



B

Disconnection of adjacent tendons on the SAP and accessory and transvers processes allows extending the graft for a more conventional lateral fusion in the situation where it is felt that sacrificing muscle is warrented for a more generous bony fusion. This view demonstrates both the ESA tendons seperated to provide access to the joint, and a mediolateral opening through the dorsolumbar fascia, preserving significant integrity to this layer with a segmented approach.

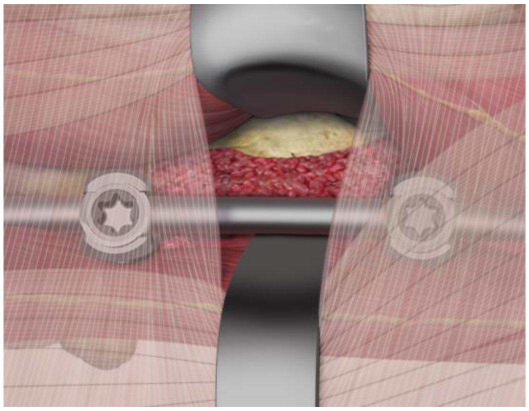


Figure 4

A

Axial section through a facet fusion. Peek rods are seen in cross section adjacent to the dorsal joint, in the intermuscular plane between multifidus and longissimus.

B

Dorsal view of reconstruction, demonstrating facet fusion along the articular complexes.

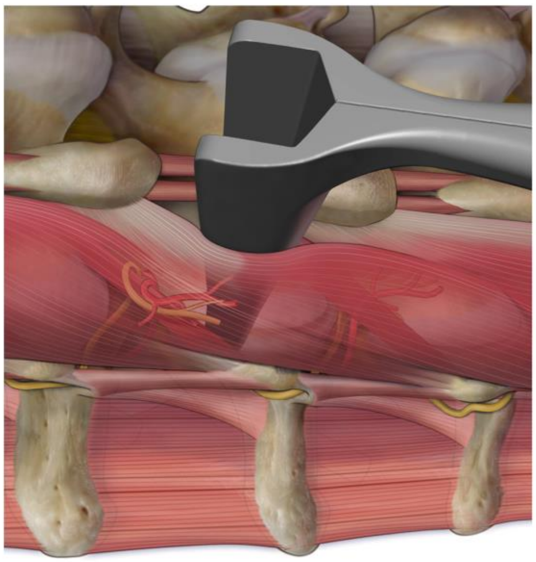
C

Lateral reconstruction demonstrating the robust fusion along the articular complex, with an interbody fusion at L5-S1.

Figure 5

A

View of medial approach. Inserting a speculum along the spinous process elevates the muscle from the lateral spinous process and lamina.

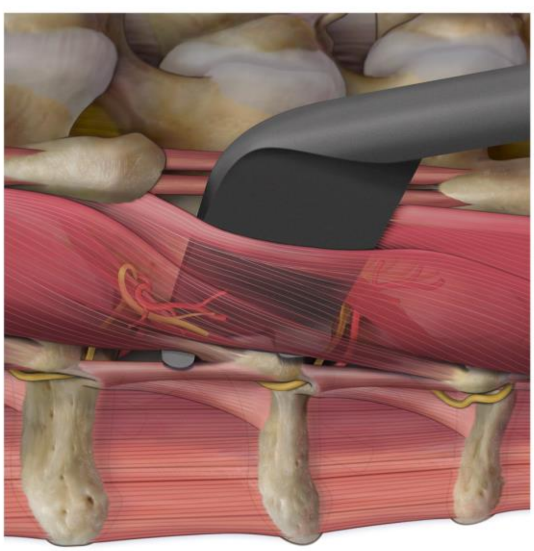


B

Opening the speculum provides a protected path for inserting the retractor blade to the dorsum of the lamina and articular process.

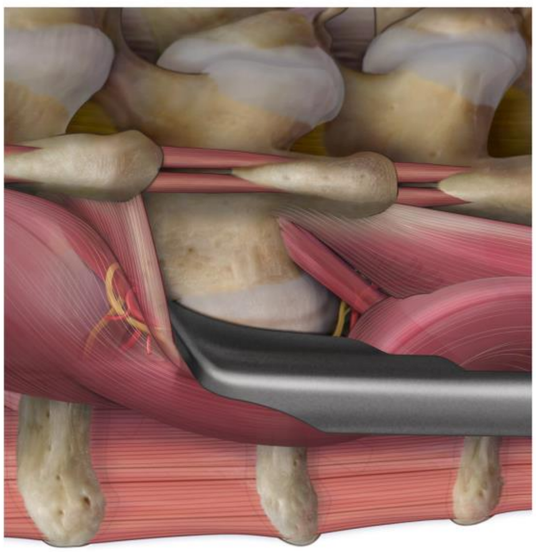
C

The retractor blade engages the tendon inserting to the SAP, and the muscle traversing to insert at the next caudal level. The assymetry in the retractor tip, with the cephalad margin being longer, allows engaging both the tendon to the SAP, and the muscle and tendon traversing to the caudal level.



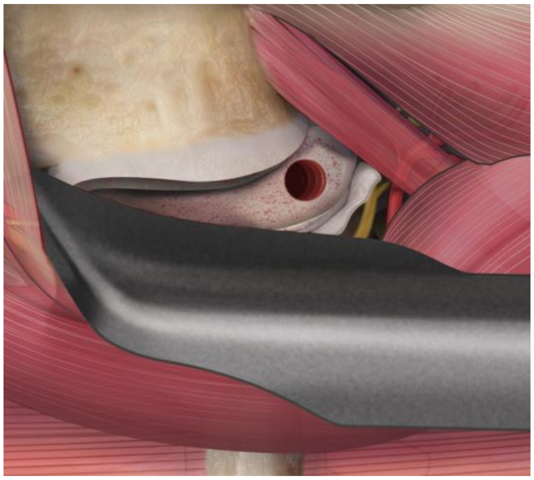
D

The retractor is in place and open. This exposes the IAP and the capsule of the joint. Medially, the fascicle of multifiidus from the adjacent spinous process is preserved. The segmental nerve and vessel retract with the muscle from the process above, while the segmental neurovascular supply to the segment below run below the joint to the segmental muscle arising on the adjacent process. The deep subfascicle arising from the transition of spinous process to the laminar margin is seen. This subfascicle frequently needs to be at least partially sacrificed for decompression in the canal or interbody fusion. There is frequently a bit of fat over the lamina and articular process which may be removed as necessary.



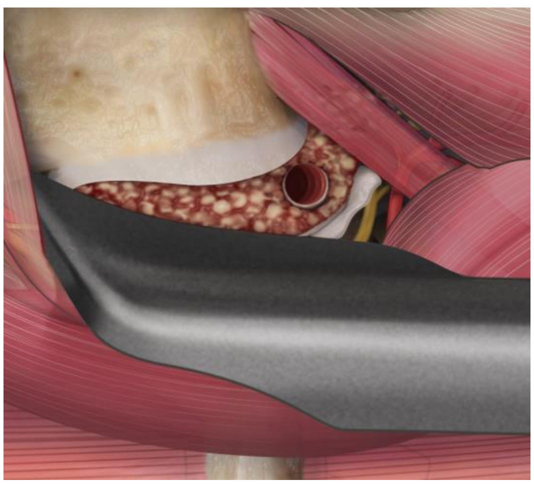
E

Opening and decorticating the joint allows for a robust facet fusion if the integrity of the articular process is respected. Medializing screw placement to the base of the superior articular process avoids risking the neurovascular elements inferiorly.



F

The facet joint is packed with graft and is ready for screw placement.



G

Final screw construct in place.

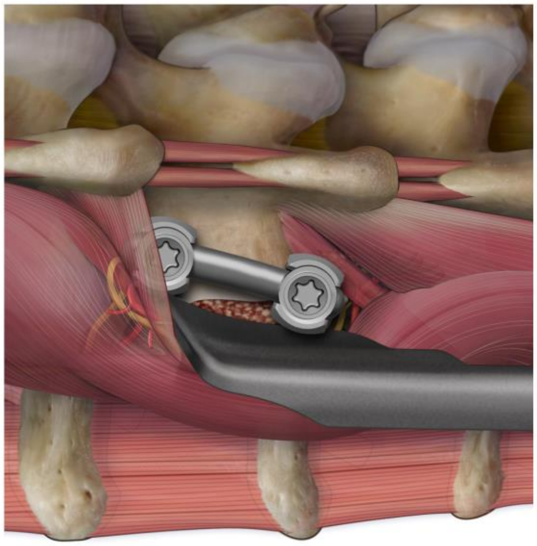


Figure 6

A coronal MRI reconstruction demonstrates the course of the deep subfascicle of multifidus from the margin of the spinous process and lamina to the SAP. This insertion is a portion of the common tendon of insertion of multiifiidus to the articular process. Engaging this tendon helps elevate the deep muscle and associated neurovascular segments to allow for screw placement.

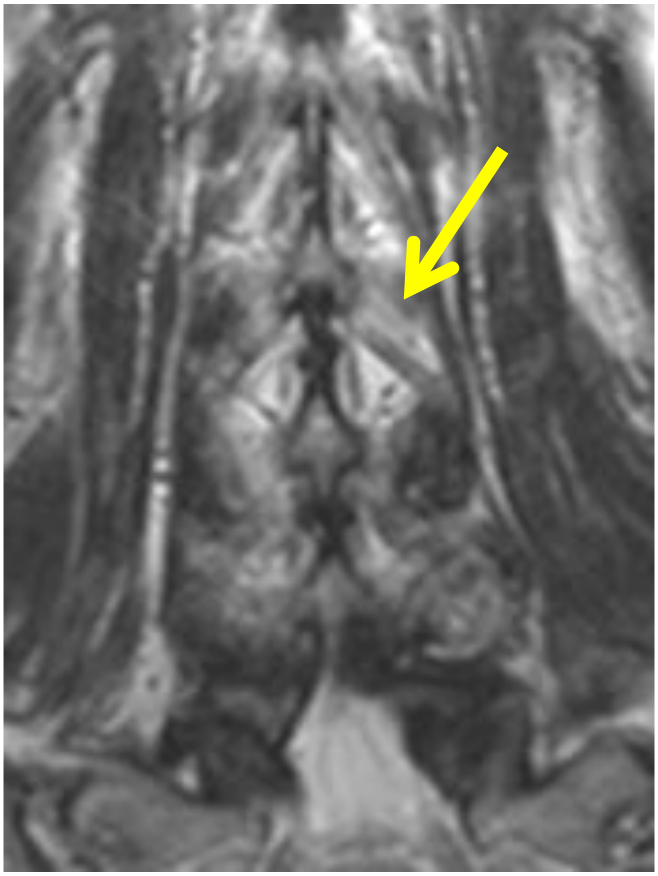
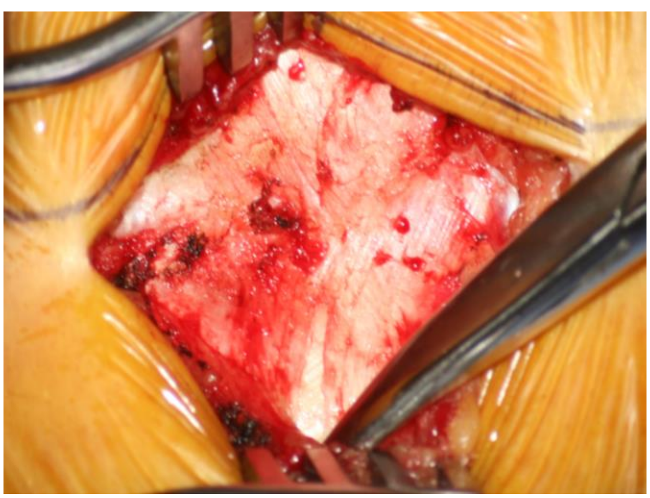


Figure 7

A

Opening the dorsolumbar fascia along the course of its fibers minimizes compromise while allowing access for segmental approach for decompression and fusion.



B

Once the dorsolumbar fascia and ESA have been opened and retractor blades placed, a suture may be placed to hold open the surgical field.

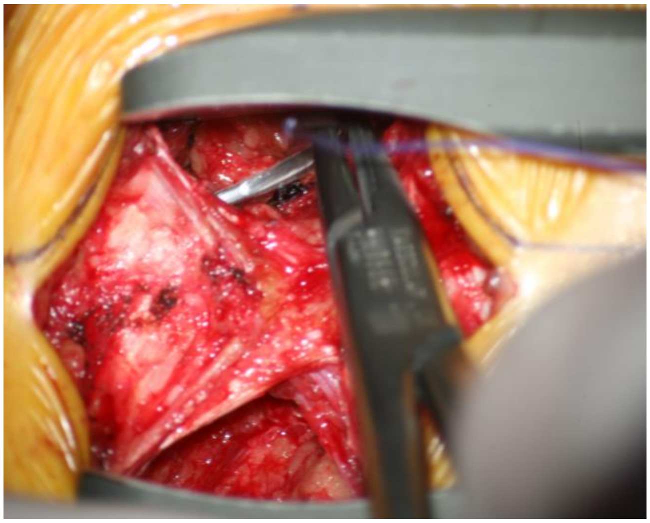
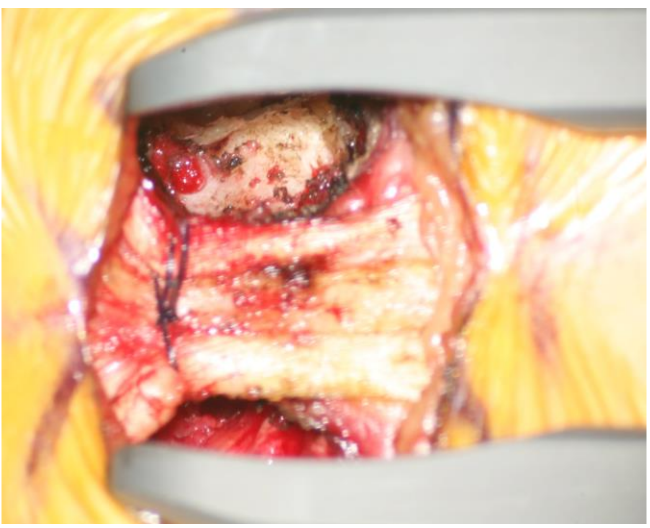


Figure 8

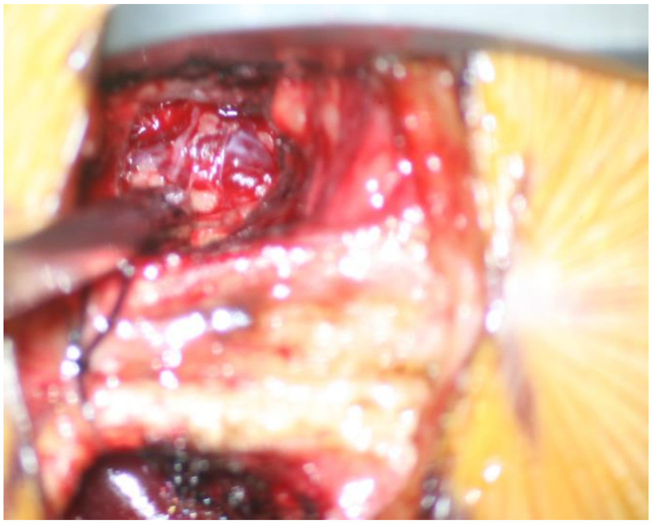
A

The lamina and inferior articular process of L4 are exposed, with the retractor engaging the tendon inserting to the articular process of L5 and traversing to sacral insertions. The multifidus arising from the spinous process is seen caudally. The retraction suture holds the cephalad margin of the exposure open, retracting the ESA medially. The dorsolumbar fascia has been freed along the spinous process and reflected laterally over the ESA.



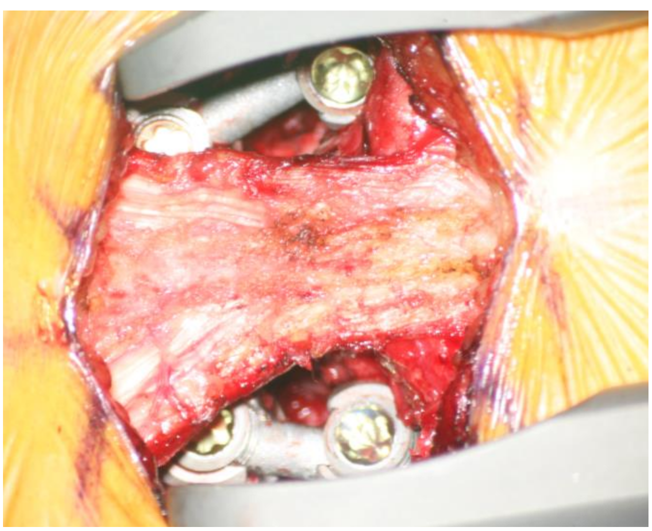
B

The inferior articular process is removed. The medial superior articular process has been removed. The foraminal venous complex overlying the disk is seen with a window for discectomy and fusion with minimal or no retraction of neural elements.



C

Screw construct is in place after interbody work is complete. The suture retaining the ESA has been removed allowing the tendons to relax towards normal position.



D

AP xray view demonstratiing preservtion of midline muscles.

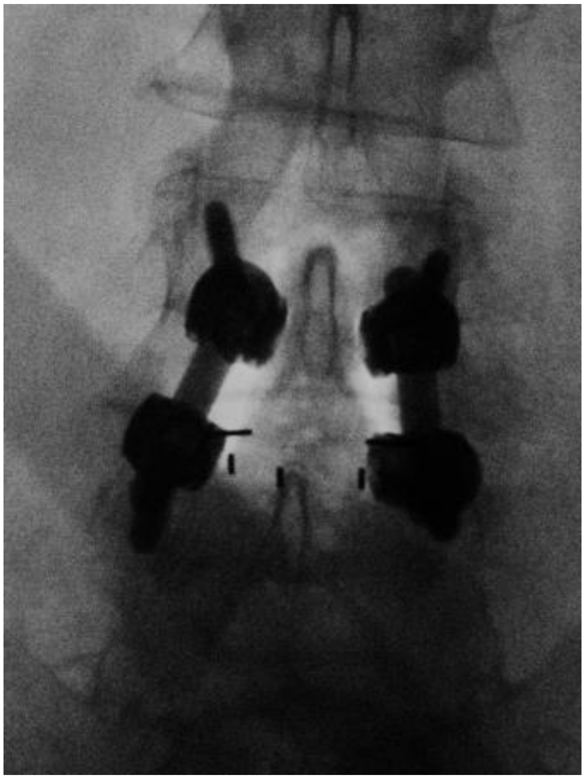


Figure 9

Landmarks for medial screw placement traversing pars. There is a keel of cortical bone running from the mammillary process to the of inferior articular process that defines the transition from dorsal surface to lateral margin of the pars interarticularis. There is an arcuate fossabetween the keel and lateral pars and the accessory process that defines the dorsal and inferior margin of the pedicle (Rick’s fossa). Palpation of the surface of the fossa defines a plane of transition for screw trajectory across the pedicle. Moving medial on the surface of the pars shifts the screw course to a tract through more cortical bone, and one that places the construct adjacent to the spinous process, better underlying the muscle from segment above.

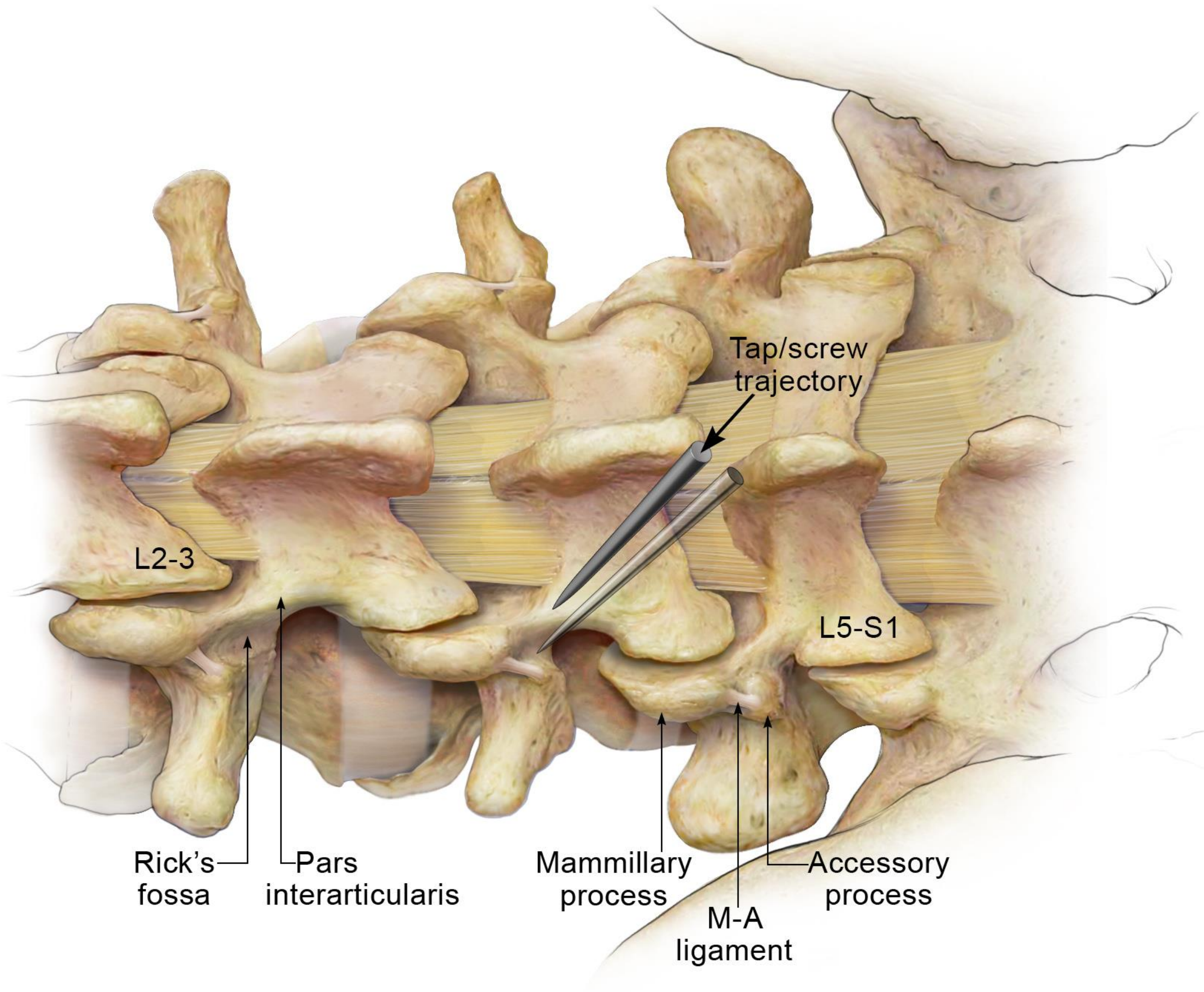
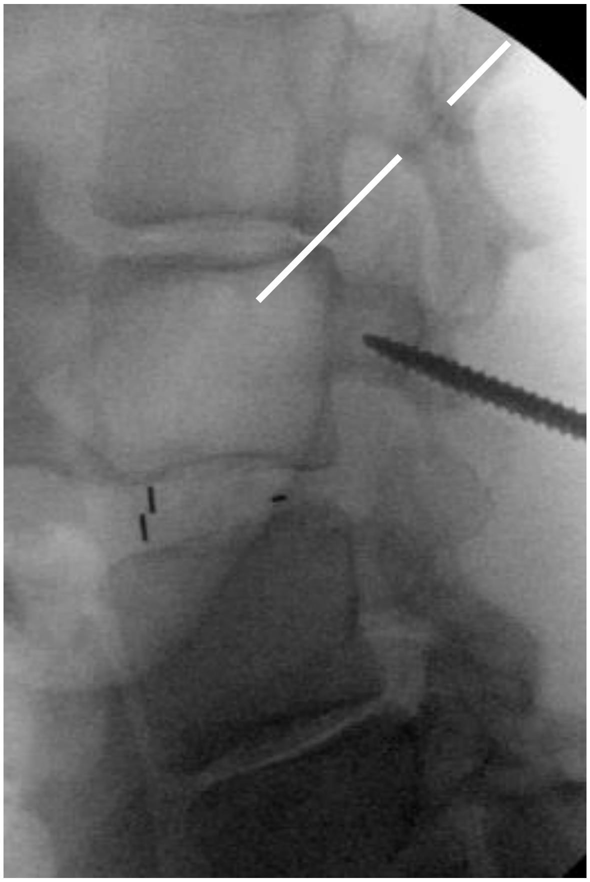


Figure 10

A

A lateral x ray demonstrates the sclerotic cortical surface of the accessory process and Rick's fossa, and defining a transition to pedicle. The white lines indicate margins of the sclerotic bone visualized on image. The tap is seen with tip projecting across cortical density into pedicle, but is rotated to traverse the pars rather than the cortical surface of the fossa.



B

AP x ray image with initial tap placement demonstrating trajectory to pedicle. On the left, the line segments define the lateral border of the pars transitioning to Rick's fossa, and a segment with ends defining the entry to laminar surface and tip position corresponding to tap. On the right, a line segment defines a direc placement trajectory. Rotating the trajectory to a medial entry over the laminar surface corresponds to the alignment of the tap.

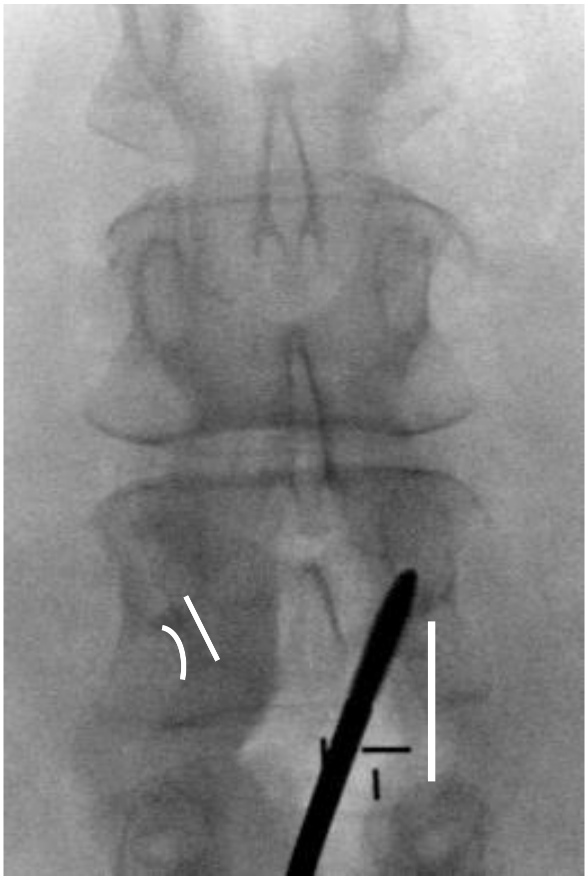


Figure 11

Medializing a pedicle screw at the caudal segment, with entry at the lower margin of the articular surface provides adequate fixation with a trajectory minimizing skin incision. When the segmental muscle origins are preserved, this avoid extending across the medial ramus and artery just below the facet.

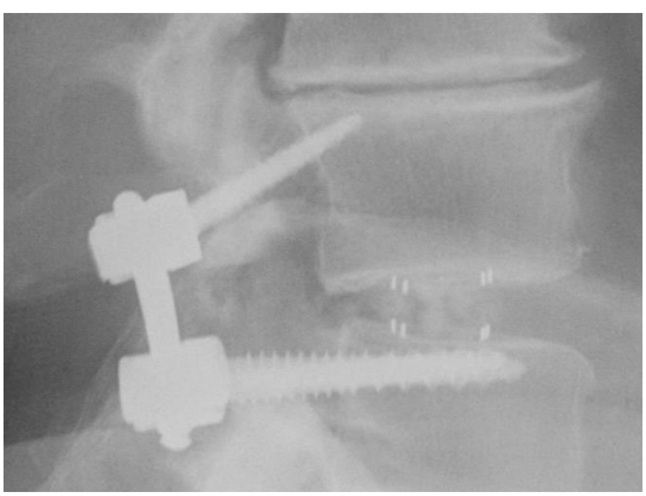
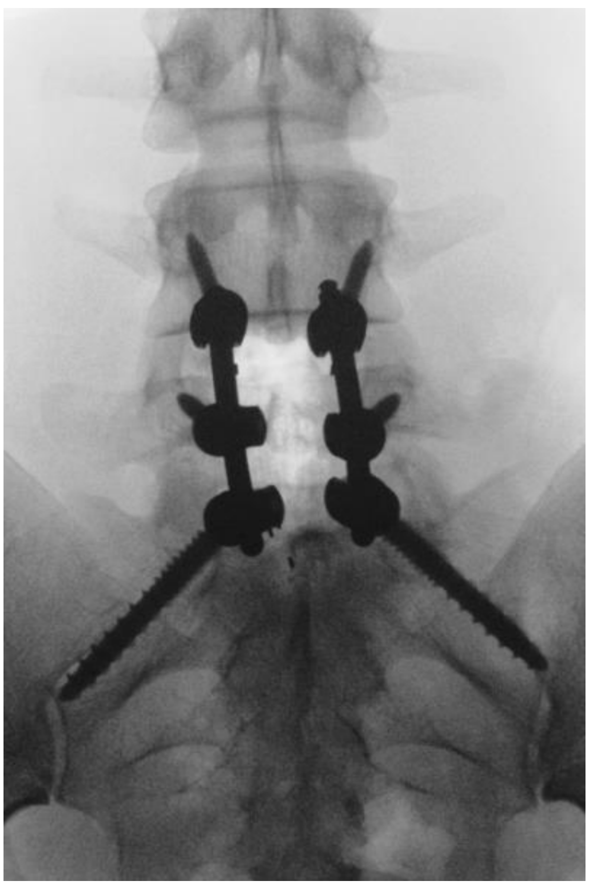


Figure 12

A

Medial screw construct with laminar exposure L4 to sacrum. Detachment of midline muscle attachments provides generous access for decompression and bone harvest while still preserving the neurovascular integrity of the muscles. The screws are placed deep to the muscle arising on the L3 spinous process and remain medial to tendon and neurovascular constraints along the articular processes. Placing a sacral alar screw avoids disrupting multifidus insertions to the sacrum.



B

A lateral view of the construct shows the cephalad trajectory traversing the pars interarticularis and pedicle.