Chapter 6
Minimally Invasive Transforaminal Lumbar Interbody Fusion

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Introduction

Minimally invasive transforaminal lumbar interbody fusion (MI TLIF) is one of the most commonly performed minimally invasive spine operations in the United States. This technique involves an algorithm of operative steps that allows safe decompression and stabilization of the diseased segment.

Indications

The indications for MI TLIF are the same as for the open TLIF:

- Lumbar instability with grade 1 or 2 spondylolisthesis
- Discogenic pain, after failure of conservative treatment and adequate work-up
- At the bottom of a long construct, e.g., for deformity correction.

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Common conservative treatments prior to considering surgical intervention include NSAIDs, physical therapy, epidural steroid injections etc. Diagnostic imaging typically starts with dynamic flexion-extension X-rays and MRI (or CT-myelogram, in patients who cannot have MRI). Further testing may include CT-SPECT [1], facet blocks, selective nerve root blocks, discogram etc.

In patients with apparent positive sagittal balance, scoliosis films and/or a full deformity work-up should be performed.

Contraindications

High-grade spondylolistheses (grade 3 or 4) should be treated by open, rather than MI, TLIF. In these cases, we often perform an open bilateral laminectomy and facetectomy, bilateral discectomy, reduction of the listhesis on the pedicle screws (inserted with bicortical purchase), and insertion of PLIF, rather than TLIF, cages.

A relative contraindication is morbid obesity, when the distance between the skin surface and the lamina is over 100 mm (the longest typical tubular retractor). However, since the fat is depressible, we have used this technique in many morbidly obese patients without having to convert to an open procedure.

Surgical Technique

The following operative steps are described:

- patient positioning
- skin incision
- graft harvesting
- retractor placement
- medial facetectomy
- lateral facetectomy and yellow ligament removal
- discectomy
- cage insertion
- ipsilateral pedicle screw insertion
- contralateral percutaneous pedicle screw insertion
- closure

Patient Positioning

The patient is placed in prone position with the arms tucked to the sides and with adequate padding for all pressure points. We take an AP image and adjust the table, not the C-arm, until the spinous process at the level of interest is perfectly centered

between the two pedicles. We place the patient in slight reverse Trendelenburg position when we operate on the L5–S1 level, in order to have less of a cranio-caudal work angle. We do NOT flex the table, since the patient would be fused with a straight lumbar spine (instead of lordotic). In fact, we occasionally extend the lumbar spine (using the re-flex option of the surgical bed) *after* inserting the interbody cage, in order to restore some of the lumbar lordosis, in selected cases.

Skin Incision

The level of interest is identified on the lateral image by placing a spinal needle in alignment with the intervertebral disc of interest. The skin incision is centered on the spinal needle entry point, and is typically 2.5–3 cm in length, parallel to the midline and about 5–6 cm lateral to it. In patients with larger body habitus, the incision has to be placed further laterally. For the L5–S1 and the L4–5 levels, the most common levels treated, the skin incision is usually just above the iliac crest. After local hemostasis for the skin edges, the incision of the subcutaneous fat and the lumbar fascia is continued with the 10-blade in a lateral to medial direction, and maintaining the same cranial to caudal angulation as the localizing spinal needle, until the lumbar fascia is encountered.

Graft Harvesting

We prefer to use bone marrow aspirate (60 cc's, later to be concentrated to 7 cc's of mesenchymal cells, mixed with demineralized bone matrix to be used as fusion material) and occasionally autologous iliac crest graft (Video 6.1). The lumbar fascia inserts on the iliac crest; therefore, once we expose the fascia, we follow it caudally to its' insertion on the crest. Typically, the crest is found just caudal to the edge of the skin incision. We follow it medially until the posterior superior iliac spine (PSIS) is palpated. Then, a Jamshidi needle is inserted in the PSIS in a cranial to caudal and medial to lateral direction, in order to not violate the SI joint, located caudal to the PSIS. Upon aspiration, the bone marrow should come into the syringe slowly; we turn the needle by 90° every 15 s and occasionally advance it by half a centimeter every minute in order to maximize aspiration of bone marrow rather than just venous blood.

If autologous iliac crest graft is desired (e.g., in smokers or patients with osteoporosis), we use to self-retaining retractors to expose the fascia over the PSIS. Then, using either a trephine or dedicated instruments (e.g., the crest harvester by Globus Medical), a cylinder of bone about 3 cm long is extracted, using the same entry point and direction as described for the Jamshidi needle. In order to minimize postoperative pain, care must be exercised to respect the direction of the iliac crest, so that only the cancellous bone is harvested (i.e., the internal and external cortices must not be violated). Also, we do not go deeper than 3 cm with the harvester, since penetrating the sciatic notch would place the sciatic nerve at risk. Occasionally, when a larger

amount of graft is needed, we harvest a second cylinder of cancellous bone just lateral to the first one, but with a separate cortical entry on the cranial edge of the iliac crest (i.e., we do NOT use the same entry hole, since that would decrease the volume of graft harvested). Hemostasis is then achieved with bone wax and Gelfoam soaked in Marcaine (for postoperative pain control). The fascia can usually be closed with a "figure of 8" 0-Vicryl on a UR needle.

Retractor Placement

The lumbar fascia is incised in a longitudinal fashion, parallel to the skin incision and slightly medial to it. The paraspinal muscles are then dissected in a lateral to medial direction, either with the index finger or with one of the small dilators.

There is an antero-posterior fascial layer, between the multifidus and the erector spinae muscles, that inserts on the tip of the lateral facet. If this fascial layer is not penetrated, the dilator will slide on its' lateral aspect and the retractor will be positioned laterally, on the junction of the lateral facet with the transverse process. In this case, the retractor is pulled out and, through the same fascial opening, the muscle fibers are penetrated more medially. Of course, the antero-posterior fascial layer, between the multifidus and the erector spinae muscles, has to be forcefully penetrated with the smaller dilator, so that the tip of the dilator lands on the lamina of interest. Occasionally, this fascial layer opening has to be enlarged by sharp dissection (i.e., scissors or Bovie cautery).

After sequential dilation and placement of the tubular or 2-blade retractor, there is typically a small amount of muscle fibers left on the lamina; this can be removed with pituitary rongeurs and Bovie cautery. In patients with hypertrophic facets, it may seem that the lamina is very deep in the exposed field; in these cases, it helps to get multiple lateral X-rays, showing that we are still superficial to the spinal canal, and start the exposure laterally, with the Bovie cautery, until the junction between the medial facet and the lamina is identified.

The correct placement of the retractor, in line with the intervertebral disc of interest, is confirmed with lateral fluoroscopy and then the retractor is locked in place with a rigid arm. Once the retractor is locked in place and the remaining muscle is removed, the operative microscope is brought into the field and the following structures should be exposed in the operative field: caudally, the caudal edge of the lamina of interest; medially, the junction between the lamina and the spinous process; laterally, the lateral aspect of the lateral facet; and in the center of the exposure, the pars interarticularis, with its characteristic appearance of a "valley" between two "hills" (the above and below joints). We prefer to enter the caudal joint with the Bovie cautery, to confirm the anatomic location and also to facilitate the removal of the medial facet later on.

There are some slight variations depending on the type of retractor used. The tubular retractor has the advantage of being compact and keeping the muscle out

of the way circumferentially. The pedicle-based retractor is described in detail below (Video 6.3). The two-blade (cranio-caudal) retractor, with the option of adding a third, medial, blade, is the one we currently use most frequently, because it is simple, it allows towing of the blades for further cranio-caudal exposure (without enlarging the skin incision), and it allows for medial-lateral angulation of the curettes and rasps to prepare both the contralateral and ipsilateral endplates without adjusting the retractor (as is the case with the tubular retractor) (Video 6.4).

Medial Facetectomy

This step begins with two osteotomies: one vertical, parallel to the spinous process and just lateral to it, and the other one horizontal, through the pars interarticularis. We use the high-speed drill to perform all osteotomies, but some surgeons may prefer to use osteotomes. We prefer to start with the vertical osteotomy, since it is similar to the one performed for microdiscectomies and quite familiar to most surgeons. This is a relatively safe step, since the underlying yellow ligament protects the dura mater. The osteotomy is started at the caudal edge of the lamina and extended cranially until the end of the yellow ligament is encountered. This typically corresponds to the caudal aspect of the cranial pedicle on lateral X-ray and marks the point where the horizontal osteotomy should be started. The vertical osteotomy is usually performed close to the spinous process, in which case the lamina is thin and the yellow ligament is encountered after only a few mm of drilling (with the typical lamina-drilling sequence of cortical bone, cancellous bone, cortical bone, yellow ligament). This allows for good central and even contralateral decompression of the spinal canal (Video 6.2). If central decompression is not necessary, the vertical osteotomy can be performed further laterally, in order to minimize the amount of dura mater exposed. In this case, the lamina is thicker and the yellow ligament is encountered deeper and at a tangential angle, as it curves towards the lateral recess.

The horizontal osteotomy is typically started at the cranial end of the vertical osteotomy, where the end of the yellow ligament is observed. The osteotomy starts in the lamina and continues through the pars interarticularis, which is much thicker than the lamina. We recommend getting a lateral fluoroscopic image at this point, to make sure that the osteotomy is below the caudal edge of the cranial pedicle. Once the horizontal osteotomy is completed, the medial facet becomes loose (when the horizontal osteotomy completes the pars transection, it also gives a tactile "pop"). We detach the capsular ligaments with the Bovie cautery, which allows the medial facet to be removed en-bloc with large pituitary rongeurs. If the facet is too bulky, we sometimes transect it in two pieces with the high-speed drill, which makes it easier to remove. At this time, the shiny medial aspect of the lateral facet is exposed.

Lateral Facetectomy and Yellow Ligament Removal

We prefer to perform this step before removing the yellow ligament, in order to protect the dura mater during drilling. The tip of the lateral facet is removed with the high-speed drill from cranial to caudal. We take a lateral fluoroscopic image to determine the projection of the cranial edge of the caudal pedicle and we mark that on the shiny medial aspect of the lateral facet, since that represents the caudal extent of the lateral facet removal. The lateral extent of the facet removal is represented by the soft tissues, where the tortuous lumbar artery is invariably encountered; fortunately, bleeding from this artery can be easily controlled with the bipolar cautery.

Once the partial lateral facetectomy is complete, the bony work is done and we can proceed with the yellow ligament removal. A small up-biting curette is flipped under the yellow ligament and followed with a Kerrison rongeur to remove the ligament in a piece-meal fashion. At this point, the lateral edge of the dural sac and the takeoff of the spinal nerve are exposed. The epidural veins are often prominent and should be coagulated with the bipolar cautery and sharply transected. The safest point to start coagulating the epidural veins is just lateral to the take-off of the traversing spinal nerve.

Discectomy

A typical degenerated disc is about 8–12 mm in height. In these cases, we start the annulotomy just lateral to the dural sac and extend it laterally for about 10–15 mm, unless the exiting spinal nerve is in the way (as is the case in patients with spondylolisthesis). A disc herniation can be removed at this time, if present, as described in the previous chapter. Once the annulus is opened with the 11 blade, we prefer inserting a small smooth shaver, e.g. 8 mm, as deep as the contralateral annulus permits; this is a tactile feel, but we also confirm it with lateral fluoroscopy, as there is a tendency to stop too soon and thus not remove enough disc material. The shaver is rotated in the disc space both contra- and ipsi-laterally, in order to dislodge as much nucleus pulposus as possible, to be then removed with pituitary rongeurs. We then use smooth shavers of increasing size, until the proper fit is achieved (again, this is determined both by tactile feel and fluoroscopic guidance). It is of paramount importance to assess the adequate desired height of the anterior, rather than posterior, disc space, since the cage will need to be inserted anteriorly and thus provide a lordotic construct. The smooth shavers of increasing size can be used to open up the disc space, since they will not violate the endplates. Once most of the nucleus pulposus is removed, we proceed with the endplate preparation. We occasionally start with undersized sharp shavers, but most of the endplate preparation is done with wide rasps, so that we don't create troughs that would decrease mechanical resistance and promote subsidence. If the disc has significant lordosis (e.g., at L5–S1), it may seem difficult to insert a large cage (as dictated by the high anterior disc space)

through the small posterior disc opening. In this case, we recommend using a sharp shaver with the same height as the anterior disc space and rotate it against the cage entry point in the posterior disc space; this, of course, requires protection of the lateral spinal sac, but if the annulotomy was started lateral to the spinal sac, usually no dural retraction is necessary. Alternatively, we can use expandable cages. Once the contra- and ipsi-lateral cranial and caudal endplates are prepared, copious irrigation with antibiotic solution is performed, prior to graft and cage insertion.

Cage Insertion

This is perceived as the most difficult step of the case, especially since we recommend inserting a cage approximately 2 mm taller than the anterior disc height. However, if the entry point for the cage is widened by using a sharp shaver of the same size as the anterior disc height, cage insertion becomes safe and easy.

Prior to cage insertion, we pack a large amount of graft material under pressure, in order to maximize the likelihood of fusion according to Wolff's law. In the mix, we use bone marrow aspirate concentrate, demineralized bone matrix, stem cells, and morselized local bone (i.e., medial facet). If bone substitutes were not available, we have used autologous cancellous bone, harvested as described above. Our protocol involves insertion of graft material until it completely fills up the empty space created by the discectomy. We then use a smaller trial (e.g., an 8 mm height trial when a 12 mm height cage will be inserted) to pack the graft and create space for the cage (which will further compact the graft). We occasionally use a larger trial (e.g., 11 mm height trial when a 12 mm height cage will be inserted) to make sure the cage will follow easily. The cage is then filled with graft material and inserted in the intervertebral space. We recommend getting the tip of the cage into the disc space with the cage inserter almost vertical; this way, the risk of the cage slipping between the posterior longitudinal ligament and the spinal sac is minimized. Once the tip of the cage is engaged into the disc space, we then drop the hand laterally, holding the inserter in a lateral to medial fashion, so that the cage crosses the midline inside the disc space.

Regarding cage insertion, several characteristics are important.

- Height. The cage should have a height 2–3 mm larger than the anterior disc height and should be inserted as far anteriorly as allowed by the anterior longitudinal ligament; this provides indirect decompression of the opposite side, decompresses the foramina, and allows for restoration of lordosis, if necessary.
- Position. We try to insert the cage across the midline, for the same reasons mentioned above (although we consider a cage that is slightly off to one side of the midline to be acceptable).
- Length. If additional lordosis is desired, we use a smaller length cage and we compress on the screws (before locking the caps on the rods). Otherwise, we use a lordotic cage that will fit the length of the disc space, without protruding posteriorly.

- Footprint. We currently use straight lordotic cages, but there are many options available. Obviously, the larger the footprint, the better the likelihood of a fusion and the smaller the risk of subsidence.
- Material. We currently use PEEK cages, but, again, Titanium-coated PEEK cages porous Titanium cages, and other combinations, are available and show promise.
- Dynamic (expandable) cages. The advantage of expandable cages is obvious—ease of insertion and, once placed anteriorly, ease of lordosis restoration. The downside is that, once the cage is expanded, the graft material may become loose and, according to Wolff's law, fusion rates may decrease. Therefore, in these cases, we recommend inserting more graft, preferably through the cage, after expansion (aka "backfill" of the cage).

After cage insertion, hemostasis is achieved with Gelfoam and/or Surgiflo. If a small cage was used, we occasionally insert more graft behind the cage, but with care not to have large bone chips potentially backing up against the spinal sac or nerve root.

At the end of the case, before fascia and skin closure, we always check one more time to make sure the bottom of the cage is well below the dural sac and the hemostasis is pristine.

Ipsilateral Pedicle Screw Insertion

We perform this step under direct visualization. First, the lateral to medial angle of the tubular or 2-blade retractor is decreased, since the direction of the pedicles is closer to vertical than the direction of cage insertion. We typically start with the caudal pedicle, since it is easier to cannulate. The entry point for the caudal pedicle screw is identified a couple of mm caudal to the corner created by the drilled edge of the lateral facet, the lateral aspect of the lateral facet, and the shiny medial aspect of the lateral facet. This entry point can also be slightly adjusted in the cranio-caudal direction based on the lateral fluoroscopic image. The cortex is broken with the tip of the high-speed drill and then a pedicle finder is used to cannulate the pedicle in a slight cranial to caudal and lateral to medial direction (each pedicle has slightly different anatomic angles, and we recommend evaluating the direction of the pedicle finder both under the microscope and from a macroscopic standpoint). The cranio-caudal direction is dictated by the lateral fluoroscopic image, whereas the lateral to medial angulation is dictated by the visualization of the lateral aspect of the spinal sac, as well as the general knowledge of pedicular direction and anatomy. When in doubt, an AP fluoroscopic image can be obtained when the tip of the pedicle finder reaches the bottom of the pedicle on the lateral fluoroscopic image, to confirm that the tip of the pedicle finder is still within the ring of the pedicle on the AP image, but this is rarely necessary. Once the tip of the pedicle finder passes the bottom of the pedicle on the lateral image, neuromonitoring is employed to confirm that

stimulation of the pedicle finder at 10 mA yields no response (i.e., there is no medial wall breach). Once the path is created, the pedicle finder is removed and a K-wire is inserted in its place.

The cranial pedicle is slightly harder to cannulate. Sometimes, the tubular or 2-blade retractor has to be angled cranially to expose the entry point for the cranial pedicle. There is a tendency to start the pedicle cannulation too medial, since the exiting nerve is often visualized and the surgeon knows that the pedicle is right above that nerve. We used this technique initially (Video 6.5), but we currently advise against it, because it is difficult to estimate the thickness of the pedicle, especially under microscope. Instead, we recommend further exposure cranially and laterally, until the junction between the cranial transverse process and its corresponding lateral facet is identified. The transverse process base should be clearly identified with a Penfield, including its' cranial and caudal edge. Then, and only then, the entry point for the cranial pedicle screw can be created with the high-speed drill at the above-mentioned junction (slightly riding on the lateral facet). Similar to the caudal pedicle, this entry point can also be slightly adjusted in the cranio-caudal direction based on the lateral fluoroscopic image. The pedicle is then cannulated with the pedicle finder as described above for the caudal pedicle, and another K-wire is inserted at this level.

Once the K-wires are in place, we remove the tubular or two-blade retractor and the rest of the procedure is performed in a similar fashion to the percutaneous technique.

Contralateral Percutaneous Pedicle Screw Insertion

The accurate placement of the percutaneous pedicle screws is dependent of the quality of the radiologic images. Therefore, obtaining true AP and lateral images prior to skin incision is of utmost importance.

The AP image should be obtained first. The C-arm is locked at 90°, perfectly centered on the vertebral body of interest. This is particularly important if the patient has significant deformity, in which case the C-arm should be readjusted for each vertebral body. The spinous process of the vertebral body of interest should be centered between the two pedicle rings; otherwise, the table (NOT the C-arm) should be tilted left or right until the desired position is achieved. Then, the table is placed in reverse Trendelenburg until the superior endplate of the vertebral body of interest becomes a single line (this may not be feasible for S1 if the sacral slope is steep).

The lateral image is obtained next. If the AP image was perfect, now the posterior margin of the targeted vertebral body should appear as a single line. The perfect lateral image is obtained by "wagging" the C-arm until the two pedicles of the vertebral body of interest overlap. At this point, the superior and inferior endplates should also appear as a single line.

After this, the bony landmarks can be marked on patient's skin under AP fluoroscopy: the midline, the left and right pedicle lines, and the interpedicular line for the

vertebral body of interest. The skin incision mirrors the opposite one and should be about 2.5 cm in length, vertical and centered on the interpedicular line, about 4–6 cm off the midline. This point is typically just lateral to the tip of the transverse process on the AP image. In large patients, the skin incision has to be made further lateral, in order to maintain the same lateral-to-medial angle of insertion.

The lumbar fascia is then incised with the knife or Bovie medial to the skin incision. It is important to remember that the fascia is the layer that limits the exploration of the deep bony landmarks. Continuing in the same lateral to medial direction, the index finger can be inserted to find the junction between the transverse process and the lateral facet. Typically, the lateral facet is first encountered (since it is the most superficial), and then the finger is allowed to slide lateral to it and land on the posterior aspect of the transverse process. If the incision is too small to accommodate a finger, the same landmarks can be identified with the tip of a Jamshidi needle, with the aid of frequent fluoroscopic images. The ideal docking point is at the junction of the transverse process with the lateral facet, as medial as allowed by the lateral facet. On the AP image, this point will appear just outside the pedicle ring; if it appears inside the pedicle ring, it is likely that the tip of the needle is actually riding high on the lateral facet, not on the transverse process. On the lateral image, the tip of the needle should be just above the ring of the transverse process, not high on the lateral facet, and the trajectory should pass through the pedicle, parallel to the endplates. If fine adjustments are necessary, the tip of the Jamshidi needle can be moved with both hands (for maximal control) in millimeter increments, on the base of the transverse process, until the desired position is achieved.

Once the correct docking point is obtained, the needle is gently tapped through the pedicle. For the lower lumbar pedicles, the direction is typically lateral to medial and cranial to caudal, but the angles vary with each level (see below). As the needle is advanced through the pedicle, there should be no increased resistance (that would signify cortical bone and therefore imminent pedicle wall breach). The most important images are obtained when the tip of the needle reaches the base of the pedicle on the lateral image; at this time, the tip of the needle should be still within the pedicle ring on the AP image.

At this time, neuromonitoring is usually employed. The shaft of the needle is stimulated, and a response of 10 mA or above signifies that the medial or inferior pedicle walls have not been breached.

A particular situation is encountered if the tip of the needle is very close to the medial border of the pedicle ring on the AP image, and neuromonitoring yields low responses (e.g., 4–7 mA). In this situation, it is likely that the needle has violated the lateral recess, which sometimes loops under the line of the pedicle ring. Therefore, it is recommended that the tip of the needle should be well within the pedicle ring on the AP images, when it reaches the base of the pedicle on the lateral images.

Another important technical tool is changing the direction of the Jamshidi needle while in the pedicle. Indeed, if the original trajectory is angled too much lateral to medial, and the tip of the needle gets too close to the medial border of the pedicle on the AP image, the angulation of the needle can be changed to a more straight trajectory, without withdrawing the needle from the pedicle. The angulation can

also be changed in a cranio-caudal direction, in order to keep the needle parallel to the endplates. Beveled needles are particularly useful in this situation, since they naturally change direction depending on the bevel orientation.

Once the needle trajectory is deemed safe, the tip of the needle is advanced into the vertebral body for a couple of centimeters, and then the center part of the needle is removed and a K-wire is inserted for about another centimeter past the tip of the Jamshidi needle, in order to stabilize it to the cancellous bone and make it less likely to inadvertently come out during the placement of the tap and screw. Then, the Jamshidi needle is removed, while the K-wire is kept in place with the other hand.

After this, most systems have a series of tubular dilators that slide over the K-wire; the outer dilator and the K-wire are kept in place, whereas the inner dilators are removed to make room for the tap and screw. The tap is then advanced over the K-wire into the pedicle of the vertebral body; it is sufficient (and recommended) to tap only past the base of the pedicle and not all the way into the vertebral body. For biomechanical reasons, we recommend undertapping by 2 mm (i.e., use a 4.5 mm tap for a 6.5 mm screw), in order to maintain the good purchase of the screw into the bone. It is important to maintain the direction of the K-wire with the tap; if the tap is not aligned with the K-wire, the part of the K-wire in the vertebral body starts to bend at the tip of the tap, and when a critical angle is reached, the tap cannot advance any more, and any further turns of the tap do nothing but strip (and destroy) the pedicle.

The tap is then removed and the screw (typically 6.5 × 45 mm for the average person) is inserted over the K-wire. Some surgeons prefer to insert all the K-wires in their respective pedicles before inserting the screws. Once the tip of the screw passes the base of the pedicle, the K-wire can be removed, and the screw further inserted through the previously created trajectory. The screw insertion must stop just before the head of the screw abuts the lateral facet; otherwise, the screw head loses its' poliaxial capabilities and makes subsequent rod insertion more difficult. All the screws have extender blades attached to their heads, in order to facilitate rod placement.

The second pedicle is cannulated in a similar fashion. A useful trick, particularly at L5–S1, is to perform the dissection with the index finger by moving it from the entry point of L5 to the entry point of S1; this also creates a working plane over which the rod can be easily inserted.

S1 The S1 pedicle is the largest. The transverse process equivalent in the sacrum is the ala, so the docking point for this level is found at the junction between the sacral facet and the ala. On the routine AP image, the tip of the needle will appear cranial and lateral to the pedicle ring, and just outside of it. On the lateral image, it will appear somewhat caudal. Since the pedicle is so large, there are a couple of options in choosing the entry point. One option involves starting the pedicle cannulation close to its cranial aspect and keeping the trajectory parallel to the endplate; this is the usual placement of screws ipsilateral to an MI TLIF construct, where the entry point is already exposed. The other option involves starting the cannulation more caudally and aim towards the sacral promontorium; this option is used when the distance

between the L5 and S1 screw heads needs to be wider (e.g., for performing an MI TLIF using the pedicle-based retractor technique). It also allows for insertion of longer screws with better bone purchase, since the sacral lip has extremely hard bone.

The S1 pedicle is typically cannulated at 30° in the lateral-medial direction and about 30–60° in the cranial to caudal direction (this angle varies with the sacral tilt).

L5 The L5 pedicle is probably the hardest to cannulate, due to its small size and often sclerotic bone, as well as the fact that the pedicle image is partially masked by the iliac crest on the lateral X-ray. The docking point is usually close to the S1 one, and we prefer to place the L5 pedicle screw as cranial in the pedicle as possible, not only to avoid damage to the L5 spinal nerve exiting around the infero-medial aspect of the pedicle, but also to offer more space between the L5 and S1 pedicle screw heads (e.g., for an MI TLIF using the pedicle-based retractor technique).

The L5 pedicle is typically cannulated at 25–30° in the lateral-medial direction and 10–20° in the cranial to caudal direction.

L4 The L4 pedicle is usually larger than L5 and easy to identify on the lateral image. The L4 pedicle is typically cannulated at about 15–20° in the lateral-medial direction and close to 0° (“straight down”) in the cranial to caudal direction.

Once the pedicle screws are in place, the rod must be placed on top of the screw heads and locked in place. Rod insertion can be done in three different ways, depending on the system.

The first way involves inserting the rod through a separate stab wound (e.g., Sextant/Longitude of Medtronic). One of the advantages of these systems is that it preserves the fascia and soft tissues between the towers. Another advantage (Sextant) is that it provides the most precise spondylolisthesis reduction. Finally, the Longitude system may provide easier navigation of the rod through the multiple towers. The main disadvantage of Sextant is that 2-level fixation is difficult (and 3-level is almost impossible). Another disadvantage is the additional skin incisions made for rod insertion.

The second way involves inserting the rod through either the cranial or the caudal tower (e.g., Revolve of Globus, ES2 of Stryker, Viper of Depuy-Acromed, Serengeti of K2M). The advantage is that it does not need an additional skin incision. The disadvantage is that it is somewhat more difficult to pass through all the towers, particularly in multilevel cases.

The third way involves dropping the rod through the towers (e.g., Spherx DBR of Nuvasive). This can only be done for a maximum of 2-level fusions. The disadvantage is that the tissues between the towers have to be disrupted; however, these tissues are already violated during screw placement. The advantage is that the rod has no overhang, and therefore the adjacent joints (particularly the cranial one) are somewhat protected from further degeneration (at least theoretically).

Regardless of the insertion method, the rod is then locked to the screw heads with appropriate caps. Most current systems have built-in reduction capabilities, which preclude the need for persuaders and can be used to reduce deformity curves. Once the rod is locked in place, the towers are removed from the screw heads and the wounds are closed in layers.

Closure

After removal of the towers, final hemostasis of the muscle is performed with the bipolar cautery at high voltage, under microscopic visualization. We perform a final examination of the spinal sac and the bottom of the cage, and we place Gelfoam over the exposed dura mater. Exparel can be injected in the paraspinous muscles for postoperative pain control.

The would is closed in layers with interrupted 2-0 Vycril on a UR needle for the lumbar fascia, followed by 3-0 Vycril and running subcutaneous 4-0 Monocryl for the skin.

Pearls and Pitfalls

Learning the MI Technique After Extensive Experience with the Open Technique

Most surgeons are initially trained in the open TLIF technique. The main difference with the MI technique, besides the limited field of view, is the angle of approach: in the open approach, the surgeon looks straight down at the laminae, the spinal sac, and the disc, whereas in the MI technique, these structures are approached obliquely. This difference is particularly important at the time of cage insertion. In the open technique, an effort is made to turn the cage in order for it to cross the midline; in the MI technique, just following the direction of the tubular retractor will take the cage across the midline. A common mistake made by the "open" surgeons when attempting their first MIS cases is to try to angle the cage even further; this can lead to insertion of the cage between the posterior longitudinal ligament and the dural sac (especially if the annular opening is not wide enough and the tip of the cage catches the medial annulus) or just anterior to the posterior longitudinal ligament, which of course is a suboptimal position. This is the reason we recommend holding the cage inserter almost vertical until the tip of the cage engages into the annular opening, and then dropping the hand laterally to drive the cage anteriorly in a lateral to medial direction, across the midline.

Skin Incision and Angle of Approach

There is some variability among MIS surgeons in terms of their preference on how lateral to place the skin incision. Obviously, the further lateral the skin incision, the more oblique the angle of approach. This lateral incision makes it a bit more difficult to place the retractor on the lamina and the surgeon has to angle the microscope throughout the case, but the advantages are that the cage is inserted at a more oblique lateral to medial angle, thus requiring less (or no) dural exposure and retraction, and

the pedicle screw insertion is also easier, as the position of the pedicles is more lateral. If the skin incision is placed more medial, it is easier to dock on the lamina, but the laminectomy has to be extended medially and the dural sac has to be retracted in order to insert the cage. We prefer to use this more medial incision in patients with spondylolisthesis, when dural retraction is mandatory to achieve sufficient exposure to insert the cage.

The Pedicle-Based Retractor Technique

This is a variation of the MI TLIF technique in which the pedicle screws are inserted first [2]. We prefer using 2 C-arms for the placement of the K-wires in the respective pedicles, similar to the setup for a kyphoplasty. This technique is particularly useful when performing a 2-level TLIF, since all 6 K-wires can be inserted at the beginning of the case. The pedicle screws on the side of the TLIF have retractor blades attached to them, rather than screw heads; these screws are left slightly proud when inserted, to allow some mobility of the blades (otherwise, if the screws are driven all the way down in the pedicle, the blades hit the lateral facet and become difficult to mobilize). The retractor blades are then lined up with the direction of the disc (based on lateral fluoroscopy) and then locked in place with a rigid arm. The microscope is brought into the operative field and the same elements are exposed, from lateral to medial, as in the tubular retractor technique: the lateral and medial facets, the pars interarticularis, and the lamina. A third retractor blade is typically used medially to hold back the multifidus muscle against the spinous process. The main difference with this retractor is that the angle of approach is more acute than with the tubular retractor; therefore, care must be exercised not to insert the cage too far onto the contralateral side. After the laminectomy, discectomy, and cage insertion, the retractor blades are detached from the screw posts, the screw heads are attached, and the rod with the appropriate caps is locked in place.

L5–S1

This is the most common level to be treated.

We place the patient in reverse Trendelenburg to decrease the angle of view throughout the case.

In patients with a steep sacral slope, the skin incision must be made very high, in order to remain in line with the direction of the disc. In these patients, an effort must be made to insert the shavers against the S1 endplate, as the tendency is for the shavers to hit and damage the L5 endplate.

The L5 lamina is very wide and, if contralateral decompression is not needed, we prefer to place the vertical osteotomy more lateral, towards the medial facet, and only expose the lateral aspect of the dural sac after yellow ligament removal.

This level is particularly important because it provides most of the lumbar lordosis. Therefore, the cage height must be planned to match the anterior disc height, despite the fact that the smaller posterior disc height may make cage insertion difficult. Another option is to use expandable cages.

Additional lordosis can be used by gently compressing on the screws; however, excessive compression on the screws may lead to contralateral L5 nerve compression and radiculopathy, since the contralateral foramen has not been directly decompressed.

Sacral (S1) Posterior "Lip"

This is a common anatomical variation (or result of degeneration), in which a posterior S1 osteophyte ("lip") blocks the access to the disc space. In these cases, we recommend using the high-speed drill to remove the sacral lip starting at the lateral edge of the spinal sac and extending it laterally for about 1.5 cm or until the exiting spinal nerve is encountered. As the drilling continues in the depth, the soft disc material is encountered. This allows for insertion of the shavers and the discectomy is continued as described above.

L4–5

This level can usually be treated by both MI TLIF and LLIF. We prefer using the LLIF whenever possible. However, the MI TLIF must still be used when there is an associated large disc herniation or when the LLIF is not technically feasible.

The L4 lamina is narrower than L5, but typically still allows for a safe TLIF, without much dural sac retraction. However, the vertical osteotomy must be done medially, at the base of the spinous process.

While the L4–5 disc is typically not as lordotic as the L5–S1, an effort must be made at this level as well, to match the cage height to the anterior disc height.

L3–4 and L2–3

We recommend using the LLIF technique to fuse these levels whenever possible. The MI TLIF technique is dangerous at these levels because the lamina is very narrow and significant dural retraction is necessary in order to insert the cage. If MI TLIF must be used (e.g., retroperitoneal scarring), we recommend extensive bony removal, from the medial aspect of the lamina to the lateral aspect of the lateral facet, and spinal sac retraction to allow for insertion of an adequate size cage.

Spondylolisthesis

These cases are more difficult because the exiting spinal nerve often limits the space available for cage insertion laterally. Therefore, in these cases, we make room by retracting the spinal sac medially. This is done by performing a full hemilaminectomy, i.e., the vertical osteotomy is made at the base of the spinous process and the yellow ligament is removed over the entire half of the exposed spinal canal. Once the epidural veins are coagulated and transected, the dural sac is retracted medially with a nerve root retractor and increasing size smooth shavers are used to perform the discectomy.

It is important to angle the shavers towards the caudal endplate (e.g., the S1 endplate for the L5–S1 disc), otherwise the shaver may hit the back of the slipped cranial vertebral body (L5 in the example above). The same angulation towards the caudal endplate is maintained when inserting the trial and then the cage. This is a good indication for expandable cages, since the available space for insertion is limited and, particularly at L5–S1, a large lordotic cage must be placed in the anterior disc space.

Once the cage is in place, the spondylolisthesis is already partially reduced. The case is finished by using the percutaneous pedicle screw reduction system to complete the realignment.

Previous Discectomy

Patients who had a previous open discectomy and need a fusion at that level may benefit from the MI technique. In fact, because of the different angle of approach, the MI TLIF can be performed almost identically to a non-operated patient. The only part where the surgeon may encounter some scarring is at the time of the medial facetectomy, since the yellow ligament was probably removed at the time of the initial discectomy.

Collapsed Disc

When the disc is almost completely collapsed, or when there is a shell of calcification or cortical bone covering the annulus, it may seem difficult to access the disc. In these cases, we use the high-speed drill to remove a thin layer of bone along with the osteophytes (if present) starting at the lateral edge of the spinal sac and progressing laterally for about 1.5 cm. This allows for exposure of the posterior-most aspect of the two hard surfaces of the cranial and caudal endplates. We prefer to insert the smallest smooth shaver (5 mm height, if available) both in the contralateral disc space as well as the ipsilateral one. If the disc space does not open to make room for small shaver, we have used an osteotome instead, just to allow for the subsequent insertion of the shavers. We then use smooth shavers of increasing size, to open up the disc space without violating the endplates. It is important to insert the shavers as deep as possible,

without violating the opposite annulus of course, in order to have increased leverage when opening up the disc space by turning the shavers. Often times, a 10 mm height cage is sufficient in these cases, since their starting disc height is less than 5 mm.

Normal Height Disc

These are typically patients with pars defects and grade 1 or 2 spondylolisthesis, but with preserved disc height and often with large disc herniations.

Obviously, the higher the disc, the more difficult it is for the graft to turn into bridging bone between the two endplates. We compensate in these cases by preparing a large fusion surface (both on the contra- and ipsi-lateral sides) and of course by thoroughly preparing the endplate surfaces. It is not uncommon to pack 10–15 cc's of graft before inserting the cage in these cases. Finally, the cage needed is often 15 or 16 mm in height.

Two-Level MI TLIF

Most commonly, this is done at L4–5 and L5–S1. The advantage is that both levels can be done through the same skin incision, since only the angle of the retractor changes from one level to the other.

If the *tubular retractor* is used, we prefer to start with the L5–S1 level. Once the cage is inserted, we recommend cannulating the S1 pedicle as described above and leaving a K-wire in. The retractor tube is then removed and reinserted to expose the level above (L4–5), leaving the S1 K-wire outside the retractor. The L4–5 TLIF is then performed and the L5 and L4 pedicles are cannulated as described above. K-wires are placed in these pedicles as well, and the retractor is removed and the procedure is completed in a percutaneous fashion.

If the *pedicle-based retractor* is used, the retractor blades are placed on the cranial and caudal screw posts (on the L4 and S1 screw posts in the example above). The L5 screw post is also inserted in the L5 pedicle, but without the head, since that would interfere with the exposure and cage insertion. The TLIFs are then performed through the same retractor, by adequately changing the direction of the retractor for L5–S1 and then L4–5. The screw heads, the rod, and the caps, are all placed at the end of the procedure, after the TLIFs are done.

Unilateral Pedicle Screws

The literature suggests that unilateral fixation after TLIF is not biomechanically as strong as the bilateral fixation, but the clinical results are similar. We occasionally recommend MI TLIF with unilateral, ipsilateral, pedicle screw fixation, in young

patients who have good quality bone, have a large amount of osteoprogenitor cells in their bone marrow, and are likely to fuse in record time. In these cases, we often insert long screws with bicortical purchase.

Direction of the Pedicle Screw Heads

Regardless of the technique used, just before the final tightening of the caps on the screw heads, we recommend bringing the screw heads as close to the midline as possible, so that they can be easier to access, in case an open approach is needed in the future (e.g., to extend the fusion cranially or caudally).

Postero-Lateral (Intertransverse) Grafting

We only perform postero-lateral grafting in patients at high risk for non-union (e.g., smokers). The ipsilateral grafting is easy, since the base of the transverse process or ala are already exposed and slight angulation of the retractor laterally allows for exposure of the entire length of the transverse process or ala, followed by decortication and graft placement.

The contralateral side can only be grafted if the minimally invasive retractor is used to expose the transverse processes (or sacral ala). In these cases, the screws can be inserted similarly to the ipsilateral side, with the entry points started with the high-speed drill under direct visualization.

Complications

Dural Tear

Inadvertent durotomies can occur, particularly in difficult cases (spondylolisthesis, extreme degeneration etc). Due to the limited exposure, a direct repair with 4-0 Nurolon is rarely feasible. We prefer to temporarily cover the durotomy with a Gelfoam and patty, and complete the TLIF. At the end, we place a small piece of DuraGuard or DuraMatrix over the durotomy and then cover with DuraSeal. Most often, due to the sealing effect of the muscle, a CSF fistula is not observed. In the few cases in which a CSF fistula does occur, we prefer placing a lumbar drain for 5–7 days, rather than re-exploring the wound.

Nerve Injury

The nerve structure most frequently injured, particularly if spondylolisthesis is present, is the exiting spinal nerve (e.g., the L4 nerve when performing an L4–5 MI TLIF). The reason is that this nerve is relatively fixed against the corresponding pedicle and therefore cannot be retracted out of the way. The only way to protect this nerve is to limit the annulotomy just medial to the exiting spinal nerve and extend it medially under the spinal sac, if needed to insert a larger cage. In patients with grade 2 spondylolisthesis, this maneuver still allows for insertion of an appropriate size cage, whereas in grade 3 or 4, there is not enough space, hence the relative contraindication.

Another possible nerve injury can be caused by excessive compression on the screw heads. The injury typically occurs on the contralateral side, where the nerve was not directly decompressed by facetectomy.

Finally, the exposed dura mater can be compressed by a postoperative hematoma (particularly if a dural tear occurred, allowing for the CSF pressure to decrease and potentially allow the epidural veins to bleed in the postoperative period). If the dura was extensively exposed (e.g., in patients with spondylolisthesis or if contralateral decompression was necessary) and a postoperative compressive hematoma occurs, a cauda equina syndrome can ensue. That is the main reason we recommend limiting the dural exposure to the minimum necessary. In most cases, only a small area of the lateral spinal sac needs to be exposed, so even if a postoperative hematoma occurs, only minimal or no deficits would ensue.

Misplacement of Ipsilateral Pedicle Screws

This is rare and usually occurs at the cranial pedicle, due to an entry point that is too medial (i.e., the entry point is chosen on the drilled aspect of the former pars interarticularis rather than at the junction between the transverse process and lateral facet. Besides AP fluoroscopy, showing the medial position of the tip of the pedicle finder, neuromonitoring also signals the problem by yielding values of less than 10 mA. If only the Jamshidi needle was inserted, the solution is simple – a new entry point is chosen at the correct location and a new, proper trajectory is created. However, if the pedicle screw was inserted in the incorrect position and the pedicle is small (e.g., L5), it may be impossible to create a second trajectory lateral to the original one. In these cases, a "cortical screw" trajectory can be attempted, starting medially at the junction between the pars interarticularis and the lateral facet and aiming "up and out", similar to the cervical lateral mass screws. This maneuver is difficult with tubular retractors and slightly easier with the two-blade retractor.

Massive Blood Loss

This is a rare and unfortunate complication that results from damage to the great abdominal vessels after penetration of the anterior annulus fibrosus by sharp or biting instruments. While we have not encountered this complication, it is recommended that, if vascular damage occurs, the patient should be turned immediately in supine position and abdominal exploration, preferably by a general or vascular surgeon, should be performed in order to stop the bleeding.

Construct Failure

This complication refers to migration of the screws into their respective pedicles and occasionally re-slippage after a reduced spondylolisthesis. The treatment has to be individualized depending on the characteristics of each case, but typically involve additional levels of fixation.

Cage Retropulsion

This complication is rare and involves delayed migration of a cage posteriorly. If the cage was inserted without any dural retraction, its' posterior migration may remain asymptomatic, as no neural structures are stretched. However, if the bottom of the cage elevates or medially displaces the traversing spinal nerve (e.g., the S1 nerve for an L5–S1 TLIF), the patient will experience radiculopathy in that distribution. In these cases, we recommend re-exploring and removing the cage through the same incision, followed by an alternative way to insert an interbody graft (e.g., ALIF for L5–S1 or LLIF for L4–5) (Fig. 6.1).

Pseudarthrosis

With proper technique, less than 10% of the MI TLIF patients should experience pseudarthrosis. Symptomatic patients can be revised by either an alternative way to insert an interbody graft (e.g., ALIF for L5–S1 or LLIF for L4–5) or by the addition of a postero-lateral, intertransverse, fusion (in which case we typically use rhBMP).

Adjacent Level Disease

This is a delayed complication that typically occurs at least 5–10 years after the original fusion. Before addressing the respective level with a fusion, we recommend obtaining standing scoliosis films, to confirm that the adjacent level failure is not related to positive sagittal balance.

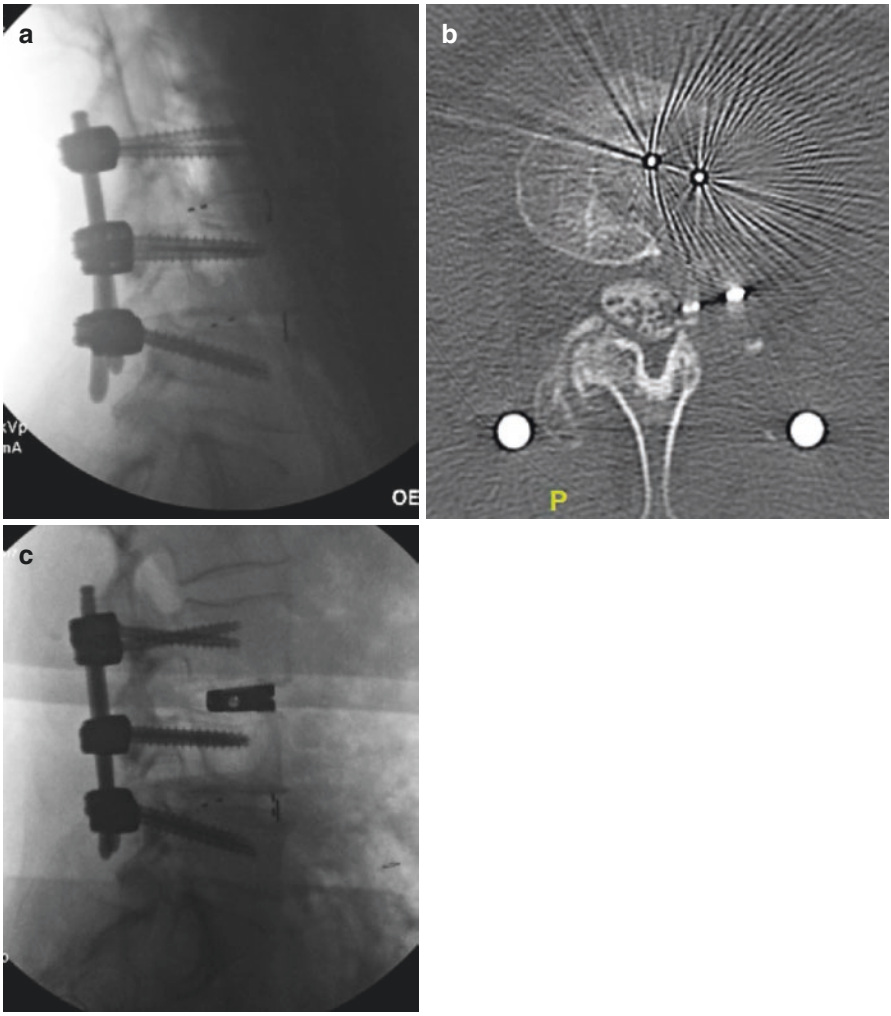

Fig. 6.1 Cage retropulsion at L3–4 after MI TLIF at L3–4, 4–5. (**a**) Intraoperative imaging showing adequate placement of the instrumentation. (**b**) Imaging at 3 months postoperatively showing retropulsion of the L3–4 cage. (**c**) Intraoperative imaging showing removal of the L3–4 cage (through the same incision) and placement of an MIS lateral expandable cage

Literature Review

There are many retrospective studies comparing MI versus open TLIF, with most of them showing MI TLIF advantages, including: decreased blood loss, decreased infection rate, decreased postoperative pain medication usage, lower cost, and shorter hospital stay [3–10]. These retrospective studies are prone to selection and recall bias, however.

Wang et al. [11] published the results of a prospective randomized study and concluded that the patients in the MI group experienced less sacrospinalis muscle

injury, resulting in early functional recovery and superior short-term treatment effects. However, they found similar long-term efficacy for the two groups.

We published some of our results in a prospective randomized study [12]. The only significant benefit we found was the shorter hospital stay. This likely explains the cost savings found in previous studies, as reduction in stay by just one day can save upwards of $3000 in an American hospital.

Nonetheless, patients seem to favor the MI technique, when the two options are offered. In addition, as surgeons become more familiar with the minimally invasive techniques, operative time & blood loss decrease while outcomes improve [13].

Conclusions

When compared to the open TLIF, the MI TLIF technique offers similar clinical improvement and fusion rates, but with shorter hospital stay.

Addendum: Informative Letter to the Patients

The following informative letter is NOT intended to cover ALL the possible complications and scenarios. It is only intended to serve as a general guide, to improve patients' understanding of the operation.

This procedure can be very long. Despite careful padding of all pressure points, abrasions and pressure sores can occur. Generally these are minor, but can be serious, especially if they occur on the face. Nerve damage, particularly at the joints, can also occur. Blood clots forming in the legs, with potential death from spread to the lungs, are always a worry, and we use special inflatable devices to minimize that risk. Blood loss during this kind of surgery is normal and unavoidable, and sometimes we need to give transfusions from the blood bank. All of the blood is carefully tested, but unfortunately no test is perfect and there is always a small risk of acquiring some disease, such as hepatitis or AIDS. Death from anesthesia reaction or massive blood loss is possible, but fortunately extremely rare.

We make a one-inch skin incision in the lower back, usually on the side of the worse leg pain. Before we go to the spine, we use this incision to take a small amount of your pelvic bone with a special device that preserves the outer part of the bone and minimizes pain after surgery. Nevertheless, it is common to experience pain and soreness at the site where bone graft has been harvested. Sometimes this is permanent. Damage to small nerves in the area can lead to numbness or even pain over the buttocks.

We then reach the spinal column with a small tube, under x-ray guidance. At this point, an operating microscope is used to allow us to keep the incision as small as possible, yet have excellent vision so we can see what needs to be done. We remove some of the bone in the back of the spine (i.e., laminectomy and facetectomy) and

then we remove the bad disc or discs and prepare the area to accept the fusion construct. If pinched nerves are present causing pain in the legs, then bone and disc material is removed as needed to take the pressure off of the nerves. When previous surgery has been done, scar tissue is always present. Sometimes this scar tissue can be very thick and tough, and getting through it to find the nerves increases the risk of nerve damage and spinal fluid leakage. After we take out the disc, we replace it with a synthetic box we call "cage" that is filled up with bone graft and will promote the bony fusion. We are careful to avoid damage to the nerves in the spinal canal, which are very close to our "working area". However, such damage (while very rare) is a risk and can result in paralysis from nerve damage, loss of bowel, bladder, and sexual function, numbness, lack of feeling or sensation, or even severe pain below the waist. X-rays are used throughout the procedure to maximize the safety.

In order to give instant strength and stability to the spine and to increase the probability of the natural bony fusion healing properly, we use metal screws and rods. We place the screws accurately with the aid of intraoperative x-ray guidance. Nerve or blood vessel damage is possible, but fortunately quite rare. These devices function as an internal cast to keep the spinal bones immobile while the bone cells are forming the fusion mass. (If you're gluing two pieces of wood together, the glue is more likely to stick if you keep the wood pieces in a vice until the glue is set.) The screws and rods have been engineered and designed for endurance, but if a natural bony fusion does not form, eventually they will work loose or break. Another risk of any type of implanted foreign (non-natural) body is the possibility of infection. If this occurs (which is rare) it is early, and not months or years later. Generally removal of the screws is not necessary (to treat the infection), but prolonged antibiotics and debriding (cleaning up) procedures could be required.

It is important that you understand that this is a serious and possibly painful operation with a long and slow recovery. Most frequently, after the surgery you will be moved from the recovery room to a normal hospital room. Occasionally, if the surgery takes longer than a few hours, you may need to be monitored in the intensive care unit. Sometimes the intestines are sluggish for a few days and until you begin to "pass gas", your intake of food may be restricted. We encourage you to walk with assistance as soon as possible, and it is hoped that the total hospital stay will be in the range of 1–4 days. Of course, this is varied as needed on an individual basis.

At home we would encourage a program of walking on a level surface, gradually increasing the distance to between 2 and 3 miles a day. At about 3 months, a home exercise regimen can be cautiously started. Return to daily activities is highly variable, but in general it is sometimes possible to return to the equivalent of a light office type job at about that time (3 months). Maximal medical improvement is generally reached around a year after the date of surgery. It is generally not advised to engage in heavy manual labor type occupations following an operation of this nature.

Over the 6–12 months after surgery, it is hoped that the operated discs will heal and grow into a strong bony mass, so as to cause a solid union between the bones. This is a gradual process and at first there is no increased strength. This healing process is dependent upon the patient's powers of healing and does not always occur properly. The use of nicotine in any form (cigarettes, smokeless tobacco, nicotine

patches, or nicotine gum) interferes with bone healing and dramatically decreases the odds of a successful fusion. You should not smoke or use nicotine in any form! Generally about 3 months is required for the fusion to begin to set, but strengthening continues for about a year or more. Also, for the first several months after surgery it is best to avoid non-steroidal anti-inflammatory drugs (such as aspirin, Motrin, Aleve, Naprosyn, etc.). These medications may interfere with bone healing. Tylenol use is OK, but you should be careful not to exceed the recommended dose. We expect to achieve a successful fusion for one disc level in about 90% and for two levels in about 80%. Sometimes postoperative x-rays show that the fusion has not healed to form solid bone. Most of the time, this does not seem to matter because a tough scar tissue-like gristle has formed instead and there are no symptoms. Occasionally, however, the failed fusion is symptomatic. That is called a pseudoarthrosis and repeat surgery is sometimes required. The type of surgery in those cases depends on individual circumstances.

Major complications (life threatening) may occur in about 2% of cases. The most common major complication is implant malposition or migration and may require reoperation. Sudden massive blood loss could occur, resulting in death. Other major complications include pneumonia and pulmonary embolism (blood clot going to the lungs).

There is also the chance that another type of fusion operation will be required if this one does not heal solidly. For example, it might be necessary to perform an additional operation in the side or front of the spine, with more bone graft added at that time. In some patients, only 360° (front and back) fusions are sufficient to give adequate strength for their particular spinal problem.

One last potential problem after fusion surgery is what we call "juxtafusional disease". After you have had a successful spinal fusion, that segment becomes immobile and the joints above and/or below that fusion are subjected to increased stress. Over the years, these joints can have problems that may require further surgery.

It is very important to emphasize that no operation or device is a "spine transplant". Results on an individual basis cannot be predicted, and therefore we certainly cannot give any guarantees or promises. Once you have a bad back, you always will have a bad back to some degree. You could be no better, or even worse. Most patients indicate that *on average* the pain is improved from "marked" to "mild". While this is a great improvement, it is usually not improved to "occasional" or "none". Whether you will be able to return to their pre-injury or preoperative level of functioning will have to be determined on an individual basis. As a general rule, it is about a year before patients are "over" the operation because recovery and reconditioning is a slow process. It is sometimes necessary to call upon the Departments of Physical Medicine & Rehabilitation and Occupational Medicine to perform functional capacity evaluations (FCE) to determine a patient's actual limitations and abilities.

My general advice to anyone with a spinal affliction of this nature is to "live with it "(if possible). Of course that's easy for me to say because I'm not the one hurting. This operation has been recommended in the belief that your condition is serious and therefore taking the risks of surgery makes sense. I believe this is a good opera-

tion that is the best choice for your particular problem. If your only affliction is pain, the decision is yours and yours alone as to whether you can live with it. While I obviously hope and believe that this operation will help you, I cannot give any guarantees or promises about results. It is possible that you could be the same or even worse. Furthermore, my general recommendation is to "live with it" if possible and avoid the risks and uncertainties of surgery. Nevertheless I am offering my surgical services in an attempt to help you, but the decision to proceed is up to you.

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