In recent years, there has been an unprecedented increase in the number of patients undergoing treatment with interbody fusion devices for degenerative disease of the lumbar spine. These devices can be placed either anteriorly or posteriorly. With the advent of minimally invasive surgery and the increasing ability of general surgeons to perform transperitoneal procedures laparoscopically, a new laparoscopic technique has been developed for placing lumbar interbody fusion devices. Although this procedure has some advantages over posterior lumbar interbody fusion, it is not without significant risk, and the learning curve is steep. The authors review a series of 32 consecutive patients who underwent single-level laparoscopic anterior lumbar interbody fusion at L4--5 or L5--S1 over a 2-year period for the treatment of single-level lumbar degenerative disease. In this report they review the technical aspects of the procedure and the important lessons they have learned through their early experience with this technique.

Key Words * laparoscopy * minimally invasive surgery * spinal fusion * threaded interbody fusion cage

The advent of minimally invasive surgery has challenged spine surgeons to refine and perfect less invasive procedures that have comparable or superior treatment outcomes compared with standard open techniques. The goals of these procedures are to decrease hospitalization time and to provide a faster return to functional status for patients. These goals are attained by achieving the same operative result but by making smaller incisions and reducing the extent of tissue dissection. The development and refinement of laparoscopic intraperitoneal surgery has offered spine surgeons new opportunities for anterior approaches to the lumbar spine.[25,29,31]

In previous reports investigators have documented that anterior lumbar interbody fusion (ALIF) decreases perioperative blood loss and eliminates nerve root retraction compared with posterior procedures (unpublished data). It has also been shown that ALIF procedures are associated with shorter operating times than posterior lumbar interbody fusion (PLIF) procedures with or without placement of pedicle screw instrumentation.[24] These advances have led to shorter hospitalization times and
comparable fusion rates.[23,24]

Presently, the standard approaches for ALIF include transperitoneal or retroperitoneal exposure for interbody fusion at L4--5 and L5--S1. More cephalad lumbar levels may also be accessible. The development of laparoscopic ALIF has allowed the spine surgeon to place interbody fusion devices via smaller incisions and to cause less bowel irritation with postoperative ileus. Laparoscopic ALIF represents a viable alternative to standard open transperitoneal approaches. We review our preliminary experience with laparoscopic ALIF in a series of 32 consecutive patients and describe the lessons learned as this procedure has developed at our institution.

**CLINICAL MATERIAL AND METHODS**

Over a 2-year period a total of 32 patients underwent single-level laparoscopic ALIF at the L4--5 or L5--S1 interspace. Operative candidates included patients with degenerative disc disease characterized by segmental disc degeneration with Modic changes with or without foraminal stenosis demonstrated on magnetic resonance (MR) imaging and with a clinical history of mechanical low back-pain with or without leg pain. Other candidates included patients with degenerative lumbar instability, spondylolisthesis classified as less than Grade II, postsurgical spinal instability, and pseudarthrosis after attempted posterior fusions (Fig. 1 and Table 1).

![Fig. 1. Sagittal MR image with long TR sequence demonstrating Grade I spondylolisthesis with a collapsed disc space in a patient with intractable back pain.](image)

Conservative therapy, including any combination of nonsteroidal or narcotic medications, physical
therapy, or other local pain procedures, had failed in all patients. Provocative discography was used only in patients when the symptomatic level was in question. In those patients, needles were placed into the disc of interest as well as in adjacent disc spaces, which served as a control. Sterile saline solution or contrast material was injected. Discograms were considered "positive" only if the injection recreated the patient's pain at the appropriate level of interest. Additionally, injection at adjacent levels had to produce either no pain or "discordant" pain. Some patients also underwent diagnostic facet blocks to help confirm the pathological level. Patients with discordant pain dissimilar to the their chief complaint in terms of location and intensity were not considered appropriate candidates, did not undergo surgery, and were not included in this analysis. Patients in whom there was evidence of posterior pathological process such as a disc fragment within the canal, facet hypertrophy, lateral recess or central spinal stenosis, a history of multiple abdominal procedures, or severe large vessel atherosclerosis were not considered good candidates for surgery and also were not included in this study (Table 1).

![Table 1: Indications and contraindications for laparoscopic ALIF](image)

**OPERATIVE TECHNIQUE**

**Patient Positioning**

The patient is placed supine on a radiolucent table. Equipment in the room is positioned to allow the surgeon an optimum view of both the c-arm camera and the video monitor (Fig. 2).
Fig. 2. Schematic diagram of the operating room setup with video-assisted monitors and fluoroscopic equipment in relation to the surgical team.

Pillows are placed under the patient's hips to accentuate lumbar lordosis at the lumbosacral junction and beneath the knees to prevent hyperextension. The arms are placed at the patient's side, low enough to prevent interference with the fluoroscopic view (Fig. 3). Straps are placed on the patient's ankles to prevent sliding because a steep Trendelenburg's position is required during the procedure to allow the abdominal viscera to move rostrally out of the pelvis. A nasogastric tube and foley catheter are placed to decompress the stomach and bladder, respectively. Both catheters are usually removed at the completion of the procedure.
Operative Technique

Nonsteroidal agents are discontinued at least 1 week prior to surgery to minimize blood loss and to promote fusion. The bowel preparation consists of one bottle of magnesium citrate taken the night before surgery. Patients are advised that the procedure routinely includes the possibility of an open laparotomy in the event of uncontrolled bleeding or poor visualization of the lumbar spine, in addition to other potential complications (Table 2).

Prior to exposure it is essential to obtain a template of the proper-sized interbody implant based on an adjacent normal disc space as demonstrated on a preoperative lateral lumbar radiograph. We create a
template based on an adjacent normal disc space seen on preoperative lateral radiograph. Axial computerized tomography or MR imaging templates can also be used to confirm that the selected implants fit properly within the confines of the diseased disc space. The implant size should approximate the disc height of the adjacent normal interspaces and also account for the space required by reaming and tapping into the cortical endplates. This allows for the appropriate annular tension to maintain the interbody implant under compressive forces.

The patient is prepared and draped in sterile fashion. Autologous bone is harvested from the anterior iliac crest, usually on the right side, at the beginning of the procedure. Prior to insufflation, an incision line centered on the midline approximately 1 to 3 cm wide above the pubis is marked. The fluoroscopic equipment is then brought into place before the incisions are made to verify the midline. It is important to obtain adequate fluoroscopic views for proper intraoperative visualization of the vertebral bodies and to estimate trajectory.

Four incisions are used. The two lower paramedian incisions allow placement of portals for the working forceps (Fig. 4). The incision for the interbody channel and devices is centered over the midline suprapubic region and measures 2 to 4 cm in length. The viewing camera is placed through the curvilinear umbilical incision and is held by a robotic arm (AESOP; Computer Motion Inc., Goleta, CA). This robotic arm responds to verbal commands from the laparoscopic surgeon and moves the camera to the specified position. This allows the surgeon two free hands with which to place the instrumentation.

Fig. 4. Diagram showing the four routinely made incisions. Two paramedian incisions provide conduits for the working forceps. The viewing camera is placed through an umbilical incision. The working channel is placed through a midline suprapubic incision measuring 2 to 4 cm in length.
As the bone graft is harvested from the iliac crest, the laparoscopic surgeon gains entrance, and the abdomen is insufflated. The patient is placed in a steep Trendelenburg’s position to mobilize the abdominal contents out of the pelvic inlet. If necessary, the sigmoid colon is tacked to the abdominal wall to gain better exposure.

Adequate disc space exposure is critical. The sacral promontory is identified by palpation and confirmed by fluoroscopy. The peritoneum is then opened sharply. In male patients, the unipolar cautery should be avoided and a blunt Kittner dissector is used with a gentle sweeping motion to mobilize the presacral sympathetic plexus. This maneuver may decrease the incidence of retrograde ejaculation, which is a known complication associated with anterior approaches. In female patients, monopolar electrocautery can be used to expose the anterior face of the vertebral bodies and disc space.

The first anatomical structures seen are the middle sacral artery and vein (Fig. 5 left). Although these vessels do not reliably predict the midline of the vertebral body, the preoperative MR images may demonstrate their relationship to the midline.[10,16,26] The preoperative axial images should be examined for the presence of eccentric anterior osteophytes, which may indicate to the surgeon a false localization of the lateral convexities. The middle sacral artery and vein are ligated and divided (Fig. 5 right). The anterior curvature of the lumbosacral junction is palpated as are the left and right lateral convexities in conjunction with intermittent fluoroscopy to identify the midline further. The left iliac vein protrudes more anteriorly and may require more retraction. If the midline cannot be accurately identified, the surgeon should consider an open conversion because higher rates of complication are more likely.

After confirmation of the midline, the instrumentation placement phase can begin. Depending on the instrumentation system, the entry sites for the trephines are prepared. In laparoscopic approaches for interbody fusion the surgeon may use titanium BAK cages (SpineTech, Minneapolis, MN), allograft

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![Fig. 5. Diagrams. Left: Laparoscopic view of the vascular anatomy of the lower lumbar region. In the artist's depiction the middle sacral artery and vein appear on the midline; however, this is not a reliable landmark to determine the midline. Right: Laparoscopic view of the L5--S1 interspace demonstrating clip ligation of middle sacral artery and vein](image-url)
bone dowels (Regeneration Technologies, Alachua, FL), and the titanium Interfix cages (Medtronic Sofamor Danek, Memphis, TN). Lordotic threaded titanium cages (Novus; Medtronic Sofamor Danek) cages are currently under investigation and have not been FDA approved. The trephine is used to core out soft disc material in each paramedian entry site. The trephine should enter the disc space in a trajectory parallel to the endplates to avoid eccentric placement of cages into the vertebral bone. The largest trephine possible should be used to optimize maximal disc material removal. Additional disc material is removed using pituitary rongeurs.

Progressively larger distractors are then tamped into the disc space to restore the disc height to the appropriate level and to provide tension for the annulus fibrosis (Fig. 6 left). Once a distractor is in place on one side, the remaining disc material and subjacent cortical bone on the opposite side is removed using a reamer. It is better to ream to a depth longer than the length of the selected interbody implant to allow placement of additional bone graft anterior to the interbody device and to allow countersinking of the implant, if desired. Underreaming may promote stripping of the threaded pattern during attempted tapping. This occurs because the tap is prevented from advancing by the presence of residual disc material deep in the posterior disc space. The holes are then tapped to the premeasured depth. The implant is inserted in proper alignment (Fig. 6 right).

Additional bone graft is packed anterior to the device. This promotes additional bone fusion and allows the surgeon to assess the presence of a solid arthrodesis with anterior bone bridging on follow-up radiological studies. These steps are then repeated on the contralateral side after removing the distractor plug. Ideally the collapsed disc space should be distracted by the implant to reapproximate its original size (Fig. 7).
Fig. 7. Left: Intraoperative predistraction lateral radiograph demonstrating severe disc space collapse at L5--S1 with degenerative spondylolisthesis. Right: Intraoperative postdistraction radiograph obtained after placement of threaded cortical bone dowels at L5--S1.

Anteroposterior (AP) and lateral fluoroscopic views are obtained to verify proper positioning of the device. The peritoneum is closed using clip ligation, and the abdominal wall incisions are closed with interrupted absorbable suture.

**Postoperative Care**

Patients are mobilized early and are allowed to ambulate on postoperative Day 1. The diet is advanced as tolerated, provided there are adequate bowel sounds present. A hard or soft lumbar orthosis is used, depending on the degree of preoperative spinal instability, the presence of osteoporosis, and size of the patient. Patients usually are discharged on postoperative Day 2. Postoperative radiographs are obtained prior to discharge, as well as at 6 weeks, and 3, 9, 12, and 24 months. The determination of a solid arthrodesis can be problematic. A distinction must be made between "stability" and "arthrodesis." In previously published studies of titanium cages the authors classify successful "fusion" as the absence of lucency around the implant and absence of movement on flexion--extension films.[21,22] The presence of bone within the cage, however, does not necessarily imply solid arthrodesis. Solid bridging bone (between the vertebral endplates) anterior to the cage may signify a solid arthrodesis. We believe evidence of fusion is best demonstrated on reformatted fine-slice sagittal computerized tomography scans that reveal: 1) incorporation of cancellous bone within the cage/dowel, 2) subchondral increase in endplate sclerosis, and 3) a solid arthrodesis in the bone graft placed anterior or posterior to the cage/dowel. With allograft cortical bone dowels incorporation of the threads can be seen, combined with a progressive diminution in the "halo" demonstrated on the AP radiographs. An advantage to using bone dowels is that they allow a more direct assessment of arthrodesis. Evidence suggesting pseudarthrosis on plain AP and lateral radiographs includes lucency around the device, persistent movement at the level at which instrumentation was placed, or lack of a solid bone mass. Movement can be defined by translational change in position or change in angulation of the disc space on flexion--extension lateral
Procedure-Related Complications

In our series of 32 patients there was one case of disc space infection with a bone dowel that was successfully treated with intravenous antibiotics. Early in our experience there was one case of nerve root contusion following lateral cutout of the disc space. This occurred because we had not properly selected the exact midline from the start of the case. Two cases of iliac vein thrombosis requiring anticoagulation were believed to be caused by retraction of the vessels. Three of 15 male patients reported retrograde ejaculation at their most recent follow-up visit. Two other procedures were converted to open transperitoneal approaches for adhesions, and one for better visualization of a spinal deformity. There were no procedural conversions necessitated by bleeding.

Although not encountered in our series, other major procedure-related complications include vascular injury requiring conversion to an open procedure to control bleeding. Minor complications reported in the literature include ileus and retrograde ejaculation. There has been no series in which the authors report problems with impotence or inability to achieve orgasm. We believe it is important to inform the male patient preoperatively regarding the risk of retrograde ejaculation.

DISCUSSION

Zucherman and colleagues[32] were the first to perform the technique of laparoscopic anterior interbody fusion. In their first reported series of 17 patients, they experienced three technical complications, two of which required conversion to open laparotomy secondary to venous bleeding from the middle sacral vein. Subsequently, numerous reports of this technique have been described.[1-9,11-15,17-20,27,28] Zdeblick[30] demonstrated higher fusion rates and shorter hospitalization and return to work times in a prospective randomized series in which they studied two posterolateral fusion techniques: rigid pedicle screw instrumentation with and without interbody grafting as compared with laparoscopic BAK fusion cages.[31] Their study confirmed significant cost advantages and outcomes compared with posterior open techniques in patients with L5--S1 disc disease.

When comparing results relative to interbody fusion, it is important to understand the difference between fusion and spinal stability. Evidence of fusion is based on the radiographic findings discussed previously such as increase in subchondral endplate sclerosis, bridging bone incorporating the anterior bone graft, and diminution in the "halo" seen on AP radiographs. Evidence of stability is based on radiographic findings of nonmovement on flexion--extension radiographs. It may be possible to have a stable construct without fusion. Stability rates for threaded interbody cages appear excellent and approach 98% at 3 years in the BAK series. Several large clinical trials have demonstrated marked improvement in pain.[10,21,22]

CONCLUSIONS

Laparoscopic ALIF is a safe and effective method for placing threaded cylindrical lumbar interbody implants.[12,22,30,32] The benefits of this procedure over posterior fusion procedures include the elimination of nerve root retraction and potential dural injury. Because less muscular dissection is required, there is decreased blood loss and postoperative pain. The drawbacks of the procedure include a steep learning curve and the low, but real, incidence of retrograde ejaculation in male patients. Larger series in which long-term follow-up evaluation is conducted will bear out whether one procedure is superior to another or whether they are complementary techniques. Keys to avoiding complications...
include proper identification of the midline, applying an initial "toe in" force to discourage lateral cutout, and having the flexibility to convert to an open approach in the event of inadequate exposure. Laparoscopic fusion in which stand-alone interbody devices are used may have limited success in treating patients with mobile instability and/or high-grade spondylolisthesis. In these cases, supplemental posterior stabilization should be considered.

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