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Minimally invasive 360° instrumented lumbar fusion

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Abstract A retrospective preliminary study was undertaken of combined minimally invasive instrumented lumbar fusion utilizing the BERG (balloon-assisted endoscopic retroperitoneal gasless) approach anteriorly, and a posterior small-incision approach with translaminar screw fixation and posterolateral fusion. The study aimed to quantify the clinical and radiological results using this combined technique. The traditional minimally invasive approach to the anterior lumbar spine involves gas insufflation and provides reliable access only to L5-S1 and in some cases L4-5. A gas-mediated approach yields many technical drawbacks to performing spinal surgery. A minimally invasive posterior approach involving suprafascial pedicle screw instrumentation has been developed, but without widespread use. Translaminar facet fixation may be a viable alternative to transpedicular fixation in a 360° instrumented fusion model. Past studies have shown open 360° instrumented lumbar fusion yields high arthrodesis rates. The study examined the cases of 46 patients who underwent successful 360° instrumented lumbar fusion using a combined minimally invasive approach. Anterior lumbar interbody fusion (ALIF) at one or two levels was performed through the BERG approach; a gasless retroperitoneal approach to

the lumbar spine allowing the use of standard anterior instrumentation. Posteriorly, all patients underwent successful decompression, translaminar fixation, and posterolateral fusion at one or two levels through one small (2.5–5.0 cm) incision. Results showed mean hospital stay of 2.02 days; mean combined blood loss was 255 cc; and mean pain relief was 56%, with 75.5% of patients reporting good, excellent, or total pain relief. Forty-two of 46 patients (93.2%) achieved a solid fusion 24 months after surgery. A total of 47% of all patients working prior to surgery returned to work following surgery. The study showed that minimally invasive 360° instrumented lumbar fusion, when performed utilizing these approaches, yields a high rate of solid arthrodesis (93.3%), good pain relief, short hospital stays, low blood losses, accelerated rehabilitation, and a quick return to the workforce. The BERG approach offers technical advantages over the traditional gas-mediated laparoscopic approach to the anterior lumbar spine.

Key words Minimally Invasive · 360° lumbar fusion · Combined anteroposterior · Gasless endoscopy · Translaminar fixation

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Introduction

While debate concerning single-stage anterior stabilization for lumbar spine pathologies continues in the spine surgery community, utilization of combined anteroposterior (360°) approaches for lumbar fusion has consistently yielded high rates of solid arthrodesis [1–3, 5, 7–9, 14, 23, 24]. Even though a combined approach leads to a high fusion rate in most cases, many surgeons are hesitant to use it due to operative time or insurance constraints, longer hospital stays for combined procedures, and the increased risk of infection and morbidity that comes with performing two procedures as opposed to one.

Since Obenchain first described laparoscopic discectomy and fusion in 1991 [16], multiple investigators have adopted a transperitoneal, gas-mediated laparoscopic approach to the lumbar spine. While many surgeons report success [11–13, 17, 19–22, 25, 26, 27] using this approach for minimally invasive anterior surgery, the transperitoneal gas-mediated approach has several technical drawbacks.

The primary drawback to the transperitoneal gas-mediated approach is that it can only be used at L5-S1. In most cases, access to L4-5 can be obtained through this approach, but this is more technically demanding. The use of CO₂ gas insufflation contributes to a multitude of potential problems. Carbon dioxide can cause significant physiologic and hemodynamic changes during the surgical procedure [6]. Suction to remove blood is limited because suction devices often remove CO₂ from the abdomen faster than the insufflator can deliver it. This may cause a loss of exposure within the operating cavity. A gas environment does not allow for large tissue removal, nor large instrument access to the spinal column. In addition, use of valved ports causes instrument fulcrums to be too far away from the operative field making spinal surgery inefficient. This significantly limits the surgeon with regards to disc and bony removal as well as choice of instrumentation.

The BERG (balloon-assisted endoscopic retroperitoneal gasless) approach to the lumbar spine was developed as an alternative to the transperitoneal gas-mediated approach. The BERG approach is completely gasless, thereby eliminating the drawbacks of a gas-mediated approach. Since there is no pneumoperitoneum to maintain, there are no valved ports and suction is not a problem. A gasless environment permits the surgeon to utilize standard anterior instrumentation normally reserved for open procedures. Since the BERG approach is a true retroperitoneal approach, it provides for *reliable* access up to L2, and in some cases to L1.

As anterior minimally invasive surgery has expanded over the past 5 years, posterior minimally invasive surgery has experienced a much slower evolution. A suprafascial minimally invasive approach to transpedicular fixation has been described by Lowery et al. [10]. The technique was designed to supplement anterior lumbar interbody fusion (ALIF) in cases where there may be torsional instability.

However, the technique does not include a posterolateral fusion, and requires the procedure to be performed under fluoroscopy. A secondary procedure is also required to remove the hardware at 9–12 months after surgery.

Fixation using translaminar facet screws, invented by Magerl for posterior stabilization, was first described by Montesano et al. in 1988 [15]. The successful use of translaminar fixation has been documented both biomechanically [8] and clinically [4, 15] by multiple investigators. Translaminar screw fixation involves placing screws through the laminae into the facet joint in a criss-cross fashion. This is instrumental in completing the tension band which is the goal of a 360° instrumented environment. Translaminar screws are inherently less invasive than transpedicular screws, and implantation through a minimally invasive approach improves upon this concept.

Materials and methods

This is a retrospective study concerning 46 patients, 25 male and 21 female, with an average age at the time of surgery of 46 years (range 27–67 years). Eighteen additional patients in this group were converted from the BERG approach to an open anterior approach. Reasons for conversion were as follows: vessel laceration ($n = 6$), retroperitoneal scarring from previous abdominal surgery ($n = 4$), obesity ($n = 3$), thin peritoneum ($n = 2$), scarring of iliac crest due to previous bone graft ($n = 1$), inability to retract the bowel ($n = 1$), and nerve lying on disc space ($n = 1$). The 18 converted patients are not included in this analysis. Of the 46 patients operated successfully using the BERG approach, 29 (63.0%) were smokers and 19 (41.3%) were industrial insurance compensation cases. Eighteen patients (39.1%) had undergone at least one prior lumbar surgery. Primary diagnoses were as follows: internal disc disruption ($n = 20$), failed laminectomy ($n = 14$), degenerative disc disease ($n = 8$), isthmic-lytic spondylolisthesis ($n = 2$), and spinal stenosis ($n = 2$).

There were 30 single-level, and 16 double-level fusions. Levels of fusion were L2-3 in 1 patient, L3-4 in 3, L4-5 in 18, L5-S1 in 8, L2-4 in 1, L3-5 in 2, and L4-S1 in 13. All but four patients tolerated both anterior and posterior procedures on the same day. Several different fusion devices/bone grafts were utilized in this series (Table 1).

Table 1 Devices and bone graft materials

	No. of patients
Anterior	
AO Titanium interbody spacer (TIS) (with Pro Osteon 500 center)	20
Femoral ring/Pro Osteon 500 coralline hydroxyapatite	18
Femoral ring/Pro Osteon 500 coralline hydroxyapatite/Grafton	6
AO Syn cage/autograft	1
Combined AO TIS/femoral ring	1
Posterior	
Autograft harvested from iliac crest	28
Autograft/Pro Osteon 500 Coralline hydroxyapatite/Grafton	16
Autograft/Pro Osteon 500	2

Surgical technique: ALIF via the BERG approach

In all cases, the ALIF was performed first. The approach is executed with one spinal surgeon, one vascular/general surgeon, and one endoscopically-trained technician (Fig. 1). The patient is placed in the supine position. Following general anesthesia, the patient is draped and prepped in standard fashion, and preoperative antibiotics are given. Fluoroscopy is used to find the landmarks of the appropriate lumbar level. The skin is marked, identifying the level and angle of the pathological disc interspace(s). These are drawn on the lateral aspect of the left abdomen, marking the angles of the disc spaces to be addressed.

A transverse 20-mm left flank incision is made, approximately 1 cm above the left iliac crest in the mid-axillary line (Fig. 2). The dissection is taken down through the external oblique, internal oblique, and transversus muscles under direct vision to the preperitoneal fat layer, using a clear-ended, endoscopic dissecting port. The retroperitoneal space is then gently insufflated with a bulb syringe and digitally dissected into the iliac fossa, to allow for balloon insertion. An undeployed elliptical-shaped preperitoneal balloon is advanced through the incision until the entire balloon is within the retroperitoneal space.

A 0° angle endoscope is placed through the lumen of the dissection cannula and the balloon is expanded to an approximate volume of 1 l. The endoscope is directed toward the anterior abdominal wall. This allows identification of the peritoneal reflection on the anterior abdominal wall, at the rectus sheath, above and below the Line of Douglas. The peritoneal reflection is used as a landmark for the anterior working port. The anterior working port is located lateral to the peritoneal reflection on the rectus sheath. This port is formed at a level determined by the pre-operative markings on the abdomen, which correspond to the interspace angulation. A 2- to 3-cm paramedian incision is made through the anterior abdominal wall and carried down through the fascia. This is done lateral to the peritoneal reflection and with great care to avoid the peritoneal sac. This creates the anterior working/retraction port. The balloon is removed after a 1-cm malleable retractor has been placed between the two ports under direct endoscopic vision. Once the retroperitoneal space has been mobilized, the next goal is the retraction of the abdominal wall.

There are three levels of retraction necessary to access the anterior lumbar spine. The first of these is distraction of the anterior abdominal wall. This is accomplished by the insertion of a fan retractor into the initial flank port. The fan retractor is expanded under direct endoscopic vision. Once expanded, the fan retractor is attached to a mechanical lifting arm. The abdominal wall is elevated by this combination, creating the retroperitoneal space and replacing the need for gas (Fig. 3). A flexible non-valved port, utilized for lateral visualization and retraction, is placed directly below the legs of the fan retractor to provide a clear path for the endoscope.

The second level of retraction is necessary to displace the peritoneal contents past the midline to provide access to the lumbar spine and vascular anatomy. A long retractor with an inflatable end is inserted through the newly created lateral working port in the initial left flank incision to push the peritoneal sac and intra-abdominal contents aside, creating the working space (Fig. 4). The third level of retraction in this approach, is vascular. Following establishment of the operative cavity, the psoas muscle and vascular anatomy are used as reference landmarks. The psoas muscle is bluntly dissected to expose the pathologic disc space(s). The L5-S1 vascular retraction begins by identifying the right iliac vein and utilizing an AO anterior vascular retractor to retract the fascia and pre-sacral veins, thereby exposing the anterior aspect of the L5-S1 interspace. Through the visualization/retraction port, a standard vein retractor is passed and is used to retract the iliac vein laterally. Once this is done, the pre-sacral veins are ligated or cauterized with bipolar cautery. Great care must be used in dissecting the anterior soft tissues, in order to maintain the integrity of the pre-sacral plexus.

The L4-5 exposure is more complex. It begins by utilizing the AO anterior vessel retractor and displacing the vena cava or left iliac vein. This is placed on tension, and the iliolumbar vein is identified. The iliolumbar vein is ligated using a right-angled clip and corporeal knot tying. This is generally re-enforced with two specific ligatures. The posterior aspect of the iliolumbar vein can be handled with vascular clips. Once the iliolumbar vein is ligated, gentle soft dissection is used to retract the left iliac vein, exposing the L4-5 interspace past the midline. The vascular retraction for L3-4 is performed in a similar way but does not require ligation of the iliolumbar vein.

Following psoas dissection and vessel retraction, a spinal needle is placed into the pathologic disc(s) and fluoroscopy is used to confirm the operative level. The anterior working port allows both for vascular retraction and for the introduction of standard spinal instruments such as dissectors, rongeurs, curettes, and endplate cutters.

Our experience with the BERG approach consisted of ALIF. The technique for ALIF is essentially the same as with an open anterior retroperitoneal approach. Discectomy begins by incising the anterior annulus with a long-handled scalpel, both cranially and caudally as well as left and right. Endplate cutters, rongeurs, and curettes are introduced and utilized through the anterior working port. Once the disc is removed, the surgical team has several options for fusion, such as anatomic cages, screw-in cages, allograft, or autograft. After the allograft, disc prosthesis, or cage is placed, the option of AO anterior buttress locking plate fixation is possible. Following this, the implant position is confirmed through fluoroscopy.

Upon satisfactory imaging, the retroperitoneum is inspected and the three levels of retraction are removed. Incisions are closed in standard fashion (Fig. 5).

Surgical technique – translaminar fixation and posterolateral fusion via a minimally invasive approach

Great care is made to limit the incision (2.5–5.0 cm) (Fig. 6) and the dissection from the musculature to the facet joints and not past L5-S1. Following decompression, percutaneous incisions are made to the left and right of the initial incision. A 3.2-mm drill is placed through the first percutaneous incision and against the spinous process. The hole is drilled across the lamina to the opposite facet joint, from left to right, and then right to left. Once this is completed, stainless steel cortical screws, 4.5 mm in diameter, are placed through the drilled holes. Bone graft is applied to the lateral gutters in standard fashion.

Results

Mean operative time for a single-level fusion was 183 min (anterior 97 min, posterior 86 min). Mean operative time for a double-level fusion was 215 min (anterior 130 min, posterior 85 min). Of the 42 patients undergoing antero-posterior surgery on the same day, mean hospital stay was 2.02 (range 1–5, median 2) days, with 30 patients (71.4%) discharged within 47 h. Total mean blood loss was 255 cc. Mean anterior blood loss was 155 cc (range 25–1200 cc). Mean posterior blood loss was 100 cc (range 25–1000 cc). Perioperatively, there was one vessel laceration and six dural tears, all repaired without sequelae. There were no postoperative complications except for one male patient who expired from a myocardial infarction unrelated to his surgery 6 months after the operation.

Mean follow-up in this series was 33 months, with a range of 24–42 months. Solid radiographic fusion, deter-

mined by less than 5 mm of translational motion and lack of halo on lateral, flexion, and extension plain films, was evident in 40 patients (Fig. 7). One patient had an unacceptable halo and could not be listed as fused. Posterior hardware was completely removed in four patients, resulting in two solid fusions and two pseudarthroses. This yielded an overall fusion rate of 93.3% (42/45, with one lost to follow-up). There was one instance of a lateral TIS (titanium interbody spacer) migration and one instance of a lateral femoral ring migration, as well as two instances of rotational migration of a TIS. These migrations did not affect fusion.

Mean self-reported decrease in pain using an analog scale was 56%, with 75.5% listing their pain relief as good (37.8%), excellent (22.2%), or complete (15.5%). Eight of 17 (47%) privately insured patients working prior to surgery returned to work at an average of 3.3 months after surgery. Nine of 19 (47%) of industrial insurance compensation patients returned to work at an average of 10.0 months after surgery.

Discussion

The gas-mediated transperitoneal approach to laparoscopic lumbar surgery is an adaptation from non-spinal laparoscopic applications. General surgeons familiar with the gas-mediated approach assisted spine surgeons in tailoring this form of endoscopic surgery to retro-fit ALIF. Unfortunately, the lack of natural surgical technique due to inefficient instrumentation, and lack of adequate access above L4, severely limits this technique to a small minority of cases of degenerative disc at L5-S1 and virgule or in some cases at L4-5. The extended learning curve of the technique also contributes to its limited appeal.

In contrast, the BERG approach offers the surgical team better access to the mid to upper lumbar spine via the true retroperitoneal approach. The importance of using standard

instrumentation endoscopically, i.e., instrumentation normally reserved for open procedures, cannot be overstated. The gasless environment allows for a more natural operating technique as opposed to utilizing long and inefficient instrumentation in a gas-mediated approach. The ability to use larger-sized implants and graft materials is also a benefit not afforded the surgical team in a gas-mediated technique.

A mean operative time of just over 3 h for single-level 360° instrumented fusion is exceptional, as is a combined blood loss of just 255 cc. With a mean of 2.02 days for simultaneous combined cases, this series compares favorably to a mean of 4.68 days in a random sample of 50 360° cases done through an open approach in the same time period. The high fusion rate in this series (93.3%) is comparable to other open 360° instrumented fusion studies cited previously. Pain relief and return to work rates are also excellent.

Our conversion rate (28%) was admittedly high for an initial series. However, the learning curve of the BERG approach coincided with the surgical team's endoscopic learning curve. In addition, most of the patients converted in this series were somewhat contraindicated to the procedure, due to obesity or retroperitoneal scarring concerns. It is the opinion of the authors that an attempt at minimally invasive surgery and conversion to an open procedure is better than no attempt at all. Eliminating the "classically contraindicated" patients from the series yields a much lower initial conversion rate of 15%.

In an effort to develop a minimally invasive approach with a lower learning curve, the mini-laparotomy was developed. The mini-laparotomy, as a minimally invasive approach to ALIF, is quite effective in dealing with degenerative discs at one or two levels. However, the mini-laparotomy is somewhat of a "one-trick pony" in that single-level and sometimes double-level ALIF is the furthest extent one can take the approach. Even though ALIF was the major goal of the development of the BERG approach, we believe this approach can be adapted in the future to handle tumor resection and deformity as well as ALIF at multiple levels.

While laparoscopic and endoscopic approaches to ALIF have accelerated, due in large part to the advent of screw-in cages, posterior minimally invasive surgery has remained somewhat stagnant. Our technique for minimally invasive translaminar fixation and posterolateral fusion offers posterior stabilization for the ALIF and piece of mind that comes with a 360° fusion. The technique, performed in this series with a power screwdriver, can also be performed utilizing a manual screw-in technique. This small incision technique allows quick incisional healing time, resulting in less incisional pain and morbidity.

Conclusions

From these initial results and our initial experience with minimally invasive 360° instrumented lumbar fusion, we

◀ **Fig. 1** Operating room setup for the BERG (balloon-assisted endoscopic retroperitoneal gasless) approach

Fig. 2 The first incision in the BERG approach is made approximately 1 cm above the iliac crest in the mid-axillary line

Fig. 3 The completed BERG setup, with distension of the abdomen by the fan retractor and lifting arm combination. The anterior working port is shown in the foreground

Fig. 4 A long-handled retractor is utilized to push the peritoneal contents laterally, thereby exposing the anterior lumbar spine

Fig. 5 Scars from the BERG approach 12 months after operation

Fig. 6 The small posterior incision

Fig. 7 Anteroposterior and lateral radiographs 24 months after surgery of a 40-year-old woman presenting with degenerative disc disease at L4-S1. Her grafts are fully incorporated. She returned to work 2 months after surgery. The patient reported an 85% reduction in pain

conclude that the combination of these two approaches yields excellent technical and clinical results. The use of the BERG approach combined with a minimally invasive translaminar fixation and posterolateral fusion yields short hospital stays, low blood losses, relatively short operative times, high fusion rates, good to excellent pain relief, and

good return to work rates. The BERG approach offers technical advantages over the traditional gas-mediated laparoscopic approach to the anterior lumbar spine, most importantly access up to L2 and the ability to use standard anterior instrumentation.

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