Paracoccygeal Transsacral Approach: A Rare Approach for Axial Lumbosacral Interbody Fusion

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Abstract:

Lumbosacral interbody fusion is a mainstay of surgical treatment for degenerative spinal pathologies causing chronic pain and functional impairment. However, the optimal technique for this procedure remains controversial. Well-established open approaches, including anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), and transforaminal lumbar interbody fusion (TLIF), have historically been the standard of practice. A recent paradigm shift in spinal surgery has led to the investigation of minimally invasive approaches to mitigate tissue damage without compromising outcomes. This extensive review aims to examine current clinical and biomechanical evidence on the paracoccygeal transsacral approach to an axial lumbosacral interbody fusion. Since this technique was first described in 2004, accumulating evidence suggests it results in high fusion rates, consistent improvements in pain and function, reduced perioperative morbidity, and low rates of complication. Although early clinical outcomes have been promising, there is a paucity of comparative data investigating outcomes of the paracoccygeal transsacral approach to traditional alternatives and other minimally invasive techniques. Here, we summarize current evidence and discuss pertinent topics for the spinal surgeon considering this novel approach, including indications, advantages, relevant anatomy, contraindications, and technical considerations.

Keywords:

Paracoccygeal, Transsacral, Axial lumbosacral interbody fusion, AxiaLIF, Lumbar interbody fusion

Introduction

Treatments of excruciating degenerative spinal pathologies remain a challenge due to the risk of complications that may result from damage to ligamentous, vascular, neural, or muscular structures, as well as the risk of pseudoarthrosis. Of the newly developed surgical treatments, the paracoccygeal transsacral approach provides a minimally invasive option that achieves the fusion of lumbar interbodies from a singular fusion at L5-S1 or two fusion processes at L4-L5 and L5-S1. This specific approach is performed by surgically accessing the region anterior to the sacrum, an anatomical plane that is devoid of critical structures. This technique is known as the presacral approach, or the axial lumbar interbody fusion (AxiaLIF).

First attempted in preliminary cadaver and animal studies by Cragg and colleagues in 2004, this surgical technique was introduced into clinical practice after receiving its clearance from the US Food and Drug Administration in 2005[1,2]. This novel minimally invasive presacral approach was then performed on live patients by Marotta et al. in 2006[3]. Three years later, in 2008, the FDA cleared a similar surgical device designed to fuse both the L4-L5 and L5-S1 segments. The transsacral approach appears to be a feasible alternative to other interbody fusion techniques that have been in use previously. Lumbar interbody fusion techniques have been

Table 1. Operative Techniques and Approaches in Lumbar or Lumbosacral Interbody Arthrodesis.

| Technique	Advantages	Disadvantages
Posterior lumbar interbody fusion (PLIF)	• Good access to the laminae, ligamentum flavum, nerve roots, and facet joints • Large potential fusion area through one incision	• Iatrogenic paraspinal muscle and nerve root injury • Difficulty in correcting lordotic deformity • Dural tears and epidural fibrosis
Transforaminal lumbar interbody fusion (TLIF)	• Good access to the laminae, ligamentum flavum, nerve roots, and facet joints • Better preservation of the ligaments compared to PLIF	• Iatrogenic paraspinal muscle and nerve root injury • Difficulty in correcting lordotic deformity
Anterior lumbar interbody fusion (ALIF)	• Well suited for L5–S1 pathology • Direct midline access to disc space • Good for lordotic deformity correction and endplate preparation	• Increased risk for vascular and visceral injury
Lateral lumbar interbody fusion (LLIF)	• Well suited for coronal or sagittal deformity • Rapid postoperative mobilization	• Not suitable for L5–S1 pathology due to iliac crest • Potential injury to bowel, lumbar nerve plexus, or iliac vessels
Oblique lumbar interbody fusion (OLIF)	• Well suited for coronal or sagittal deformity • Rapid postoperative mobilization	• Potential injury to sympathetic nerves and vasculature
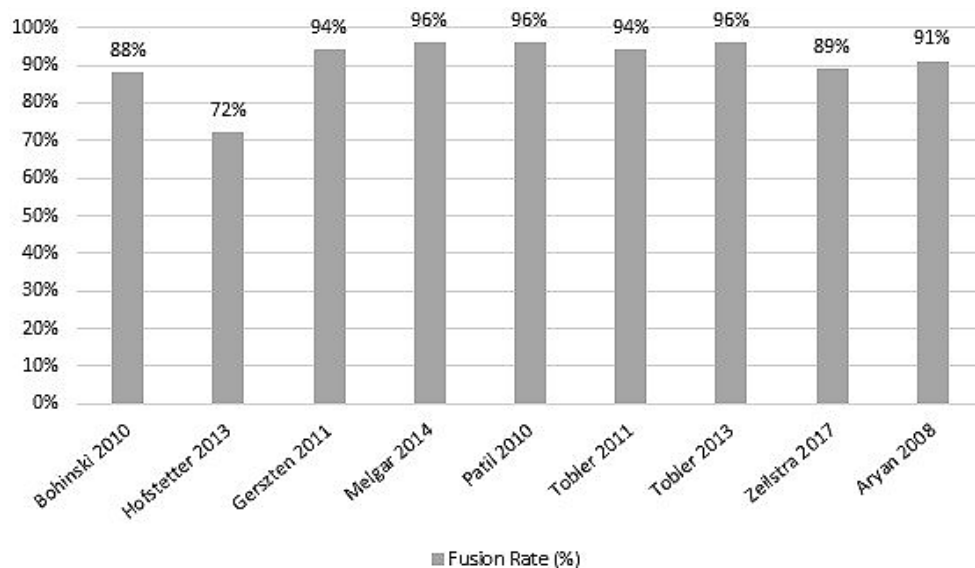
Figure 1. Axial lumbosacral interbody fusion rates reported in the literature.

used as a treatment option for painful degenerative pathologies of the spine; however, some techniques such as the anterior approach are not possible in some patients, and the posterior approach is often associated with high risks of neural complications and muscular injuries[4]. In such cases, the transsacral AxiaLIF technique is preferred to allow access to the L5-S1 disc space in a minimally invasive manner, posing a relatively low risk to ligamentous, vascular, neural, and muscular damage during the operation.

This paper aims to evaluate and synthesize the published literature on paracoccygeal transsacral interbody axial lumbar interbody fusion (AxiaLIF) to inform clinical decision-making and further research endeavors. Our objective is to review, compile, and provide relevant information for clinicians on paracoccygeal transsacral AxiaLIF, including its origins, advantages, anatomical considerations, indications, contraindications, patient positioning, and biomechanics. A

myriad of surgical techniques and implants have been developed for the purposes of lumbar spinal fusion (Table 1). The decision on which surgical technique to apply weighs heavily on the pathology, the patient's past surgical history, and the professional medical opinion and training of the individual surgeon (Fig. 1). We aim to provide guidelines for consideration that clinicians may use to weigh the risks and benefits of a paracoccygeal transsacral AxiaLIF which can aid in making clinical decisions on whether or not a patient might be a suitable surgical candidate that may benefit from a paracoccygeal transsacral interbody AxiaLIF to optimize the success of the surgical technique.

Advantages

Degenerative disc disease and spondylolisthesis pathology are frequently found at the L4-L5 and L5-S1 levels, and in

such cases, fusion is necessary to restore stability in the lumbosacral spine. Of the procedures available for treatment, many of the open techniques are invasive in nature and require dissection, retraction, and mobilization of soft tissues and critical structures such as nerve roots, major vessels, ligaments, annuli, and abdominal viscera[5]. Such conventional methods are often associated with postoperative complications, including pain, disability, denervation of musculature, relatively longer recovery times, and dysfunction.

Using a paracoccygeal transsacral approach, AxiaLIF is advantageous in that it allows the surgeon to gain access to the L5-S1 region using a minimally invasive approach. Through this technique, the anterior and posterior longitudinal ligaments are left undisturbed and the disc annulus intact. The technique will also avoid the need for dissection and mobilization of critical vascular and neural structures, thus reducing the potential for injury that frequently occurs with traditional approaches of anterior interbody and posterior interbody fusion, respectively[4]. This approach avoids critical structures, namely, the left and right internal iliac arteries, medial internal iliac veins on the left and right, the middle sacral vessels, and the sacral nerves, all of which should be circumnavigated by beginning with an entry point distally at the tip of the coccyx and entering the sacrum at the S1-S2 junction through a coronal safe zone measured to be 6.8 cm and 5.4 cm in females and males, respectively, by CT and 6.9 cm and 6.8 cm in females and males, respectively, by MRI. In the sagittal plane, the presacral safe space averages a diameter of 1.3 cm (range 0.3-3.5 cm) and 1.2 cm (range 0.3-3.1 cm) by CT and MRI, respectively[6].

In such pathologies of spondylolisthesis and degenerative disc disease, AxiaLIF is advantageous for many reasons, notably for its minimally invasive nature. The smaller incision size and position allow the surgeon to avoid disturbing critical structures, resulting in significantly reduced blood loss, postoperative pain, reduced length of hospital stay, and use of narcotics postoperatively[5]. Additionally, the minimally invasive technique has discernible improvements in reduced complication rates[7,8]. In particular, single-level AxiaLIF use of a transsacral rod through the paracoccygeal approach has shown the following characteristics: short-term average follow-up (range, 5-24 months), minimal blood loss (range, 30-88 cc), and high average fusion rates (range, 85%-93%). The technique has also demonstrated a low complication rate (0%-3%) and a shorter length of hospital stay (1-2.6 days)[5].

Anatomic Considerations

AxiaLIF system: operative technique

Under induction of anesthesia, the patient is prepared for surgery and positioned prone upon a radiolucent operating table. The surgeon may opt to use an intrarectal catheter to allow either the removal of air or the use of contrast during the procedure for optimal rectal visualization. To perform a single-level AxiaLIF fusion procedure, a paracoccygeal incision is made just lateral to the tip of the coccyx, and the underlying fascia is opened. This is performed entirely under fluoroscopy and without direct visualization of the surgical operative field. A blunt cannulated dissector is then passed through the avascular presacral region and slightly rotated to align with the presacral corridor before being advanced further and anchored upon the sacrum, oriented precisely in the desired position for the entry of the screw. Following this placement, a durable guide pin is inserted through the dissector into the sacrum and placed into the disc space. A series of dilators are then advanced over the guide pin, and a functional cannula is docked upon the sacrum. The surgeon then uses a cannulated drill to create an entryway into the L5-S1 disc space, advancing the drill over the guide pin. As a preventative measure, the surgeon will insert a nitinol cutter sequentially into the disc space to trim the nucleus pulposus and decorticate the superior and inferior endplate, as they frequently provide a mesh-like structure for undesired bony fusion. The surgeon will then prepare the disc space for bone grafting by removing pathologic disc material using tissue extractors and by replacing it with autologous bone and bone graft extenders. The surgeon may opt to use bone morphogenic protein along with or in place of the bone graft extenders. After the surgeon places the bone graft, the guide pin can be replaced and passed into the inferior endplate of L5. A channel is then created through the L5 vertebral body using a twist drill while maintaining uncompromized integrity of the superior L5 endplate structure and the L4/L5 intervertebral disc space. The surgeon will then advance the guide pin to the proximal end of the L5 drill channel. The previously placed cannula that was anchored upon the sacrum is then removed, and a larger cannula suited to house the axial rod is then inserted and passed over the guidewire until it is completely level with the anterior surface of the sacrum. Once the surgeon has confirmed the larger canula is properly placed, it is secured to the sacrum using K-wire[9-13].

An array of lengths may be used in the rod-shaped titanium alloy AxiaLIF system. The surgeon may also use varying thread pitch in the S1 section of the axial rod (compared to the L5 section) to achieve distraction of the disc space; currently, there are three varieties of differential pitch to allow for a range of disc space distraction. Afterward, the AxiaLIF system is passed over the guide pin and positioned through the sacrum into L5, to the more proximal extent of the channel. During this time, the surgeon may insert additional bone graft material with a syringe into the disc space using the central rod openings. As a final step, a set of pedicle or facet screws are installed with minimally invasive placement to augment posterior stability. After the procedure, the surgeon will then remove the cannula and suture the incision in a standard fashion before injecting air or contrast into the intrarectal catheter to verify the structural integrity of the rectum and to detect any iatrogenic bowel injury. Fig. 2 demonstrates the rod placement with considera-
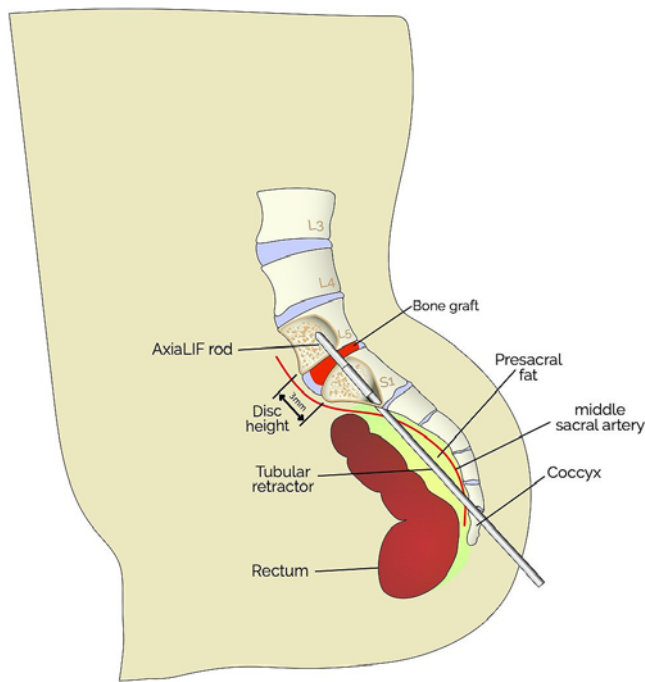
Figure 2. Sagittal representation of paracoccygeal approach to AxiaLIF demonstrating rod trajectory in consideration of presacral area (Credit: Rogelio Avila).

tion for the presacral space. Alternatively, several other methods may be used to confirm the structural integrity of the rectum, including saline or dye injection and direct proctoscope visualization[1,9-13].

To perform a two-level system, the single-level procedure is similarly followed in addition to a few necessary changes. A two-level system will require additional steps after grafting the L5-S1 disc space to allow access, decortication, and grafting of the L4-L5 disc space. The two-level rod is advantageous in that it is comprised of a modular two-piece support system whose individual segments may be customized to the specifications which are best suited for the anatomy of the individual patient[9-13].

Anatomical considerations for the presacral space

Prior to the surgery, it is crucial to evaluate the anatomical structures in the region of interest, namely, the sacrum and the presacral space, as this will be the path of interest for access to the L5-S1 segment. It is essential for the surgeon to identify any aberrant vasculature within the presacral space, determine the thickness of the perirectal fat pad, and locate the interface between the rectum and sacrum[14,15]. Traditionally, three approaches have been undertaken to achieve L5-S1 arthrodesis, namely, ALIF, PLIF, and TLIF, all three representing unique anatomical scenarios. In ALIF, a retroperitoneal approach is used to reach the L5-S1 disc space, with access below the bifurcation of the aorta into the common iliac arteries. The anatomical risks in ALIF are the possibility of injury not only to the iliac vessels, particularly the iliac vein, but also to the sympathetic plexus, which can cause retrograde ejaculation if injured in a male patient. In

the case of PLIF or TLIF, smaller cages are used due to the limitations in space for entry around the L1-L5 level which contains the cauda equina and nerve roots. In the majority of cases, a direct lateral interbody approach cannot be used for L5-S1 arthrodesis due to the overhang of the iliac wing and lumbosacral plexus nerve roots obstructing access[16]. When embarking on the paracoccygeal approach, it is vital to thoroughly understand the anatomical relationships of the presacral space, a region that may be familiar to the general surgeon, but less so to the spine surgeon. Several researchers have done extensive studies on this region, including Havenga et al., who characterized the anatomy of the presacral space as it related to nerve preservation in rectal cancer surgery, as well as Fritsch and Hotzinger, who compared gross tomographic anatomy of the pelvis with sectional CT and MRI[17,18]. The pelvic wall is formed posteriorly by the sacrum, which itself is lined by a slender layer of parietal fascia. This parietal fascia represents the posterior limit of the loosely organized connective tissue-filled presacral space, while the anterior border is comprised of the visceral fascia of the mesorectum[3]. The rectum is encased by adipose tissue and defined posteriorly by the mesorectum, which itself has blood vessels and lymphoid tissue supplying the rectum[1,19]. In an MRI study of ten patients, Guvencer et al. found that the distance between the ventral surface of the sacrum and the posterior border of the colon/rectum was as close as 11.44 ± 7.69 mm[20]. Oto et al. similarly used MRI to determine the width of the presacral space on 193 patients (87 men, 106 women)[21]. They measured the distance from the anterior surface of the S1, S2, or S3 vertebral body to the nearest aspect of the posterior wall of the rectum. The authors found that the mean width was 16.2 vs 11.9 mm (S1), 14.9 mm vs 11.2 mm (S2), and 13 mm vs 10.6 mm (S3) for men vs women, respectively. Given that presacral width was narrower in women, special attention should be given to female patients with regard to potential bowel complications. Li et al. conducted a cadaveric anatomic study employing the AxiaLIF approach on 16 pelvic specimens[22]. They were able to identify five distinct presacral fascial structures: periosteum, parietal presacral fascia, rectosacral fascia, autonomic nerve fascia, and fascia propria of the rectum. The authors defined the sagittal safe zone for the presacral space as the max width allowable for noninvasive dissection of the parietal presacral fascia and fascia propria of the rectum when opening the presacral space. They suggested that manipulation within the lower presacral space is limited conservatively to an area of 2×4 cm. Yuan et al. also reported anatomic measurements on 12 patients using CT and MRI[6]. The authors determined a "safe zone" using the sagittal length of the presacral space and the distance between the most medial adjacent internal iliac vessels. They determined the coronal safe zone to be an average of 6.9 cm and 6.0 cm on MRI and CT, respectively.

Anatomical considerations for nerves

The neurological structures to consider in this region are

the sympathetic nerves from the ventral roots of L2 and L3, which form the preaortic plexus at the sacral promontory. Based on cadaver study, Guvencer et al. reported that the distance between the sacral midline and sympathetic trunk ranged between 22.4±5.8 and 9.5±3.2 mm at different levels between S1 and the coccyx[20]. Damage in the sympathetic plexus can result in retrograde ejaculation in men; however, the damage is unlikely given that the planned entry point for AxiaLIF is below the location of this plexus. Around 1 cm lateral to the midline at the sacral promontory are the hypogastric nerves, which traverse laterally and course in parallel relative to the internal iliac arteries. The parasympathetic nerves here enter the pelvis laterally via the sacral foramen and are derived from the ventral roots of S3-S4 or S2-S4 in males and females, respectively[19]. Li et al. observed the position of the entry guide pin for AxiaLIF in relation to the pelvic splanchnic nerves and found that these nerves limited the dissection of the lower rectum[22]. They noted that the minimum distance from the guide pin to the pelvic splanchnic nerves was as small as 4 mm, indicating a small margin of error for the placement of the blunt stylet through which the guide pin is passed. Fig. 3 demonstrates the consideration of the hypogastric nerves.

Anatomical considerations for vasculature

The vasculature of the posterior pelvis includes the middle sacral artery and veins, which are variable in size and usually travel in the region of the sacral promontory. Yuan et al. found that the middle sacral artery descends with a variable course anterior to the L5-S1 disc space down to the coccyx, giving off parietal and visceral branches to the lateral sacral arteries and posterior rectum, respectively[6]. Guvencer et al. found in cadavers that the middle sacral artery was present on the right side in 55% of cases, the left side in 31.7% of cases, and the midline in 13.3%[20]. Additionally, there is the presence of presacral veins, which are situated posterior to the parietal fascia. During the AxiaLIF procedure, it is possible to induce bleeding from the transverse sacral veins or the middle sacral artery; however, given the percutaneous nature of the procedure, the risk of bleeding from these veins is relatively low. Generally, at the S2 level, the middle sacral artery is either small or nonexistent, but it may be protected or ligated with endoscopic dissection of the sacral face. Li et al.'s study on cadaveric specimens presented concerns with the so-called safe zone of the presacral corridor[22]. The authors note that most studies have focused on the longitudinal vessels in the region as opposed to fascial structures of the presacral space and the presacral venous plexus. They found that communicating veins anastomosing the lateral and median sacral veins were arranged in a stair-like fashion and were indeed variable. These veins are susceptible to bleeding if injured, as the pelvic venous system contains no venous valves. Other sources of bleeding could be from sacral cancellous bone or a malpositioned screw. Furthermore, under blind conditions, pelvic packing or bone wax implementation cannot be done to stop such
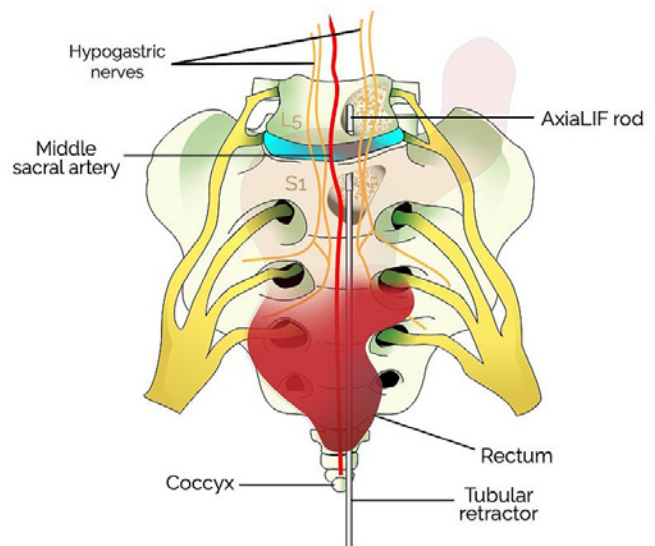

Figure 3. Coronal representation of paracoccygeal approach to AxiaLIF demonstrating rod trajectory in consideration of the middle sacral artery, hypogastric nerves, and rectum (Credit: Rogelio Avila).

bleeding. In order to avoid vital presacral structures, it is important to maintain direct midline contact with the anterior sacrum during access and take advantage of fluoroscopic, endoscopic, or even 3D NAV systems as described[23]. Fig. 3 demonstrates the consideration of the middle sacral artery and rectum.

Indications

The paracoccygeal approach to the lumbosacral junction for interbody fusion is indicated for interbody fusion with posterior fixation at L5-S1 or L4-L5 and L5-S1. The pathologies that may underly the need for such an approach are degenerative disc disease with or without radiculopathy, spondylolisthesis (grade 1 or 2), pseudoarthrosis, spinal stenosis, revision surgeries postlaminectomy, and prior failed fusion at the L4-L5 and L5-S1 segments[23]. Additionally, there have been reports of AxiaLIF for adult scoliosis[23]. The authors found good clinical results for both short and long constructs in adult scoliosis surgery. The ideal candidate for this procedure would be a patient with moderate BMI and classically shaped sacrum. The morphology of the sacrum, as well as the presacral fat pad, can be evaluated with preoperative films. Body habitus may be more of a limitation for alternative approaches to interbody fusion, as higher BMI increases the working depth for ALIF/TLIF/PLIF. However, in the case of AxiaLIF, obesity does not affect the working depth of access to the L5-S1 disc space. One limitation in the case for obese patients, however, may be a degradation in the resolution of fluoroscopic images, which is critical for guidance during this minimally invasive procedure[1].

Table 2. Study Characteristics and Outcomes for Review of the Paracoccygeal Approach to Axial Lumbosacral Interbody Fusion.

Study	N	Mean FU (months)	Mean Blood Loss (ml)	Mean LOS (days)	Fusion	Mean ODI Improvement	Mean VAS Improvement	Revision Surgery
Bohinski 2010 [34]	50	12	218	2.5	88%	50%	49%	2%
Hofstetter 2013 [9]	32	26	164	2.6	72%	26.3%	50%	13%
Gerszten 2011 [12]	99	24	50	1.5	94%	56.4%	67%	10%
Marchi 2012 [35]	27	24	81.5	1.4	NR	40%	50%	18.5%
Melgar 2014 [33]	58	29	250	3	96%	52%	77%	12%
Michael 2019 [36]	149	76	NR	NR	NR	NR	NR	25.5%
Patil 2010 [11]	50	12	NR	NR	96%	52.2%	55.6%	6%
Tobler 2011 [37]	155	24	NR	NR	94%	54%	63%	9.6%
Tobler 2013 [31]	52	24	220	3	93%	50%	75%	3.8%
Zeilstra 2017 [32]	164	54	<100	2.57	89%	76.8%	73.8%	9.5%

FU=follow-up. LOS=length of stay. NR=not reported. ODI=Oswestry Disability Index. VAS=Visual Analogue Scale

Contraindications

Careful attention must be given to the presacral area as there are factors that can contraindicate the procedure due to the potential of reduced efficacy or complications. Patients with a history of surgery or radiation therapy to the presacral area have shown the tendency to develop fibrous adhesions resulting in a contraindication for this method of fusion as it interrupts the trajectory of the procedure[24,25]. Among the complications reported with AxiaLIF, a common incident has been rectal perforation[4,24,26-28]. Seeing as displacement and manipulation of the patient's rectum is involved, a history of bowel or rectum disease, colitis, or perirectal abscess results in contraindication of this method[24,27].

Patients with severe spondylolisthesis and scoliosis pose a potential contraindication as it may interrupt the efficacy and safety of the procedure[27]. In severe spondylolisthesis, the anterior dislocation of the involved vertebral body poses a risk during surgery, such that too great of a displacement upsets the trajectory of the rod posteriorly and may come into contact with the spinal cord[24]. Normally, some dislocations can be reduced actively or passively, allowing the surgery to proceed[24]. Furthermore, patients with a history of spinal tumor, trauma, bone malformation including sacral agenesis, coagulopathy, and current pregnancy are not suitable candidates for the procedure[4,26,27]. Notably, a history including a cesarean or hysterectomy do not pose any contraindications so long as no damage or alteration resulted in the presacral space[24].

Biomechanics

The typical load of an intact lumbar spine accounts for 80% of the axial load over the anterior column, making the anterior spine a common objective for stabilization[29]. Compared to existing approaches, the biomechanical stability of the axial transsacral approach has been studied by Ledet and colleagues by mechanically testing 24 lumbar motion segments, using an unconstrained flexibility protocol, to implement sagittal and lateral bending, torsion, and axial compression[30]. Specimens implanted with an annulus-sparing axial fixation rod exhibited significant increases in stiffness and decreases in range of motion. Axial fixation rod also increased lateral and sagittal bending stiffness in extension. Torsional stiffness and axial compression were comparable to plate and rod constructs. It was concluded that the axial approach offers greater biomechanical stability than other approaches and may be suitable to reduce pathological motion, producing bony fusion[30]. According to Erkan et al., single-level AxiaLIF using a transsacral rod through a paracoccygeal approach has shown biomechanical stability through clinical results, with high average fusion rates (range, 85%-93%)[29]. Oswestry Disability Index questionnaire and Visual Analog Scale assessing back and leg pain showed improvements with low complication rates (0%-3%) as well. AxiaLIF II axial torsion, lateral bending, and flexion-extension movements have also been biomechanically tested, concluding that standalone transsacral rod fixation reduces range of motion more than 42% at L4-L5 and 66% at L5-S1 compared to the intact condition. No statistical difference was found between standalone transsacral rod fixation and additional posterior fixation with facet screws or pedicle screws except in flexion-extension movements at L5-S1 and lateral bending at L4-L5. Facet screws and pedicle screws in conjunction with rod systems can be used to enhance construct stability and reduce the stresses at implant surfaces[29].

Results

The paracoccygeal transsacral approach to interbody fusion at L5-S1 is associated with high fusion rates, consistent improvements in pain and function, and low complication rates. Table 2 presents the results from studies investigating the outcomes of this novel approach. Axial lumbosacral interbody fusion, a percutaneous technique, is associated with less perioperative morbidity than traditional approaches that require the mobilization of the vasculature or intra-abdominal contents. Studies report minimal procedural blood loss (range, 50-250 ml) and short mean hospital

length of stay (range, 0-3 days) with axial lumbosacral interbody fusion[9,12,31-33].

In the postoperative period, patients are assessed clinically and radiographically for successful arthrodesis. Multiple prospective and retrospective studies have reported high fusion rates with axial lumbosacral interbody fusion (range, 85%-96%) (Fig. 2)[11,12,19,31-33,37-41]. Rates of fusion achieved after axial interbody fusion are comparable to alternative, more common approaches for lumbosacral fusion including ALIF, PLIF, and TLIF. A systematic review by Schroeder et al. reported postoperative fusion in 90.5% (range, 79.0%-97.0%) with axial interbody fusions, 97.2% (range, 91.0%-99.2%) with ALIF, and 99.2% (range, 96.4%-99.8%) with TLIF. A paired analysis was subsequently performed to compare fusion techniques, and the only significant difference in fusion rates was between axial lumbosacral interbody fusion and TLIF[42]. This finding was challenged by results of a recent retrospective study by Yi et al., which reported no significant difference in the rate of fusion for 36 patients who underwent axial lumbosacral interbody fusion or TLIF[43]. Similarly, two retrospective analyses comparing axial lumbosacral interbody fusion to ALIF reported no significant difference in fusion rates for the approaches[40,44].

The Oswestry Disability Index (ODI) and Visual Analogue Scale (VAS) are validated, vigorous condition-specific outcome measures used in the management of spinal disorders to assess function and back pain, respectively[45]. A postoperative decrease in ODI and VAS from the preoperative baseline indicates improved function and pain. All studies in Table 2 reported improvement in both ODI (range, 26.3%-76.8%) and VAS (range, 49%-73.8%)[9,11,12,31-35,37]. At present, no studies have been undertaken to investigate whether alternative surgical approaches result in different ODI and VAS outcomes. Table 2 presents the rates of complications and reoperation for the reviewed studies. The most commonly reported complications of axial interbody fusion are pseudoarthrosis and superficial infection. Additionally, bowel perforation, rectal injury, and pelvic hematoma were reported[9-13]. Intrapelvic hematoma formation was the only vascular complication observed. A reoperation rate of 2%-13% was cited by the studies referenced in Table 3. Pseudoarthrosis was the most common indication for reoperation at the same level of the spine. Removal of failed hardware and adjacent segment disease accounted for the remainder of reoperation indications. A recent systematic review of 700 patients by Jia et al. similarly reported that revision surgery at the index level was most frequently performed for cases of pseudoarthrosis[46].

Avoidance of Complications

Due to the position of the rectum in the AxiaLIF parasacral approach, prevention of rectal obstruction is one of the main complications and requires extra-operative steps to avoid such complications[47]. Consultation with a colorectal surgeon is essential to identify any potential rectal injuries

Table 3. Rates of Complications and Reoperation Reported by Studies Evaluating the Paracoccygeal Approach to Axial Lumbosacral Interbody Fusion.

Study	Complication Rate	Types of Complication	Re-Operation Rate
Bohinski 2010[34]	4%	Bowel perforation (1/50) Pseudoarthrosis (1/50)	2%
Hofstetter 2013[9]	21%	Wound infection (3/38) Pseudoarthrosis (5/38)	13%
Gerszten 2011[12]	0%	-	NR
Marchi 2012[35]	4%	Wound infection (1/24)	NR
Melgar 2014[33]	0%	-	NR
Michael 2019[36]	4%	Pseudoarthrosis (6/149)	4%
Patil 2010[11]	20%	Wound infection (5/50) Rectal injury (1/50) Pseudoarthrosis (2/50) Pelvic hematoma (2/50)	4%
Tobler 2011[37]	NR	NR	NR
Tobler 2013[31]	9.6%	Pseudoarthrosis (5/52)	9.6%
Zeilstra 2017[32]	0%	-	9.5%

NR=not reported

that can predispose patients to infection, presacral abscesses, possible osteomyelitis, or likely temporary colostomy. Vascular injuries should also identified, including coagulation status of the patient[48]. Administration of broad-spectrum antibiotics is also indicated to reduce risk of infection. Bowel perforation prevention requires patient preoperative preparation and meticulous surgical technique. Preoperative patient preparation includes mechanical bowel cleansing to enhance rectal pliability during the blunt dissection phase of the procedure and to lower contamination risk in the event of a bowel injury[47]. In preoperative planning, it is also important to check the patient's anatomy using lateral X-rays to determine if a feasible and safe rod trajectory exists[29].

Necessary steps can be taken to avoid intraoperative complications as well. Rectal visualization can be enhanced prior to insertion of a blunt dissector into the sacrum by use of rectal catheters to aid in the prevention of obstruction of the bowel. Blunt dissection with a finger following initial incision can also allow safe entry into the presacral area[47]. Use of retractors and shielding pads can aid in protection of the bowel and has shown to reduce the incidence of perforations as well[48]. According to Tobler and Nasca, AxiaLIF devices have been reengineered to eliminate loss of distraction force, potential subsidence, and radiolucencies. In patients with annular defects, avoidance of packing graft material in the direction of the defect can minimize the chance of extravasation of grafting material into the spinal canal[48]. Following completion of the procedure, air or contrast can be injected into the catheters to inspect the rectum and sigmoid colon to ensure that no iatrogenic injury to the bowel occurred during the procedure. However, with enhanced visu-

alization from rectal catheters, the AxiaLIF procedure still has visual limitations and requires spinal surgeons to become very familiar with presacral anatomy due to the procedure primarily being visualized under fluoroscopy with no direct observation of disc space[47].

Study Limitations and Future Outlook

In this review, the AxiaLIF approach shows the equivalency for achieving arthrodesis, minimizing pain, and improving function. However, no randomized studies have been conducted; thus, high-quality evidence for the efficacy of AxiaLIF is limited. Therefore, this technique is considered somewhat experimental or investigational. Additional studies are necessary, including randomized controlled trials evaluating AxiaLIF to standard of care for spinal fusion, to provide higher-level evidence for clinical decision-making.

Conclusion

The accumulating evidence presented in this review supports the equivalency of the AxiaLIF approach to traditional lumbosacral interbody fusion techniques for achieving arthrodesis, minimizing pain, and improving function. Additionally, advantages associated with this technique may include reduced procedural blood loss and hospital length of stay. At present, data on early clinical, biomechanical, and patient-reported outcomes are promising, but no randomized studies have been conducted to compare this approach to alternatives. Thus, the optimal approach for lumbosacral interbody fusion remains inconclusive. Additional studies are necessary to compare open and minimally invasive approaches to a lumbosacral interbody fusion. Furthermore, this approach can be technically challenging, and spinal surgeons must be cautious to prevent severe complications, including rectal perforation and sacral fracture. Preoperative imaging may be used to identify at-risk structures and plan optimal patient positioning for surgery. Patient-centered communication is an invaluable tool for elucidating treatment goals. The individual needs of each patient should remain a central consideration for spinal surgeons evaluating the advantages and disadvantages of this novel approach.

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