Antepsoas Approaches to the Lumbar Spine

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KEYWORDS

- Lumbar interbody fusion (LIF) • Anterior to the psoas (ATP) approach
- Oblique lateral interbody fusion (OLIF) • Minimally invasive • Pre-psoas

KEY POINTS

- The ATP approach provides favorable clinical and radiographical outcomes in well-selected cases, while sparing the psoas muscle and, for many surgeons, obviating the need for neuromonitoring.
- The ATP approach is associated with a relatively low complication rate. Transient leg weakness and sensory changes are the most common complications after surgery. Unique complications—although rare—include vascular injury, ureteral injury, and sympathetic chain injury.
- Recent advancements such as navigation and robotic assistance improve the safety and efficiency of the ATP approach.

INTRODUCTION/HISTORY/DEFINITIONS/BACKGROUND

Lumbar interbody fusion (LIF) has been a cornerstone of treatment for patients with degenerative disease pathology for decades. For the majority of its existence, LIF has been accomplished via posterior-approach surgery. However, as LIF became an increasingly common method of lumbar arthrodesis, there has been growing interest in less invasive approaches, leading to innovations in the techniques used for LIF. These advancements, such as the transforaminal, lateral (ie, transpsoas), and oblique [i.e., anterior to psoas (ATP)] approaches, have added to the more traditional anterior and posterior approaches.

Originally described by Capener in 1932, anterior lumbar interbody fusion (ALIF) is an alternative to the posterior approach as it avoids extensive parasinal muscle dissection and permits the implanation of taller cages with larger footprints.[1,2] The anterior approach offers (1) a direct, wide visualization of the disc space, facilitating more complete discectomy and end-plate preparation and (2) the ability to place taller, lordotic cages to aid in better restoration of disc height and segmental lordosis.[3] By avoiding a posterior dissection, it may lead to less postoperative axial back pain and a reduced risk of adjacent segmental disease.[4] However, the anterior approach necessitates the dissection and mobilization of the peritoneum and prevertebral vessels, which may require an access surgeon to perform the approach and a risk of injury to the vessels and nearby structures (eg, ureter, sympathetic plexus).[5–8]

In 1997, Mayer modified the ALIF approach to include an anterolateral approach.[1] ATP interbody fusion has become an increasingly popular alternative to ALIF, offering a minimally invasive approach for interbody fusion from L1-S1.[1,9] The lumbar spine is accessed via the anterior oblique

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approach, which avoids the psoas muscle and the abdominal vessels. Its advantages include the sparing of the psoas muscle and lumbar plexus, access to L4-L5 and L5-S1 regardless of the anatomy of the iliac crest, and direct visualization of critical structures.[10–12] Further, with avoidance of a transpsoas approach—and thereby, risk of injury to the lumbar plexus—there is a decreased need for neuromonitoring.[13] A summary of all the approaches are pictured in **Fig. 1**.[14]

Both ATP interbody fusion and ALIF are techniques that may provide indirect decompression. Indirect decompression allows for decompression of the spinal canal and foramina by restoring disk height, reducing spondylolisthesis, and stabilizing the vertebral segment, without directly removing the compressive bony or discoligamentous tissue (ie, direct decompression).[15]

In this article, we will cover the indications of ATP approaches for spinal fusion, its relevant anatomy, preprocedural and intraoperative preparation, outcomes, recovery, complications, and future directions.

INDICATIONS AND CONTRAINDICATIONS

The ATP approach for fusion is suitable for a number of diverse pathologies including degenerative spondylosis, lateral olisthesis, spondylolisthesis (Meyerding Type 1, 2, or 3 in certain cases), mild to moderate spinal central, lateral recess, or foraminal stenosis, and scoliosis.[16–19] It may be used to treat more extensive central, lateral recess, or foraminal stenosis if combined with a direct decompression. The ATP approach for spinal fusion offers the ability to achieve both sagittal and coronal corrections, especially for those patients with degenerative lumbar scoliosis with lateral-olisthesis or lateral ostephytes.[14,16,20]

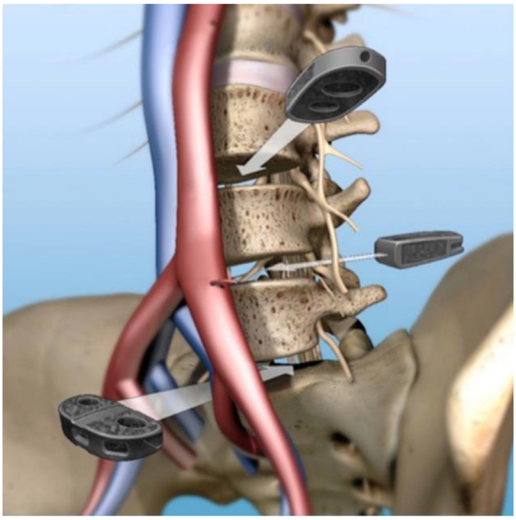

Fig. 1. ALIF, LLIF and ATP, TLIF fusion; Minimally invasive interbody approaches: anterior (ALIF), lateral (LLIF, and ATP), and osterior (TLIF). Copyright to Praveen V. Mummaneni.

Patients with spontaneous autofusion of the interverbal space or posterior facet joint ankylosis are not generally not candidates for ATP interbody fusion, as they require a three column osteotomy to achieve correction. Following the minimally invasive spinal deformity (MISDEF) classification system, these patients are classifed as Type III, and may require a more extensive spinal fusion for stablization after the osteotomy.[21] Furthermore, spondylolisthesis greater than Meyerding grade II is also technically difficult due to the overlap of the segmental endplates that may not be sufficient enough to support an interbody disc, as well as the spondylolistehsis obscuring the surgical corridor secondary to the anteriorly displaced femoral plexus.[16,22]

Subsidence can occur due to poor bone mineral density (T values < -1) or violation during endplate preparation. The fragility of the endplate is tied to patient bone quality. Thus, standalone constructs should be avoided in patients with osteoporosis. Rather, these patients should receive bilateral transpedicular screw fixation or avoid fusion surgery altogether until bone density can reach satisfactory levels.[23]

ANATOMY

At incision, the first muscle layers encountered are the external oblique, internal oblique, and transversus abdominis muscles, covered by the transversalis fascia.

The ATP approach uses a retroperitoneal oblique corridor between the psoas major muscle and the great vessels (when accessing L2-L5) and between the bifurcated iliac vessels (when accessing L5-S1).[24] The psoas muscle is positioned laterally, while the vessels are positioned medially.[9] The ATP approach should only be performed from the left side; as it cannot easily be performed from the right side due to the position of iliac vessels and the presence of the inferior vena cava on the right side which can easily tear with manipulation. Thus the left sided approach offers an easier and safer corridor between the aorta and the psoas muscle. A left-sided approach is also used given its larger area (see **Fig. 1**) and fewer anatomic variations.[9] The corridor itself can be as wide as 16 mm at L2-L3, but narrows to 10 mm at more caudal levels.[25] However, this corridor can be expanded with careful dissection and mobilization of the vessels and psoas muscle.

In cadaveric studies conducted by Davis and colleagues,[9] the average width of operation windows from L2-L5 range from 24.45 to 27.00 mm with mild retraction on the psoas muscle. In a recent study by Deng and colleagues, they found the average width of the operative window to be narrower, ranging from 16.6 to 20.27 mm. Specifically, at L4-L5, the average width was 16.6 mm and increased to 26 mm with the retraction of the psoas major.[20,26]

The lumbar plexus lies within the psoas major, and caution must be given when retracting the muscle. The plexus starts more posterior at proximal levels and then moves more anterior distally.[27,28] This plexus is a collection of nerves arising from a contribution of the subcostal nerve, the anterior divisions of the first three lumbar nerves, and the greater part of the fourth lumbar nerve. It is a retroperitoneal structure which is situated posteriorly, anterior to the transverse processes of then lumbar vertebrae, and within the psoas major muscle.[29]

From a lateral decubitus position, the lumbar plexus is located in the posterior fourth of the vertebral body and dorsally. The nerves pass obliquely outward from the vertebral body, then behind and through the psoas muscle. While passing through the psoas, nerves distribute filaments within the muscle. Distal members of the plexus have been shown to marginate anteriorly as they descend within the muscle at descending disc spaces.[29] For example, the femoral nerve, the largest branch of the lumbar plexus and formed by roots of L2, L3 and L4, is found deep within the psoas muscle moving in a posterior-to-anterior trajectory as it reaches the L4–5 disc space. As it continues to descend, it travels between the psoas and iliacus muscles, under the inguinal ligament and into the upper leg, where it splits into the anterior cutaneous and muscular branches.[29]

The sensory nerves arising from L1, the ilioinguinal and iliohypogastric, as well as the lateral femoral cutaneous nerve arising from L2 and L3 emerge from the posterolateral border of the psoas major. They then travel obliquely into the retroperitoneal space, crossing in front of the quadratus lumborum and the iliacus muscles eventually reaching the iliac crest The ilioinguinal and iliohypogastric nerves, coming off of the L1 nerve root, may cross deep to the internal oblique at the L4-L5 level and should be avoided during dissection. The genitofemoral nerve, arising from L1 and L2, is the exception. Starting at its origin, it travels obliquely through the psoas, traveling across the L2-3 disc space and then emerging at the medial border anterior and superficial at the L3-L4 level. Next, it descends along the surface of the psoas and on the anterior quarter of the L4 and L5 vertebral bodies. It splits into the spermatic and lumboinguinal nerves, which innervate the skin around the inguinal and genital region as well as the anterior and medial portion of the upper thigh respectively.[29]

Further, Uribe and colleagues[29] created an anatomical zoning system, which provides safe zones relative to disc spaces to prevent nerve injuries during the transpsoas approach which is tantamount in understanding relative anatomy in the ATP approach. They found that all of the nerve roots could be found within Zone IV, the posterior fourth of the vertebral body. Specifically, at levels L1-L2, all of the respective nerve roots (the L1 root, iliohyopgastric and ilioinguinal) were found posteriorly in Zone IV. At levels L2-L3, all of the nerve roots (L2 root) were found within Zone IV, except for the genitofemoral nerve, which was found in Zone II, the middle anterior quarter. At levels L3-L4, all of the never roots (L2 division, L3 root, and the lateral cutaneous nerve) were found within Zone IV. However, the genitofemoral nerve was found within Zone I, the anterior quarter. At levels L4-L5, the L2 and L3 divisions as well as the L4 root, which together make up the femoral nerve, the obturator nerve and the branches to the psoas were found within both Zone IV and Zone III, the posterior middle quarter.[29]

While there typically are not any major vessels encountered, they should be repected to avoid injury. The positions of the abdominal aorta and the IVC may vary in different individuals and segments. There have been some reports that these large vessels are not entirely in front of the anterior tangent of the vertebral body. The position of the abdominal aorta at L1–5 may occasionally cover part of Zone I, while on the right side of the vertebral body, the inferior vena cava trunk may also partly cover Zone I.

The shape and relationship of the psoas muscle to nearby structures affects the approach used. The psoas major muscle is divided into 2 parts: the superficial and deep parts. The superficial psoas major originates from T12-L4 and the neighboring intervertebral discs. The deep psoas major originates from the transverse processes of L1-4. Fibers of psoas major are oriented inferolateral and come together as a common tendon that descends over the pubis and shares a common insertion with the iliacus muscle on the lesser trochanter of the femur.

In patients with aberrant anatomy such as in patients with scoliosis, the space between the vessels and the psoas muscle may vary. When the psoas major muscle rises laterally or anteriorly at the L4-5 disc level and detaches from the most posterior aspect of the L4-5 disc space despite the absence of transitional vertebrae, this instance is called the “rising psoas sign.”[30] The rising psoas sign is related to a higher pelvic incidence and lumbar scoliosis.[31] The space between the psoas muscle and the quadratus lumbourm muscle may increase in some patients, which could lead to mistaking this gap for cooridor between the artery and the psoas muscle. Different positions have an influence on the shape of the psoas muscle. In the right decubitus position, the left psoas major muscle is affected by gravity and is closer to the vertebral body. Hip flexion and knee flexion will also relax the psoas major muscle, thus increasing the cross-sectional area of the psoas major muscle.[21] In contrast, a neutral hip position will decrease the cross-sectional area of the psoas major muscle and widen the corridor between the psoas muscle and the artery.

Mai and colleagues,[32] reviewing magnetic resonance (MR) imaging from 180 patients, set out to define some of the anatomic variations among patients undergoing a lateral LIF. They found that vascular anatomy on the right side was significantly more variant than anatomy on the left. Thus, giving more reasons why the ATP approach is preferably performed from the left. Additionally, age was associated with increased variability of vascular anatomy bilaterally, and the presence of bowel within the operative corridor correlated with BMI. Lastly, amongst age-disturbed patients who underwent lumbar MR imaging, the rising psoas sign was seen in 26.1% of patients.[32]

PRE-operative/Pre-PROCEDURE PLANNING

In pre-procedural planning, lumbar arterial and venous vessels should first be identified on MR imaging to confirm a safe corridor. Their posterior and lateral migration on the side contralateral to the approach should also be appreciated.[33] Each patient may present with unique local anatomy, thus careful assessment of the imaging is crucial. Wang and colleagues reviewed MR imaging of the lumbar region of 300 patients. They found that the location of the left major psoas and major vasculature varied widely across a number of vertically and horizontally defined zones at L2-L3, L3-L4, and L4-L5.[34] The size of corridor can be measured from the psoas anteriorly and the left lateral border of the anterior vessels. However, one must remember that the retraction of the psoas muscle allows for a more flexible corridor size.[3] Corridor distance has been shown to vary by side, age, and disc level.[35] Mean widths of the corridor narrows at lower lumbar disc levels. Left-sided corridors are wider at all lumbar levels, and widths increase with age.[35]

One the advantages of the ATP approach is its reduced rate of lumbar plexus injury,[10–12] However, it is still paramount to appreciate lumbar plexus anatomy when reviewing MR imaging especially in cases of abbrent anatomy. The lumbar plexus often migrates anteriorly in patients with transitional vertebrae, especially at L5-L6 in the instances of patients with 6 lumbar vertebrae. Therefore, for risk management, it is important to evaluate the psoas major, especially for a rising psoas, and its surrounding structures before.[31]

Typically, the visualization of an unobstructed corridor in the pre-operative MR imaging is required to proceed with the ATP approach.[36] However, this assessment is often subjective and can change based on the surgeon experience.[37] Molinares and colleagues,[25] reviewing previous MR imaging, set out to define the safe corridors across patient populations. They found that 90% of cases involving L2-L5 and 69% of cases involving L5-S1 have a safe operative corridor.[25] The major vessels that overlie the intervertebral disc at L5-S1 may contribute towards the discrepancy in safety.[38] Additionally, the right lateral decubital position, and its associated downward migration of the left common iliac vein, may further decrease this corridor.[39] Pictured in **Fig. 2** are the pre-operative films showing an appropriate window for L4-5 ATP approach for fusion.

In 2003, Moro and colleagues[40] set out to define anatomical parameters to clarify safety zones in retroperitoneal endoscopic surgery. The classification name has been aptly named Moro’s classification and divides the lumbar intervertebral space into six zones starting with A (anteriorly), I, II, II, IV, and P (posteriorly).[40] In 2020, Ng and colleagues[41] modified Moro’s to objectively measure the feasibility of the ATP approach at the L4-L5 level. In their system, the corridor was graded from 0 to 3, where 0 is considered no corridor. Psoas classification was included to clarify difficult to pass anatomy (ie high-rising psoas). They proposed that an inoperable corridor was defined as either having a corridor score of 0 or a high riding psoas. Applying this methodology to their patient cohort, they found that 10.5% of patients did not have a measurable corridor, confirming similar results from Molinares and colleagues.[25] Further, 20% of patients had a high-rising psoas. Together, they found that 25% of patients did not have corridor appropriate for the ATP approach. Follow-up studies have examined the reliability of the modified Moro’s classification system, and gradings were found to be consistent and highly reliable.[37]

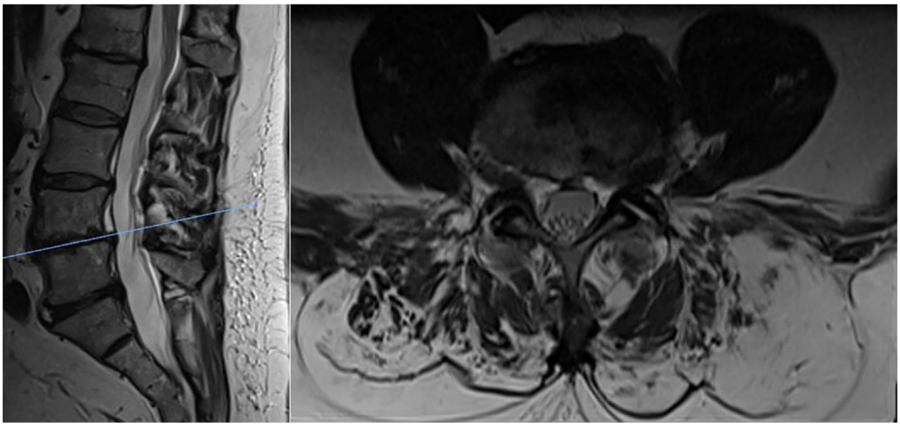

Fig. 2. *MR imaging of corridor window*; MR sagittal and axial cuts of a patient who underwent ATP fusion to L4-5. There is lateral listhesis at L4-5. There is vacuum change in L4-5 disc space, as well as up-down foraminal stenosis at L4-5 (not pictured on parasagittal views) as well as auto-fusion at L5-S1. There are no no vessels obstructing the corridor to access the L4-5 disc space. This patient underwent successful fusion with percutaneous posterior fusion.

Liu and colleagues[42] proposed an alternative methodology where, at each vertebral level, intervertebral space anatomy is categorized into the following sections: the vascular window, bare window, psoas major window, ideal operative window, and actual operative window. Ultimately, they found that, at the L4-L5 level, 6.7% of their population did not have an appropriate corridor, a smaller proportion when compared to Ng and colleagues and Molinares and colleagues.[25,41,42] Together, these studies indicate that despite attempts at objective classification systems, intra-reliability among systems remains inconsistent.

Vascular structures should be assessed using axial and sagittal MR imaging, and the following features should be considered: location of the left common iliac vein, size of the vascular corridor, and the presence of a fat plane (best viewed on T1 imaging) between the left common iliac vein and the intervertebral disc.[24,38] Segmental artery anatomy must also be appreciated. Segmental arteries specifically at the L5 level have a high rate of adjacency to the intervertebral disc, interfering with the surgical site and increasing the risk of hemorrhage.[43]

Alternatives to an ATP approach should be considered if the left common iliac vein crosses the midline, if the vascular corridor is narrow or if a fat plane is absent.[24,38,44] Lastly, accessing the L5-S1 level is not possible when the angle of L5-S1 intervertebral disc in the sagittal plane goes underneath the symphysis bone.[24,38] Similarly, when planning the approach for L4-L5, extra consideration must be paid as the corridor may be obstructed by vascular vessels or a high-riding psoas muscle.[41] In this circumstance, the corridor may be improved by an optimized incision site and placement of the patient in the lateral decubitus position.

Cage subsidence can lead to poor clinical and radiological outcomes, and may be a sequelae of poor bone quality or endplate injury.[24,45] Pre-operative bone density scan may be helpful in preventing this complication. Additionally, hounsfield units (HUs) from preoperative CT imaging can be used to estimate the strength of the endplates. Studies have found that low HUs at the ipsilateral epiphyseal ring were an independent risk factor for endplate violation, and low HUs at the central endplate were associated with delayed cage subsidence.[46,47] Thus, bone density and HUs of the endplate are strong predictors of intraoperative endplate violation and delayed cage subsidence, and should be considered in preprocedural planning, preoperative optimization with anabolic agents for osteoporosis, and during endplate preparation. Observation of modic changes on endplates, or preoperative endplate sclerosis, can also help prevent cage subsidence.[48]

ATP approaches with stand-alone cages, and without posterior fixation, have been shown to be a reasonably safe and effecacious option for a group of well-selected patients.[49] However, a number of studies have reported instances where ATP fusion with stand-alone cages was insufficient.[50,51] Guo and colleagues[51] compared range-of-motion (ROM), stress of the cage and stress of fixation among the stand-alone model, the lateral rod-screw model, the lateral rod-screw plus contralateral translaminar facet screw model, the unilateral pedicle screw model, and the bilateral pedicle screw (BPS) model. They found that bilateral pedicle screw (BPS) fixation had the lowest ROM, stress of the cage, and stress of fixation, and thus provided the greatest stability. Meanwhile, the stand-alone model had the greatest ROM and cage stress, which they ultimately decided was insufficient and placed the cage at risk for subsidence.[51] Song and colleagues[52] similarly showed the superiority of BPS in both normal and osteoporotic vertebrae. Thus, stand-alone constructs may be less appropriate for patients with heightened risk of subsidence, such as those with poor bone quality.

PREP AND PATIENT POSITIONING

ATP approach to spinal fusion should be performed with the patient placed in the right lateral decubitus position. Once again, the ATP approach should only be performed from the left side, as a right sided ATP approach would be too high risk to manipulation to the right-sided position of the inferior vena cava.[1,53,54] The ipsilateral leg can be extended at the hip-knee to stretch the psoas and reduce its girth, thereby potentially reducing the need for retraction.[55] Kotheeranurak and colleagues found that the surgical corridor in the neutral hip position was significantly larger than the flexed position at all levels. Further, anterior thickness and cross-sectional area of the psoas muscle were minimized in the neutral position.[56]

The table should be radiolucent for radiographic visualization and arranged in a slight Trendelenburg. The patient's bony prominences should be padded and body fastened with adhesive drapes to avoid manipulation. A 270-degree prep and drape should be used to allow for both abdominal and posterior access if needed.[57] Anterior-posterior (AP) and lateral fluoroscopic projections should be confirmed to be working effectively before starting the surgery in the given set up. The bed should be positioned so that true AP and lateral images are obtained. Such imaging can also be used to mark the anterior, midpoint, and posterior of the intervertebral space of interest on the skin. The levels of the disc spaces should also be marked following fluoroscopic confirmation.[58] The iliac crest, anterior superior iliac spine, and twelfth rib should also be marked. A typical patient set up is pictured in **Fig. 3**, performed at our institution.

PROCEDURAL APPROACH

- 4 to 6 cm incision should be made following splitting dissection of externaloblique, internal oblique and transversalis.[55,57]
- Transversalis should be split carefully posteriorly to anteriorly to avoid injury to the peritoneum.
- Iliohypogastric and ilioingual nerves may also be present below the internal oblique, and should be avoided.
- Retroperitoneal fat is identified, peritoneum is pushed anteriorly with tonsil sponges, and the psoas major belly is exposed. The psoas major will be the lateral border of the surgical corridor.
- Perivascular fat of the major vessels anterior to the psoas is identified. The surgical corridor is created with blunt and gentle dissection. Tonsil sponges and bipolar cautery may also be used.
- Typically, for cases involving levels L1-L4, ligation of segmental vessels is not necessary.
- The appropriate target level is confirmed by imaging.
- The discectomy is performed, while making sure to preserve the vertebral endplates.
- The endplates are prepared, with extreme care to avoid endplate violation.
- The anterior longitudinal ligament should not be released to avoid anterior "spitting out" of the cage. Intentional ALL release has different indications described elsewhere.
- Appropriate cage dimensions should be determined based on intraoperative trial sizing and preoperative measurement or planning.
- Graft material is added to the cage and the cage is inserted with the aid of imaging.
- Once the cage is confirmed to be in the correct place by imaging, the retroperitoneal space should be evaluated for any active bleeding and major structures should be examined to ensure integrity. The abdominal muscles and soft tissue can then be closed in layers.
- For posterior fixation, the patient can then placed prone on a Jackson frame table or simultaneous or sequential single position surgery, also in the lateral position, may be chosen.
- The pedicle screw-rods system is placed, a direct decompression may be completed as well from the posterior approach along with a posterolateral arthrodesis if desired

Pictured later in discussion in **Fig. 4** are preoperative and post-operative standing films of the patient undergoing an ATP approach for fusion at L4-5.

RECOVERY, POST-PROCEDURE CARE, AND REHABILITATION/MANAGEMENT

Several studies have shown that the ATP approach may have lower complications rates when

Fig. 3. (*A–F*): Pre-op positioning and prep; Patient positioning at our institution: (*A*) Patient is in placed in right lateral decubitus position, all pressure points appropriately padded and patient is strapped in. The incision is marked. (*B*) The patient is sterily drapped, with the appropriate marking of the intervertebral space of interst listed. (*C*) Navigation is used to confirm the levels of interest (*D*) After incision and retroperitoneal dissection, a retractor access system is used, navigation is once again used to confirm location. (*E*) Subsequent disckectomy is performed (*F*) Patient is closed in usual multilayer cosure, the patient is then turned prone for posterior instrumented fusion.

compared to transpsoas LLIF and ALIF.[55,59] Specifically, ATP fusion may have lower rates of peritoneal laceration and sensory nerve injury.[59] However, deep vein thrombosis (DVT) and lower extremity atrophy have been reported to occur following ATP fusion.[60]

Wang and colleagues[60] compared patients with ATP fusion who underwent lower extremity rehab for three months to patients with ATP fusion who did not receive any postoperative rehab. They found that within the first two weeks, patients undergoing rehab had lower total pain and lower

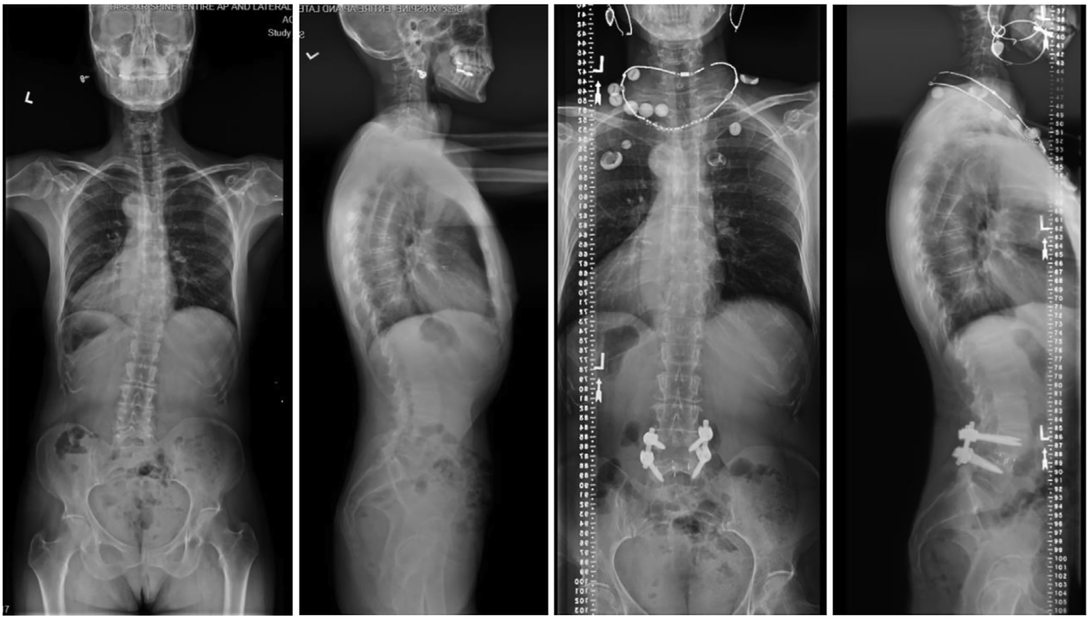

Fig. 4. Pre and poststanding scoliosis films.

back pain compared to the control patients. However, after one month of rehab, they no longer experienced a statistically significant advantage. Those same patients also had a significant improvement in disability scores, but for only the first week. DVTs were lower in those with rehab at both one week after surgery and three months after surgery. At three months after surgery, the decrease in the incidence of DVTs were statistically significant. Lastly, those who underwent postoperative rehab experienced greater patient satisfication.[60] Wang and colleagues also demonstrated the importance of postoperative rehab in improving pain, function, and satisfaction, but their study may have been limited by sample size. Further studies are required to better understand the necessary duration of lower extremity rehabilitation.

OUTCOMES

A number of clinical studies have reported ATP fusion to be a safe and effective option for LLIF. Ohtori and colleagues[61] examined patients receiving ATP fusion for degenerated lumbar spinal kyphoscoliosis. They found pain and balance scores were significantly improved after surgery, and fusion rates were 90%. Among the 12 patients, there were no major complications. Similarly, in a separate study, Ohtori and colleagues, reviewing 35 patients with spinal degeneration disease, found that pain scores were significantly improved following surgery and no patient experienced a major complication.

More recently different groups have compared ATP fusion to other approaches of lumbar interbody approaches. Compared to transpsoas LLIF, ATP fusion's hypothetical advantages are avoidance of direct injury to the psoas muscle and, thus, decreased risk of lumbar plexus injury. However, injury to the plexus still can occur due to the retraction of the psoas.[27,29,62,63] A meta-analysis by Li and colleagues,[64] comprised of 56 studies, found that visual analog scale (VAS) and Oswestry Disability Index (ODI) were more improved in ATP fusion compared to transpsoas LLIF. Psoas injury, and the associated anterior thigh syndrome, were thought to contribute to these differences. In this same study, radiological disc height restoration was identical. However, the fusion rate among ATP fusion was 96.9%, while the fusion rate was 91.6% among transpsoas LLIF. Similar trends in fusion rates were reported in another meta-analysis by Souslian and Patel.[65] Further, Walker and colleagues[66] found that operation times were significantly shorter with ATP fusion when compared to transpsoas LLIF.

ATP fusion and ALIF are comparable options for L5-S1 fusion.[67,68] ALIF fusion involves a retro- or transperitoneal approach in the supine position to access L5-S1, while ATP involves a retroperitoneal approach from the lateral decubitus position.

Studies have reported conflicting benefits when comparing these two approaches, and no definitive conclusion can be made.[67,68]

COMPLICATIONS

The most common complications following ATP fusion are transient leg weakness and numbness most likely secondary to the retraction of the psoas muscle and sensory nerves. Fujibayashi and colleagues[59] set out to elucidate the complications associated with LLIF across institutions in Japan. Among 992 patients who underwent ATP fusion, 3.5% of patients experienced sensory nerve injury. The majority of these injuries were transient. Additionally, 3% experienced postoperative psoas weakness.[59] Digorgio and colleagues[69] found a similar rate of transient leg numbness, 6.1%, among their patient 49-pateint cohort. There have been reports of symptoms associated with anterior thigh syndrome–sensory deficit, hip flexion weakness, and pain, however studies have shown this can resolves after three to six months.[70]

Another complication, although less common, is vascular injury. In their study, Fujibayashi and colleagues[59] found that only 1 of the 992 patients experienced a major vascular injury. Tannoury and colleagues,[55] who retrospectively reviewed the complications of 940 patients with ATP fusion, found no major vascular injury. Mehren and colleagues,[71] having reviewed 812 patients, found only 3 instances of major vascular injury. Kim and colleagues,[24] reviewing 752 ATP fusion cases, similarly showed that only 3 cases involved major vascular injury. Preoperative planning involving the identification of major vessels and their proximity to the surgical corridor is paramount to avoid injury to the major vessels. Additionally, segmental arteries can also be injured and cause bleeding intraoperatively. Fujibayashi and colleagues reported an incidence of 0.7% among their 992 patients.[59]

Although intraoperative vascular injuries are rare in ATP fusion, patients remain at risk for deep vein thrombosis (DVT) of the lower extremities after surgery. Wang and colleagues[60], studying the effects of lower limb training during the postoperative period, reported a DVT rate of 16% within 1 week of surgery. Xi and colleagues[72], focusing only on patients who underwent ATP fusion with navigation, reported a much lower rate of DVT, 0.93%. Similarly, Oh and colleagues reported 0 incidences of DVT across 143 ATP fusion surgeries.[73] This reason for the discrepancy is unclear, but the reduced rate of DVT recorded in studies by Xi and colleagues and Oh and colleagues may be due to poor patient follow-up after surgery.

The ureter may be encountered during the retroperitoneal approach as it is attached to the posterior wall of the peritoneum. Injury to the ureter has been reported in several case reports.[75,76] Fujibayashi and colleagues[59] reported a 0.3% incidence of ureteral injury. While, similar large cohort studies reported 0% incidence.[55] To avoid injury, the ureter should be swept anteriorly with the peritoneum, which should be directly visualized.

Direct bowel injury is extremely rare following ATP fusion.[55,59,77] Although not a direct injury, Tannoury and colleagues[55] reported one incidence of a major bowel complication due to superior mesenteric ischemia leading to eventual partial colectomy. Fujibayashi and colleagues[59] noted no instances of bowel injury in their 992-patient ATP fusion cohort. Similarly, postoperative abdominal wall hernias are rarely reported with a rate of 0% to 0.3%.[55,59,77]

Postoperative ileus (POI) remains a common complication in ATP.[55,71,77,78] In their 460-pateint study, Park and colleagues[78] reported a 3.9% rate of POI. Among these patients, intraoperative administration of remifentanil and inadvertent endplate fracture were identified as independent risk factors for POI. Additionally, POI increased length of stay.[78] Postoperative pain following fracture may stimulate inhibitory neurons and contribute to POI. Further, the release of cytokine and other inflammatory mediators following fracture may have effects on the nearby lumbar plexus.[24,78] Other studies have reported rates of POI ranging from 0.9% to 2.9%.[55,71,77,79]

Reported incidences of lesions to the sympathetic chain are varied across the literature. The “safety corridor” enclosed by the anterior longitudinal ligament medially and the psoas muscle laterally is lined with fibers of the sympathetic chain.[71] Varying rates of reported incidence could be due to slight inter-institutional differences. However, the clinical effects of the injuries are unclear as it has been reported that the sacrifice of the sympathetic chain only produced a “warming” of the affected leg that was unnoticed by the patient.

Cage subsidence is another debilitating complication of ATP fusion that may be associated with poor clinical and radiological outcomes, including the reduction of segmental lordosis, reversal of indirect decompression, and clinical recurrence of radiculopathy.[24,45] Among a 79-patient cohort, Cheng and colleagues[18] reported 10% experienced cage subsidence. For those patients with intraoperative violation of the endplates, the risk of subsidence increases to 18.7%.[74] Despite reported poor clinical and radiological measurements, leg pain, risk of revision surgery, and risk of pseudoarthrosis were found to not significantly increase when comparing ATP fusion with cage subsidence versus ATP without cage subsidence.[79–84] Large cohort studies are required to better understand that impact of cage subsidence in ATP fusion. To avoid endplate violation, and subsequent cage subsidence, bone quality should be assessed preoperatively and the disc space must be prepared with caution, employing serial implant trials and avoiding any excessive force along the endplate.[46,74]

FUTURE DEVELOPMENTS

Spinal navigation assistance systems have become an increasingly popular alternative to fluoroscopy in ATP fusion.[69,79,85] Xi and colleagues,[79] having reviewed over 200 cases with navigated ATP fusion, reported a high accuracy rate of 94.86%. Only one patient returned for revision surgery, and the rate of transient neurologic symptoms was 10.28%, within the normal expectations of ATP fusion surgery.[79] Navigated assistance was shown to be safe and effective. Further, its use reduces exposure to harmful radiation to the surgeon and operative staff. Additionally, the ATP approach allows for two sets of surgeons to perform ATP fusion and posterior fixation simultaneously during single-position surgery. Ouchida and colleagues[86] found that single-position ATP fusion led to less blood loss, time spent in the operating room and surgery time, while exhibiting comparable clinical outcomes.

Diaz-Aguilar and colleagues,[87] recently published the first instance of robot-assisted single-position ATP fusion with posterior fixation. They reported their procedures to have accurate screw placement of 95%, a shortened OR time of 112 minutes, and no major complications. However, a larger study comparing robot-assisted to more traditional ATP fusion is warranted to fully understand its benefits. This is especially important as surgeons embark on the learning curve.

Lastly, in select cases, spinal endoscopy has been added to the ATP approach to assist surgeons treating disk herniation and seeking direct decompression.[88] Without endoscopy, direct removal of these damaged particles may be inhibited by interference of tubular retractor or difficult-to-access deeply located disk. Further, blind removal of these particles cannot be safely performed. By adding a spinal endoscope, fragments can be removed directly under endoscopic visualization.

SUMMARY

ATP fusion is a safe and effective method of LLIF that has applications across a diverse array of pathologies including degenerative spondylosis, spondylolisthesis, spinal stenosis, and scoliosis.[16–19] Its advantages over alternative lumbar interbody fusion methods include avoiding transgression of the psoas muscle and avoiding the lumbar plexus, and possible increased accessibility to L4-5 compared to the transpsoas approach.[10–13] Before the procedure, it is critical that vasculature is identified and bone density is evaluated. Although it can only be performed from the left, it is an alternative to the transpsoas approach.

CLINICS CARE POINTS

- ATP interbody fusion is a minimally invasive lateral, retroperitoneal approach for performing lumbar interbody arthrodesis.
- The advantages of the ATP interbody approach is that it avoid transgression of the psoas muscle when performing an LLIF.
- Patients with severe central canal stenosis may require an additional direct (posterior) decompression.
- The size of the corridor, as well as the location of key vascular structures, should be identified on preoperative imaging, while bone density should be evaluated prior to surgery.
- Transient leg weakness and sensory loss are the most common complications following ATP interbody fusion.
- Intraoperative navigation, robotic-assistance, and single-position surgery are emerging additions to the ATP interbody approach that may potentially improve workflow and efficiency.

DISCLOSURES

The authors have nothing to disclose.

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