Complications during anterior surgery of the lumbar spine: an anatomically based study and review

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Procedures involving anterior surgical decompression and fusion are being performed with increasing frequency for the treatment of a variety of pathological processes of the spine including trauma, deformity, infection, degenerative disease, failed-back syndrome, discogenic pain, metastases, and primary spinal neoplasms. Because these operations involve anatomy that is often unfamiliar to many neurological and orthopedic surgeons, a significant proportion of the associated complications are not related to the actual decompressive or fusion procedure but instead to the actual exposure itself. To understand the nature of these injuries, a detailed anatomical study and dissection was undertaken in six cadaveric specimens. Critical structures at risk in the abdomen and retroperitoneum were identified, and their anatomical relationships were categorized and photographed. These structures included the psoas muscle, kidneys, ureters, diaphragm and crura, esophageal hiatus, thoracic duct, greater splanchnic nerves, phrenic nerves, sympathetic chains, medial arcuate ligament, superior and inferior hypogastric plexus, segmental and radicular vertebral vessels, aorta, vena cava, median sacral artery, common iliac vessels, iliolumbar veins, lumbosacral plexus, and presacral hypogastric plexus. Based on these dissections and an extensive review of the literature, the authors provide a detailed anatomically based discussion of the complications associated with anterior lumbar surgery.

Key Words * anterior lumbar surgery * complication * cadaveric dissection

The first case in which the lumbar spine was exposed via an anterior approach reported in the literature in the 1930s by Capener[11] and Burns[10] who detailed their experiences with transperitoneal approaches for the treatment of spondylolisthesis. Since that time, anterior lumbar procedures have evolved due to increasing application for a variety of pathological conditions including trauma, deformity, infection, degenerative disease, sympathtectomy, failed-back syndrome, and primary or metastatic neoplasms.[1,13,17,21,23,29,31,35,36] Direct access to ventral lesions, sparing of the lumbar paraspinal musculature and improved postoperative mobility, decreased chronic muscular pain, avoidance of previous posterior surgical scars, and the ability to place bone graft in the predominant load-bearing column of the spine are only a few of the features that have popularized anterior techniques. It is now
well recognized that the ability to approach the ventral neuraxis safely is prerequisite for any modern surgeon who is involved in the management of patients with complex spinal disorders. The recent growth of minimally invasive and laparoscopic interbody fusion techniques has made facility with these ventral lumbar operations even more important.

The early experience with anterior approaches to the lumbar spine has demonstrated the myriad complications that may occur during the procedure. Because performing these approaches requires detailed knowledge of anatomical structures often unfamiliar to most neurological and orthopedic surgeons are unaccustomed, many spine surgeons undertake these operations in conjunction with a general, vascular, or urology surgeon. Despite this assistance, the majority of reported procedure-related complications are still related to injury of the visceral, vascular, pulmonary, lymphatic, and neural structures of the region and not to actual damage of the spinal cord and vertebral bodies.[1,4,5,14,16,19,27,32,36-38] Thus it behooves all spine surgeons to gain an intimate familiarity with the complex regional anatomy to minimize the risk of these fearsome complications.

After having reviewed the literature and our own surgical experiences, we compiled a list of the structures most commonly damaged during ventral procedures on the lumbar spine (Table 1). To shed light on the nature and cause of these injuries, we performed several detailed anatomical dissections in the ventral lumbar area. By delineating the location and course of the critical structures at risk, we identified the areas most likely to be injured during the anterior surgical approach and grouped the complications accordingly. Based on this analysis, a brief overview of the common anterior approaches and a detailed anatomically based discussion of their complications are provided.

| TABLE 1  |
| Complications of anterior lumbar surgery grouped by type |
| Type of Injury | Description |
| vascular | aorta & vena cava laceration or avulsion |
| | iliolumbar vein laceration, occlusion, or avulsion |
| | segmental vessel laceration or avulsion |
| | spinal cord ischemia & stroke |
| | retroperitoneal hematoma |
| visceral | splenic injury & rupture |
| | liver parenchyma injury & hematoma |
| | peritoneal tear |
| | bowel perforation & ileus |
| | pneumothorax | hemothorax |
| muscular | diaphragmatic injury or hernia |
| | abdominal wall & incisional hernias |
| | latissimus dorsi rupture |
| | psoas muscle hematoma & injury |
| urogenital | kidney injury |
| | ureteral injury | delayed stricture |
| | presacral hypogastric plexus injury | (retrograde ejaculation & infertility) |
| peripheral nerve | femoral nerve palsy |
| | incomplete lumbosacral plexus (root or nerve) injury |
| | sympathetic dysfunction |

MATERIALS AND METHODS

Six cadaveric trunks that included the thorax and abdominal contents were fixed in a 10% formalin
solution and their vessels were perfused with colored silicone rubber (Microfil; Canton Bio Medical Products, Inc., Boulder, CO). The filling of the arterial trees was performed under controlled manual pressure. In total, six anatomical dissections were performed with the aid of the gross dissecting microscope only. Two were completed via an anterior retroperitoneal approach through a standard midline incision, whereas in the other four a flank incision with an anterolateral approach to the lumbar spine was used.

The dissections were performed primarily to identify the critical abdominal and retroperitoneal structures at risk during the common approaches to the lumbar spine. These structures were the psoas muscle, kidney, ureters, diaphragm and crura, esophageal hiatus, thoracic duct, greater splanchnic nerves, phrenic nerves, sympathetic chain, medial arcuate ligament, superior and inferior hypogastric plexus, segmental and radicular vertebral vessels, aorta, vena cava, median sacral artery, common iliac vessels, iliolumbar vein, lumbosacral plexus, and presacral hypogastric plexus. We attempted to identify each of these in all the cadaveric specimens. Photographs of the optimum prosections were obtained and labeled.

RESULTS

The salient findings of our dissections are summarized in the following sections and illustrated by photographs. Prosection photographs were limited to the retroperitoneal area and to other structures commonly at risk during anterior lumbar spine approaches. Although perforation of the bowels and viscera is clearly a significant risk during these procedures, we have omitted a detailed description of them for the sake of brevity and clarity.

Anterior View of Retroperitoneal Contents

Figure 1 provides an anterior view of the retroperitoneal contents after the abdominal viscera, peritoneum, and retroperitoneal fat were removed. The great vessels are seen in proximity to the disc spaces and vertebral bodies, and by visualizing their association we could see how vascular injury can occur during procedures performed via both anterior and posterior approaches.
The psoas muscle lies along the anterolateral aspect of the spine between the transverse processes and the lateral vertebral bodies and disc. The kidney, ureter, and perinephric fat are located anterior to the psoas and are usually mobilized medially during retroperitoneal exposures. The ureter passes along the psoas muscle and then lies anterior to the iliac vessels. Although there have been reports of ureteral injury during posterior approaches, in our study it was usually located laterally, and it was easily mobilized so as not to cause injury during retroperitoneal exposures.

The crura of the diaphragm lie along the anterolateral aspect of the upper lumbar vertebral bodies, and their tendinous fibers merge with the anterior longitudinal ligament. They must be incised and mobilized during exposure of the upper lumbar spine.

The sympathetic chain which enters the abdominal cavity from beneath the medial arcuate ligament, can be seen along the anterolateral aspect of the vertebral bodies along the entire length of the lumbar spine. The superior hypogastric plexus and inferior hypogastric plexus can be seen in this specimen along the aorta and near the L5/S1 disc space. Injury to these structures may cause retrograde ejaculation, infertility, and incontinence.

**Anterolateral View of Upper Lumbar Area**

In the specimen shown in Fig. 2, we see the esophageal hiatus and the opening for the vena cava and the
aorta. The muscular diaphragm and its tendinous attachments to the lumbar spine form these apertures. Knowledge of diaphragmatic anatomy is important to obtain exposure as well as proper closure to prevent postoperative complications such as hernia and pulmonary problems.

Fig. 2. Intraoperative anterolateral view of the upper lumbar area.

The diaphragm is composed of a central tendinous portion and a muscular portion. In the central tendinous portion there is no bony attachment, and it exerts its effects through the attachments of the muscular portions. Each side of the body has three muscular portions. The costal portion is attached to the six costal cartilages and the lower four ribs, and the sternal portion attaches the central tendon to the back of the xiphoid process.

The lumbar muscular portion is located near the anterolateral aspect of the upper lumbar spine and must be mobilized when surgery is performed in this region. This lumbar muscular portion has two origins: one is the median and lateral arcuate ligaments, which are fibrous arches over the psoas and quadratus muscles, respectively; the other is from the crura, which arise from the bodies of the upper lumbar vertebrae and ascend to where they are attached to the central tendon. The right crus arises from the upper three lumbar vertebrae, and the left crus arises from the upper two. As the crura join, they form the aortic opening, which also passes the thoracic duct and greater splanchnic nerves.

The surgeon exposing the upper lumbar spine must often divide the crura and reflect them laterally to
gain exposure. It is often helpful to place a making suture for closure and reapproximation. Because the nerve is supplied via the phrenic, which enters medially and innervates the diaphragm toward the periphery, the diaphragm should be incised peripherally with a small cuff left for closure.

Lateral View of the Psoas Muscle and its Origin

Figure 3 shows the lateral view of the psoas muscle at its origin. The psoas muscle is a long fusiform-shaped muscle that occupies the anterolateral aspect of the lumbar spine between the lateral vertebral bodies and the transverse processes. It must be mobilized to gain access to the spine and can be of formidable size in young athletic patients. Knowledge of its anatomy can make for easier exposure and prevention of complications.

The psoas muscle is innervated by branches of the lumbar plexus that contain fibers from L-2, L-3, and L-4. The psoas functions as a powerful flexor of the thigh at the hip joint. It may assist in maintaining an erect posture by preventing hyperextension at the hip joint. The anatomy and function of the psoas muscle are surgically relevant for the spine surgeon. If the body is flexed at the hip to relax the psoas for mobilization during surgery, retraction of the muscle will be easier and will prevent traction on the lumbosacral plexus, which is located within its substance.

Lateral View of the Aorta and Vena Cava

Figure 4 provides a lateral view of the aorta and vena cava. The aorta has paired segmental vessels at the
lumbar levels that pass laterally over the vertebral body at the midportion of the vertebral body. The disc spaces are prominent, and the midvertebral levels can be seen as valleys when observed from the lateral view.

Fig. 4. Intraoperative lateral view of the aorta and vena cava.

The segmental vessels are attached by soft tissues and can be mobilized and tied off. The segmental vessels actually arise from the dorsal surface, as seen in the specimen shown in Fig. 4. If the vessel is ligated too close to the aorta, it may retract beneath the aorta and be very difficult to locate if it continues to bleed. The blood supply to the spinal column is derived from these segmental vessels, which supply two networks: one feeds the bony elements of the vertebrae, the paraspinal muscles, and the extradural space; and the other, an inner network, nourishes the spinal cord itself.

The segmental arteries hug the vertebral bodies, giving off a main dorsal branch as they approach the neural foramina. This main dorsal branch continues posteriorly below the transverse process, supplying the bone of the posterior elements and the paraspinal muscles. Shortly after its origin, the dorsal branch gives off an intraspinal branch, which feeds the nerve root and dura. At certain levels, separate vessels arising from the dorsal segmental artery supply the anterior two thirds of the spinal cord. These are known as anterior segmental medullary arteries. One large vessel occurs commonly at the upper lumbar or lower thoracic levels: the artery of Adamkiewicz. This is considered a major feeding vessel to the anterior spinal artery and if ligated may cause paraplegia.

The bifurcation of the great vessels is variable, and its recognition is important for approaches to the L4/5 and L5/S1 disc spaces. The bifurcation of the vena cava occurs lower than that of the aorta and is usually located above the L5/S1 disc space. The vena cava bifurcation can be observed to the right of the aorta, and the left common iliac vein passes through the aortic bifurcation. Injury to the left common iliac vein is common during approaches to this area. The median sacral artery, the third branch or the termination of the artery, may need to be ligated for approaches to the L5/S1 disc space. It is generally small and easily mobilized. Electrocautery in this area should be minimized to prevent injury to the presacral hypogastric plexus.
Anterolateral View of Sympathetic Chain

The sympathetic chain consists of a series of ganglia that are connected by intervening cords extending along the lateral aspect of the vertebral column from the base of the skull to the coccyx (Fig. 5). The trunk contains ganglia, preganglionic myelinated fibers, and postganglionic unmyelinated fibers. All fibers may run up and down the trunk for several levels before synapsing. White rami communicantes contain spinal nerve outflow to the chain, and gray rami are the branches to the spinal nerves and postganglionic fibers. The gray rami are found in all the nerves, and the white are found only on the thoracic and upper two lumbar levels. The sympathetic trunk enters the abdominal cavity from within the psoas, behind the medial arcuate ligament, descending on the vertebral bodies with close approximation to the attachment of the psoas.

Fig. 5. Intraoperative anterolateral view of the sympathetic chain.

Lateral View of the Sympathetic Chain

The specimen in Fig. 6 shows, from a lateral view, the sympathetic chain with rami communicantes going to and from the spinal nerves. Identification of this chain can be difficult when inflammation of the prevertebral soft tissue has been caused by the pathological entity, prior trauma, infection, or surgery. Inadvertent transection and injury of the sympathetic chain near the discs and vertebral bodies during exposure and decompression is not uncommon.
Fig. 6. Intraoperative lateral view of the sympathetic chain.

**Anterolateral View of the Presacral (Superior) Hypogastric Plexus**

Figure 7 depicts the anterolateral view of the presacral (superior) hypogastric plexus. The urogenital system is innervated by three basic nerve complexes through the pudendal nerve: the sympathetic, the parasympathetic, and the somatic. Sexual function is directly affected by these nerves. The sympathetic nerve supply is a directed continuation of the thoracolumbar sympathetic nerves coursing along the anterolateral aspect of the vertebral bodies of the lumbar spine. At the level of L-3 and L-4 these ramify about the inferior mesenteric artery and the inferior mesenteric ganglion (inferior mesenteric plexus). Nearly 80% of the ramifications occur on the left side of the aorta. Once ramified, these fibers are referred to as the superior hypogastric plexus as they course distally. These superior hypogastric fibers are found in the retroperitoneal space alongside the left side of the aorta, and they cross the left common iliac artery and vein, lying anterior to L-5 within the prevertebral space. These sympathetic fibers control the normal transport of sperm and ejaculation of sperm, and they prevent retrograde ejaculation by closing the bladder neck during ejaculation. Electrocautery should be minimized during this dissection.
Fig. 7. Intraoperative anterolateral view of the presacral (superior) hypogastric plexus.

Anterior View of the L5/S1 Disc Space and Presacral Hypogastric Plexus

The specimen shown in Fig. 8 demonstrates the proximity of the presacral hypogastric plexus to the L-5 and S-1 vertebral bodies. Injury typically occurs here during exposure of the L5/S1 disc space during procedures involving anterior interbody fusion and discectomy. The incidence of retrograde ejaculation that occurs after operation has been performed near this area is somewhat controversial. In Fig. 8 also note the arterial and venous structures, the proximity of which places the plexus at risk during attempts to control bleeding. Although it was not performed in our specimen, a transperitoneal approach in which the posterior peritoneum on the right side of the aorta is opened, and subsequent mobilization of the plexus to the left as a means to prevent injury has been recommended by some authors.
Fig. 8. Intraoperative anterior view of L5/S1 disc space and presacral hypogastric plexus.

**Anterior View of the Lumbosacral Plexus**

As seen in the intraoperative photograph in Fig. 9, the right psoas muscle has been dissected free to reveal the lumbosacral plexus. Its fibers derive from the ventral primary rami of T12--S4 and penetrate within the substance of the psoas muscle. The rami enter from the posteromedial aspect of the psoas and then pass anterolaterally. Also of note is their proximity to the disc annuli, which again creates risk during lateral disc decompression, graft placement, and instrumentation insertion. Anomalies are not uncommon and can occur up to 20% of the time.
Lesions of the plexus can occur during retraction of the psoas for anterior spinal procedures, as well as a number of nonsurgical entities including malignancies, radiation change, psoas abscesses, and zoster infections.

**Lateral View of Lumbar Vertebrae After Removal of the Psoas Muscle**

As seen in Fig. 10, the probe is placed beneath the tendinous arch, which is one of the origins of the psoas muscle. The radicular vessels pass beneath these arches. The psoas muscle is not attached to the vertebral body itself at the midbody level but is attached to this structure. The psoas is attached to the body at the endplate. The fibers of this fibrous arcade are incised to mobilize the psoas laterally. Accidental injury of the vascular elements can occur during mobilization of the psoas muscle if caution is not exercised. In this case the segmental vessels should be ligated and doubly tied, if possible, to prevent accidental avulsion and rebleeding.
Anterior View of the Ascending and Iliolumbar Vein and Close-Up View of the Ascending Lumbar Vein

The iliolumbar vein begins on the lower part of the posterior lumbar wall and courses medially deep to the psoas to join the left common iliac vein (Fig. 11).

The iliolumbar vein is a left-sided venous segmental structure. In that way it is similar to the other segmental veins that are at each midvertebral level and drain into the vena cava. The low-lying location
and the frequently large size of this vessel are important to note. The vein begins on the lower part of the posterior lumbar wall and courses medially deep to the psoas to join the left common iliac vein. If the vein attaches directly to the vena cava, it may then be considered the fifth iliac. It may have connection with the ascending lumbar vein, which is shown in the specimen depicted in Fig. 12. Because the anatomy of the veins in this area is quite varied, it must be examined prior to retraction of the vena cava to the right to prevent disastrous hemorrhage.

![Image of ascending lumbar vein](image)

Fig. 12. Intraoperative close view of the ascending lumbar vein.

**DISCUSSION**

In his analysis of anterior interbody fusions, Watkins[37,4038 classified the complications of ventral lumbar spine surgery into five main categories: those of patient selection, visceral injury, vascular injury, interbody fusion technique, and donor graft site. More simply, Bell[4] has divided these complications into the pre-, intra-, and postoperative phases of the procedure. Our intent was to focus primarily on the surgery-related complications associated with the surgical approach itself. Complications related to the graft, donor site, instrumentation, and failure of fusion are more extensively reviewed elsewhere.[1,5,13,34,36,37] Based on findings in our anatomical dissections, it is clear that the majority of the structures at risk are encountered during the approach itself. A brief overview of the most common approaches used during anterior fusion procedures is presented. A detailed anatomy-based discussion of the attendant complications follows.

**Transperitoneal Approach**

Whereas it is generally used for approaches to the L5--S1 level, the transperitoneal approach is also used when injury of the retroperitoneal space has been caused by prior surgery or radiation therapy. The
disadvantages of the transperitoneal approach are the risk of peritoneal cavity contamination by infection or tumor, difficulty with preexisting adhesions, the need for a preoperative bowel preparation, and a greater risk of visceral injury, as well as the need for increased mobilization of the great vessels, less extensive exposure of the superior lumbar spine, and the increased risk of an ileus postoperatively.

The transperitoneal approach to the lumbar spine is generally performed via a midline, paramedian, or Pfannenstiel's incision. The level of the disease determines the location of the incision. Usually, a subumbilical incision is made just above the level of the pubic symphyses for an L5--S1 lesion. The incision is extended through the midline fascia, and the peritoneum is cautiously opened. The viscera are packed off with moist laps, and a self-retaining retractor system is placed. The posterior layer of peritoneum overlying the great vessels is carefully identified and incised, and the peritoneum is incised sufficiently to allow for its lateral elevation over the bifurcation. The hypogastric plexus of nerves is located in this soft tissue, and care must be taken when mobilizing these nerves off of L-5 and the area of the bifurcation.

**Retroperitoneal Approach With Flank Incision**

This lateral approach provides access to the lumbar spine from the L-1 vertebral body to the L4/5 disc space. For operations at the L5--S1 levels, the midline/paramedian retroperitoneal or the transperitoneal approach will provide better access. In approaches to the T12/L1 interspace, the diaphragm will have to be taken down for a modified thoracolumbar technique. Generally, we perform a left-sided approach, while the patient is in lateral position, because the spleen is easier to retract than the liver, and the unique anatomy of the bifurcation of the great vessels makes the approach to the L4/5 disc space much easier from the left. It is important to note that the superior or ipsilateral leg should be flexed to relax the psoas muscle and allow for gentler retraction of the ipsilateral lumbosacral plexus.

The skin incision should be centered between the lowest rib and the iliac crest, and minor adjustments should be made depending on the appropriate level. The incision should be S-shaped, with the abdominal aspect curving inferiorly as it approaches the midline and the posterior aspect curving gently cephalad. This is done to avoid cutting the rectus abdominus ventrally and the quadratus lumborum dorsally. The incision is extended down to the external oblique fascia. At this point, one may choose to perform a muscle-splitting approach that will split the fibers of all three muscle layers along their natural path. Retractors are then placed, and a small exposure to the lumbar spine is available. This muscle-splitting approach is generally not adequate when surgery is to be performed in multiple levels or when a radical decompression is desired. In the more common muscle-cutting approach, the external and internal oblique and the transversus abdominus muscles are incised. The rectus abdominus muscle should be spared at the medial aspect of the incision. Once the transversus abdominus muscle is incised, the loose areolar tissue of the retroperitoneal space is visualized. The thin translucent peritoneum can be seen, and the plane is developed with blunt dissection. The peritoneum is gently swept off the posterior abdominal walls and the abdominal surface of the diaphragm.

The abdominal contents, which are being held by the peritoneum, are then retracted medially. The kidney, ureter, and perinephric fat are located in the retroperitoneal space. The kidney is surrounded by a collection of fat known as the "perirenal fat." The connective tissue located ventral and dorsal to the kidney condenses to become the renal fascia, which envelops the kidney and surrounds the perirenal fat. There is another collection of fat surrounding this fascia, called the "pararenal fat." When mobilizing the kidney medially, one should retract the renal fascia and take care not to enter into the pararenal fat. The
The psoas muscle is identified and is the key to identifying the spine. The medial aspect of the psoas muscle is attached to the spine, and the vertebral bodies and disc spaces can be palpated. Once a disc space is identified the psoas muscle is dissected from the vertebral body by incising its attachments to the fibrous arcades that form its origin on the vertebral body.

Retroperitoneal Approach With a Paramedian Incision

In this approach the retroperitoneal approach via a paramedian incision is used and is best undertaken for the L5/S1 interspace, although it may be used for L2--4 as well. The patient is placed in the supine position, with the abdomen fully draped. An incision is made just at the lateral aspect of the rectus sheath, and the anterior rectus sheath is incised. The rectus muscle is usually split, and the posterior rectus sheath is grasped and carefully incised so as not to cut through the peritoneum. We now spare the rectus by mobilizing it aggressively and retracting it medially out of the surgical view. Once the peritoneum is identified, it is swept off the abdominal wall with blunt dissection. An alternate method is to incise the fibers of the fascia transversalis below the arcuate line. Blunt dissection can then be used to find the plane between the peritoneum and the fascia transversalis, and this can be incised rostrally. The L5/S1 disc space is approached by mobilizing the great vessels at the bifurcation. Because the vascular anatomy at this level is somewhat varied, we will further discuss the mobilization of the great vessels to gain access to this level. The surgeon should confirm the level of the L5/S1 disc space by obtaining an intraoperative x-ray film. The bifurcation of the vena cava occurs in a region lower than that of the aorta and is usually located above the L5/S1 disc space. The vena cava bifurcation is located to the right of the aorta, and the left common iliac vein passes through the aortic bifurcation.

This approach may also be used in L2--4 procedures. This requires that the vena cava and aorta be mobilized to one side for access to the disc spaces. Even after mobilization of the vessels, the exposure generally is not as good as that obtained via the flank incision. When extensive debridement and reconstruction are needed, the flank incision is preferred because it allows greater exposure lateral to the great vessels.

Vascular Complications

According to Baker, et al.,[3] vascular injuries during anterior lumbar spine surgery may occur in up to 15% of cases. This incidence is higher than had been previously thought and is important to consider because these complications can be potentially life threatening. Injury to the vascular structures can be divided into the following regional areas: 1) the main trunk of the aorta and vena cava; 2) the region of the bifurcation, the iliolumbar (ilioinguinal) vein, (during approaches to the left side of the L4--5 disc space); and 4) the segmental or radicular vessels at each segment.

Most intraoperative mistakes occur because the vessels are not properly dissected, identified, and managed. If the radicular vessels are not properly suture ligated, it is possible for these vessels to retract under the aorta and cause persistent vigorous bleeding. This is because the radicular vessels arise from the ventral surface of the aorta and can retract beneath when cut (Fig. 4). Osteophytic spurs, degenerative changes, infection, radiation, history of trauma, and prior surgery can all cause reactive inflammation of the prevertebral soft tissue as well as scarring and adherence of the vessels, thereby increasing the chance of injury during dissection.[36]

The termination of the aorta and the origin of the inferior vena cava each form a Y-shaped bifurcation. The aorta is typically anterior and left with the vena cava lying posterior and right. Based on our
dissections (see Figs. 1, 4, 7, 8, and 11), we found that the aortic bifurcation is usually found immediately anterior to the body of the L-4 vertebra. It is also less commonly located at the L4/5 and L3/4 disc spaces.[27] Similarly, the origin of the common iliac veins was observed mainly at the L-5 vertebral body and less commonly at the L4/5 disc space and the L-4 vertebral body. Based on the level of the aortic split and the vena cava bifurcation, Louis[25] has described six primary variants of the aortocaval anatomy: 1) the aorta bifurcates at L4/5 disc space, and the iliac veins join together just below and to the left of this point (63.5%); 2) dissociated anatomical position with the aortic bifurcation more than one level cranial to the origin of the vena cava (9.7%); 3) unusually high position of the aortic bifurcation, cranial to the L3/4 disc, and of the origin of the inferior vena cava above the L4/5 disc space (8.0%); 4) aortocaval vessels are seen forming a complex intertwining network (7.3%); 5) paradoxical aortocaval axis with the aortic bifurcation located caudal to the vena cava split (6.4%); and 6) unusually low bifurcation of the aorta and origin of the inferior vena cava, near the center of L-5 and at the L5/S1 disc space, respectively (5.1%). As such, adequate preoperative evaluation of the vasculature may help to prevent unnecessary intraoperative problems. Not only can anatomical variants be excluded but other unpleasant surprises such as aortic aneurysms, pseudoaneurysms, and large calcified vessels can also be identified.

The collateral branches of the aorta that lie anterior to the lumbar vertebrae form the inferior mesenteric artery, the middle sacral artery, and the segmental lumbar vessels (Fig. 3). The inferior mesenteric trunk arises at the ventral aorta, usually at the L2/3 or L3/4 disc space as was observed in our dissections, and then passes to the left mesocolon (Fig. 2). Importantly, distal autonomical innervation of the gut passes with these vessels as well. The middle sacral artery arises from the dorsal aspect of the aortic Y and courses anteriorly on the sacral surface, usually running with the middle sacral vein (Fig. 11). They are often deliberately sacrificed during the anterior approach to the L5/S1 disc space and usually bear no adverse clinical consequence. However, aggressive electrocautery in this region places the hypogastric plexus again at direct risk. The paired metameric lumbar arteries and veins course laterally over the "valleys" or depressed portions of the vertebral bodies toward the neural foramina. These segmental vessels are thus particularly prone to injury during exposure of the body and psoas muscle mobilization. During our dissections, the most critical area was that in which the radicular vessels passed beneath the tendinous arch of the psoas insertion (Fig. 10).

Regardless of the choice in approach, adjustments are often needed intraoperatively to accommodate the particular anatomy encountered. Many authors have preferred a left-sided approach because aortic repair is technically easier, as is splenic retraction. However, because the use of some anterior spinal fixation devices, notably the Dunn device, has been associated with delayed aortic erosion and retroperitoneal hemorrhage, some surgeons have recommended a right-sided approach in cases requiring instrumentation (unpublished data). Anteriorly placed instrumentation devices should be used with caution at the thoracolumbar junction as well because of the increased proximity of the great vessels to the lateral vertebral bodies (Fig. 2).[6]

If the bifurcation of the vena cava is high enough above the L5/S1 disc space and the left common iliac vein is sufficiently lateral to the disc space, then the approach can be performed between the iliac veins. In a certain number of cases in which the bifurcation is low and the left common iliac vein courses directly over the disc space, a lateral approach to the disc space performed by mobilizing the left common iliac vein and artery to the midline is required (Fig. 5). This left iliac vein can be very thin, attenuated, and adherent to the L5/S1 disc space (Fig. 11). A common anomaly encountered here is a large, bulbous, left iliac vein that is particularly difficult to retract.[37] Finally, retraction of large venous
structures can cause the lumen not to fill and to collapse, which is misleading. As such, the veins can be accidentally confused for a ligament and sectioned, only to bleed vigorously later on. Care must thus be taken when incising the annulus to ensure that a fold of temporarily collapsed vein is not confused with a portion of the annulus.

The artery similarly is particularly prone to retraction injury during exposure of the L4/5 disc space, with resultant temporary spasm, thrombosis, or frank occlusion.[4] The left iliac arterial pulse should be rechecked during and after the procedure, and attention should be paid to releasing retraction every so often. Thrombotic occlusions of the vessels due to prolonged compression and also surgically induced coagulopathies have also been reported.[31] Avoiding the use of "stay" retractors can prevent inadvertent occlusion of the vessel in this region.

In addition to the aforementioned structures at risk, the iliolumbar vein can often be extremely troublesome for the surgeon as well. This vein was commonly, but inconsistently, seen as a vessel directly off the vena cava or the left iliac vein in our dissections (Fig. 11). When originating off the vena cava, it is technically termed the L-5 vein. It is specifically designated the iliolumbar vein when it originates off the left iliac. After its origin, it typically courses directly lateral to join with the highly variable ascending lumbar vein complex (Fig. 12). This ascending venous system, which drains blood from the extraspinal venous plexi, is located on the lateral aspect of the vertebral bodies at the level of the neural foramina. During dissection of the neurovascular and soft-tissue structures, because the iliolumbar vein often becomes directly tethered, it is in danger of being avulsed off its parent vessel. The amount of bleeding thus encountered can be copious and impossible to control using direct pressure alone. Furthermore, the use of blind cautery carries with it the unacceptably high risk of hypogastric plexus injury.[36,37] Therefore, special attention should be paid to identifying this precarious structure early on in the exposure, prior to caval or iliac vein mobilization. Its origin should be clearly seen, clamped, tied, and cut. Our experience with the lumbar venous anatomy has demonstrated that variability is the rule rather than the exception.

Visceral Complications

The types of visceral injuries that can occur during the initial approach are protean in nature. Some of the reported injuries in the literature include splenic rupture,[18] hepatic injury,[1] bowel perforation, urogenital injury (see below), peritoneal tears, intussusception, superior mesenteric artery syndrome,[9] atelectasis, pneumonia, pulmonary embolism, postoperative ileus, pneumo/hemothorax, chylothorax, and acute cholecystitis.[2,8,15,24] A detailed discussion of each is beyond the scope of this review. Prevention of these injuries should focus on meticulous surgical technique as well, ensuring that appropriate assistance from relevant surgical specialists is available. For transperitoneal approaches, direct visualization, slow, cautious dissection, and avoiding unnecessary traction are principles that are useful in preventing visceral injury.

In retroperitoneal approaches, delicate handling of the peritoneum itself will ensure safety of the visceral contents within. In cases in which there is prior infection, a history of radiation therapy, or scarring, the presence of peritoneal adhesions can make a clean dissection nearly impossible. In our specimens, the peritoneum was also commonly adherent over the lateral wall of the abdomen and over the psoas musculature. Slow, meticulous dissection by using a combination of sharp and blunt techniques, as well as possessing an intimate knowledge of the abdominal layers, will help to keep peritoneal perforations to a minimum.[38] In our study, we found that the abdominal wall layers were generally thicker and better
developed laterally, with a well-defined transversus abdominus muscle and a cleaner peritoneal plane. Medially, these layers often become thin, flat, tendinous, and more coherent. In parapectus retroperitoneal approaches, the peritoneum should thus be identified just lateral to the rectus sheath. The risk of peritoneal perforations is reported to be higher when it is located medially.[37] Peritoneal tears should be repaired immediately to prevent enlargement. Dissection around the hole can be performed for better visualization and protection of the abdominal contents from the needle while placing the purse-string.

Bowel perforation itself often accompanies peritoneal violation in cases in which inflammation has caused the serosal surface to become adherent. In conjunction with being oversewn primarily, the area around the perforation should also be aggressively irrigated to prevent local abscess formation and peritonitis. Because torsion and mechanical ileus can also result, anatomical repositioning of the bowels and their mesentery prior to wound closure is warranted.[1,27]

The pulmonary parenchyma and parietal pleura are usually only at risk of being injured in cases of high lateral retroperitoneal and thoracolumbar approaches. During division of the diaphragm and crura, pleural violation is not uncommon because the parietal surface is adherent superiorly. Extrapleural approaches above T-11 are technically daunting and not recommended. The pleura may also be violated when aggressive dissection is performed between the transverse processes of L-1 and L-2.[1] To decrease atelectasis and prevent a possibly life-threatening complication the lungs should be inspected under positive ventilation and with the wound filled with irrigation to check for bubbles. Early placement of a chest tube should be undertaken in cases of suspected injury. Similarly, the thoracic duct also runs in close proximity to the right diaphragmatic crus. (Fig. 2) and may be injured during thoracolumbar procedures with resultant chylothorax.[30] Leakage in the lymphatic system can be recognized during surgery, and if possible, the stump should be ligated both proximally and distally, and a temporary drainage system should be placed. As was often the case in our dissections, the thoracic duct is thin, collapsed, and not identifiable.

Muscular Complications

Injury of the diaphragm most commonly occurs during lateral thoracolumbar approaches in which division of it and the crura is needed. As the phrenic innervation of the diaphragm enters centrally, division of it within 2.5 cm of its peripheral attachments to the xiphoid, costal cartilages, and lumbocostal arches will not interfere with respiratory function of the muscle (Fig. 2).[38] The placement of stay sutures at regular intervals during takedown of the diaphragm aids in the exact closure, and it helps to prevent delayed diaphragmatic hernias. As discussed above, the crura are also sometimes divided and reflected laterally to gain exposure. Reapproximation of these structures is important as well.

It is crucial that the spine surgeon be familiar with the anatomy of the abdominal wall layers and musculature. The exact skin incision varies according to the targeted vertebral level, as described above. The flank muscles act as an overall constrictive circular band that is tethered between two longitudinally arranged bands of muscle (lumbodorsal and rectus abdominus). The integrity of this cylindrical trunk is essential to maintain rigidity of the trunk and proper posture. The layers (from superficial to deep) are the external oblique fascia and muscle, internal oblique, and transversus abdominus. The fascia transversalis is continuous with the fascia of the psoas muscles, diaphragm, iliac muscle, and the pelvic cavity. The fascia transversalis covers the deep surface of the transversus abdominus and, with its fascial investments, forms a complete envelope around the entire peritoneal cavity. Between the two surfaces exists a variable amount of loose areolar and fatty tissue. It is this plane that is key to maintaining an
extraperitoneal dissection.[11,13,17,21,27,31,36] Cautious closure and reapproximation of each individual muscle layer with slowly absorbing suture are crucial to prevent abdominal wall and incisional hernias. Excessive retraction of the superficial skin and muscle flaps can also lead to injury and hematoma of the latissimus dorsi along its lateral aspect. Injury to the psoas muscle is discussed in more detail in the **Peripheral Nerve Complication** section.

**Urogenital Complications**

Urogenital complications are also of concern in anterior exposure of the L5--S1 level. Direct injury of the kidney and ureter can occur anytime during the approach. Bladder injury is rare but can occur in an inadequately decompressed bladder under intense retraction pressure. Figure 1 shows the relationship of the ureter and kidney to the vertebral column, psoas, and vasculature. Although retroperitoneal in their location, urogenital injury commonly occurs during peritoneal mobilization and also during psoas muscle mobilization. Kidney injury commonly occurs during an extraperitoneal dissection in which inadvertent entrance into the fat located posterior to the renal fascia leads to a blind space behind the psoas muscle. Ectopic and horseshoe kidneys have been encountered, and they significantly increase the risk associated with the procedure.

Aggressive retraction of the peritoneal contents can cause direct compression on the kidney as well as causing delayed ureteral strictures. As a result, delayed hydronephrosis can be caused by retroperitoneal fibrosis and stricture.[12] Furthermore, mechanical correction of severe curves and aggressive positioning may cause angulation of the ureter with hydronephrosis as well.[20] Every attempt should be made to identify the ureter during lateral retroperitoneal approaches to prevent blind injury. In patients without prior inflammatory changes, the ureter is identified by its tubular shape, rich vascular anastamotic supply, and peristaltic motion.[36] If mobilization is needed, it is best performed by including a generous portion of the periureteric tissues to avoid vascular compromise.[27] In transperitoneal approaches, the ureter is usually far lateral enough not to be routinely encountered. Tears and avulsions should be primarily repaired early in the procedure by a urology surgeon. To prevent infection, meticulous attention should be paid to preventing the soiling of the surgical site with urine.

The peritoneum in the midline over the disc space, aggressive use of electrocautery, traction of the flap containing the vessels and plexus, graft migration, and accidental ligation have all been reported as causes of plexus injury at this location.[1,4,5,13,16,19,31,38] As evident in the photograph in Fig. 7, one can easily appreciate the proximity of the plexus to the left common iliac vein, iliolumbar vein, disc space, and median sacral artery. The parasympathetic nervous system innervates the urogenital system.
through the S-2, S-3, and S-4 segments; these leave the anterior sacral foramina well below the sacral brim and course as pelvic splanchnic nerves. These nerves are usually not involved in surgical exposures of the lumbar spine. Following dissection, sterility can occur if sperm transport is interrupted, but retrograde ejaculation occurs more frequently because the nerves to the bladder are more susceptible. Symptoms that occur are retrograde ejaculation and dry ejaculation, infertility due to the lack of spermatozoa transport, and bladder incontinence in women due to incompetence and leakage at the internal urethral sphincter.[19]

In 1965, Sacks[32] originally described retrograde ejaculation as a consequence of anterior lumbar surgery. Since that report, the true incidence of these complications has been hotly debated. A recent worldwide survey conducted by Flynn and Price[16] of 20 surgeons who had performed approximately 4500 anterior approaches to the spine revealed a remarkably low (0.42%) incidence of retrograde ejaculation and infertility. The authors suggested that careful surgical technique could decrease the incidence of this complication, emphasizing that one should know the anatomy and visualize the nerves prior to mobilizing them off the disc space. Use of the electrocautery should also be avoided in this area. Incision of the posterior peritoneal plane along the right side of the aorta and along the right common iliac artery is helpful as the left-sided sympathetic nerve fibers are usually dominant. Subsequent mobilization of this flap with the plexus to the left has been found to decrease the incidence of inadvertent injury (Fig. 12). [19] Some authors have recommended a left-to-right approach as well. Injection of saline solution into the dorsal peritoneal tissue is also useful to elevate the peritoneum off the hypogastric plexus.[28] The principles of avoiding midline dissection, clip ligation of the middle sacral artery and vein, using blunt dissection when possible, and avoiding a second approach to the L5/S1 disc space are, however, uniformly emphasized.[16,27,36-38]

**Peripheral Nerve Complications**

The most common complication in our experience is transient lower-extremity weakness secondary to either psoas muscle trauma or lumbosacral plexus nerve injury. In our dissections (Fig. 9), the lumbosacral plexus was seen to arise from the ventral rami of T-12 through S-4. It then coursed to penetrate the substance of the psoas in its posteromedial aspect and coursed anterolaterally to form the discrete named nerves. As a result of this position, the nerves in the plexus may be injured whenever the psoas muscle is being stripped or retracted.[1,4,27] Additionally, the genitofemoral nerve was seen to lie on the anterior surface of the psoas muscle in all our specimens (as suggested, but not labelled, in Fig. 3). Most iatrogenic injuries to the plexus are incomplete and resolve in time. In the case of a complete lesion of the lumbar plexus the patient would present with paresis and atrophy in the distribution of the femoral and obturator nerves: weakness of thigh flexion, leg extension, thigh eversion, and thigh adduction. Sensation may be lost over the inguinal region, genitalia, and the lateral anterior and medial thigh. The patellar and cremasteric reflex may be lost on that same side as well.

In several recent articles, the investigators have focused on the possible pathogenesis of these injuries.[26,37] One possible mechanism of injury may occur when excessive force is exerted on the psoas muscle during retraction. As can be inferred from the photograph in Fig. 9, it can be appreciated that the acute angle of the superior rami near T-12 through L-2 makes these roots particularly prone to traction injury. Additionally, excessive cautery to control often poorly visualized muscle perforator vessels can lead to thermal injury of the rami as they pass anteriorly. The surgeon can minimize these complications by knowing the exact attachment of the psoas muscle and by only exerting appropriate force at this level. It is also important to mobilize the psoas muscle adequately in a rostrocaudal and
mediolateral direction so as not to create a tethering effect at the ends of the exposure and to decrease the risk of a hematoma.[1,27] Retractor blades with teeth that are used to hold back the psoas muscle may also injure the plexus within its substance. Particular attention should be paid to preventing injury to the superficially located genitofemoral nerve.[4] Use of Steinmann pins in situ as well as other gentler retraction techniques to prevent this type of injury has been described.[38]

Improper positioning of the patient can also cause injury to the lumbosacral plexus. Any position that causes increased tension of the psoas muscle and the ipsilateral plexus may increase the risk of compression damage. Lateral bending of the lumbar region may also create unwanted tension on the nerves. Flexion of the leg at the hip and knee ipsilateral to the exposure site helps to minimize these forces.

Distal weakness and paralysis can also be caused by direct injury of the cauda equina. This complication usually results from direct penetration into the canal during decompressive or grafting procedure and can be prevented by proper handling of the surgical instrument and interbody grafting techniques.[5,27] Measuring and marking instruments carefully, leaving a posterior pillar of bone in cases in which neural decompression is unwarranted, controlling impaction techniques, proper measurement of grafts, and obtaining appropriate intraoperative depth and graft x-ray films are all useful measures to decrease the chance of this rare complication.[37]

The lumbar sympathetic chain (from T12--L4) also lies in extreme close proximity to the lateral aspect of the vertebral bodies and disc spaces. Accordingly, we found that this chain was extremely vulnerable to injury during anterolateral exposure of the vertebral column (Fig. 5). Indeed, division of branches between the paraspinous chain and the superior hypogastric area was often unavoidable so as to attain adequate visualization of the disc space and/or vertebral body. The proximity of the rami communicantes to the disc endplates and annulus makes them especially vulnerable (Fig. 6). Most commonly, unilateral sympathetic nerve injury has occurred in patients who complain that their contralateral foot is cold. In fact, it is the ipsilateral foot that is warm as a result of unopposed vasodilation by parasympathetic fibers.[4,33] Although quite disconcerting, it is a clinically benign condition, and typically reassurance of the patient is all that is needed. Routine evaluation of the "cold" extremity's pulses is warranted, however, to exclude the rare case of a vascular complication.[37] Partial sympathectomy at any level is not associated with erectile dysfunction or impotence in the majority of normal men. However, up to 50% of patients with advanced peripheral vascular disease can develop erectile impotence after undergoing extensive sympathectomy.[39] It is thought that the adverse effect on peripheral blood flow is the underlying cause of this phenomenon.[19]

CONCLUSIONS

Anterior lumbar surgical approaches provide excellent visualization of the lumbar vertebrae and can be tailored to the specific level of the disease. During the surgical exposure itself, numerous vascular, visceral, muscular, urogenital, and nervous structural elements are placed at risk. The anatomical proximity of these structures to the site of decompression and grafting further increases the chance of injury. Other distal structures can also be harmed by overly aggressive mobilization and retraction. A detailed understanding of the relevant regional anatomy and the areas most at risk for iatrogenic injury is crucial to minimize the morbidity and mortality associated with these complications.

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