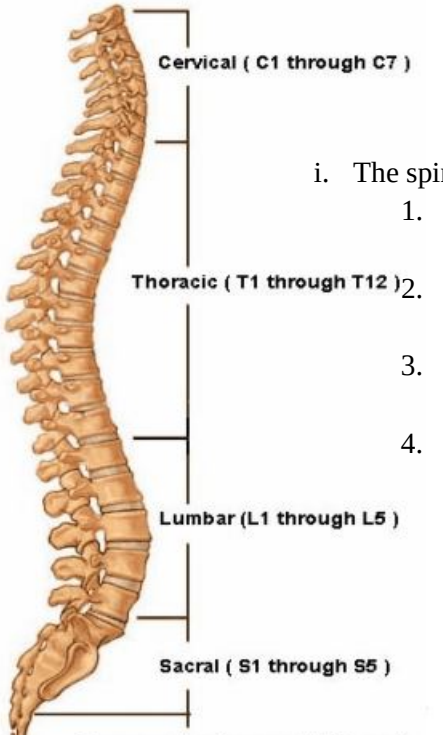
Anatomy and Pathology of Spine Surgery
By Henry F. Fabian Jr., M.D.

The human spine is an incredibly complex piece of machinery with a remarkable range of function and motion. If you have ever witness the movements of a gymnast or a Cirque de Soleil performer you have seen the capabilities of the spine at its best. Unfortunately, as with most things with a lot of moving parts, things can go awry. The aging process, poor nutrition, poor posture, bad ergonomics and inadequate exercise can lead to debilitating injuries and complaints of pain, extremity weakness and numbness, and all the loss of independence and function that go with these problems. You, as a patient who is undergoing surgery, are a crucial point where conservative care has failed or been insufficient in dealing with your problem. A fundamental understanding of the anatomy of the spine and the pathology and problems that can develop is very important. Educating yourself about this subject is the most important step in being fully engaged as a team player in your care. Learning about spine anatomy and pathology will help you to understand the entire process that follows once you have made the decision to seek surgical care.

Before you cringe at how complex the spine may seem, thinking back (maybe not so fondly) on high school biology class, remember that all systems and problems can be broken down into less complex, smaller parts. Understanding these smaller pieces of the "spine puzzle" will help you understand the bigger picture.

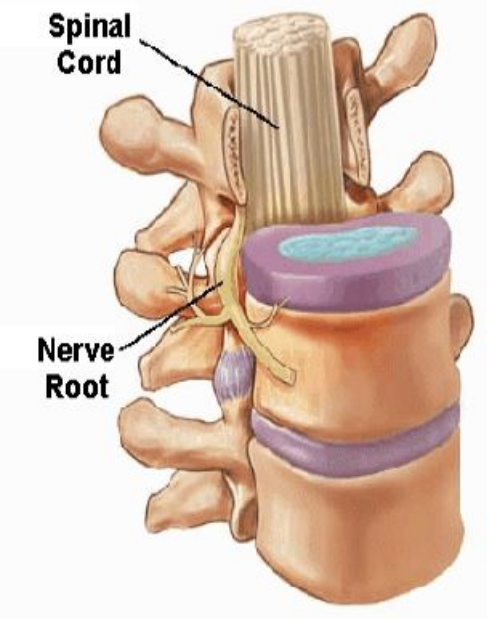
The entire spinal column is comprised of 24 vertebrae in total. There are 7 cervical vertebrae, 12 thoracic vertebrae and 5 lumbar vertebrae. In between the bony vertebrae (referred to as vertebral bodies) are intervertebral discs. These "discs" are made up of cartilage and serve as the "shock absorbers" of the entire column. Discs are labeled based on which vertebral bodies they lie between. For example, the disc between the fourth and fifth lumbar vertebrae would be labeled "L4-5" and the disc between the second and third lumbar vertebrae would be labeled "L2-3". The fifth lumbar vertebra, L5, sits on the sacrum, a part of the spinal column that links the spine to the pelvis. This disc is uniquely labeled L5-S1". The sacrum below S1 is no longer really mobile or segmented, and attaches to the coccyx. The four sections of the spine are highlighted and reviewed in the drawing below:



i. The spine is divided into four main sections:
   1. The cervical spine is composed of seven vertebrae and generally controls the arms and hands.
   2. The thoracic spine is composed of twelve vertebrae and controls the region of the chest and abdomen.
   3. The lumbar spine is composed of five vertebrae and controls the region of the legs and feet.
   4. The sacrum is the lowest part of the spine and serves as the junction between the spine and pelvis. These nerves control the bowels and bladder.

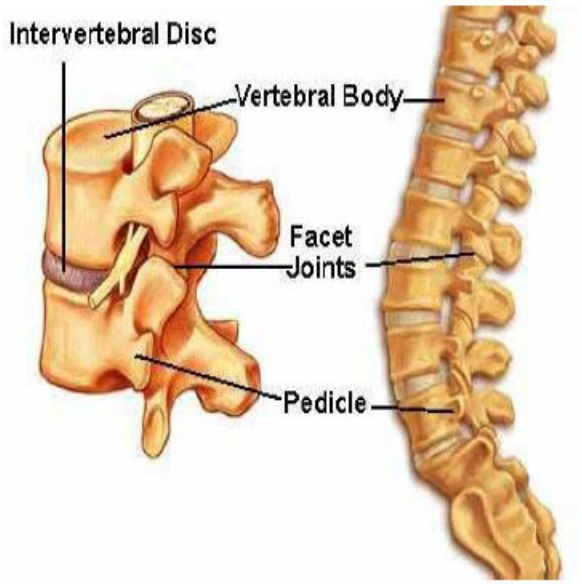
Running up and down the left and right sides of the back of the spine are the paired facet joints, labeled just like the disc levels. As an example, the left sided facet joint between the fourth and fifth lumbar vertebral bodies is called the “left L4-5 facet joint”. The facet joints are real functioning joints, just like our knee or hip joints. With two opposing surfaces covered in hyaline cartilage, a type of smooth, glistening white cartilage found in your Thanksgiving turkey legs, these joints allow a variety of movements. Our ability to flex, extend, twist and bend is because of the function of these joints. There are 44 (yes, 44!) facet joints along the entire spinal column. The intervertebral cartilage discs are also considered a type of joint and as a result, we have a total of 66 functioning joints in our spines! Total joint replacement surgeons are challenged by a shingle hip, shoulder or knee joint. Image facing the task of addressing 66 joints and you begin to realize the scope of complexity and the difficulty in isolating a single source of pain!

With all these “pieces and parts” it is best to focus on the basic building block of the spinal column, the “Functional Spine Unit” or FSU. Whether we are talking about the cervical, thoracic or lumbar spine, the “Functional Spine Unit” or FSU remains the same. A functional spinal unit is composed of two adjacent vertebral bodies with a cartilage intervertebral disc between them, paired left and right facet joints, and the corresponding ligaments between the vertebrae and attaching muscles. The drawing below shows an FSU, or functional spine unit, and its relationship to the spinal cord and branching nerve root.



The spinal column is composed of these building blocks stacked one on top of the other, from the base of the skull to the sacrum and pelvis. Each individual functional spine unit allows for flexion, extension, rotation and bending from side to side. The intervertebral disc, positioned between the vertebral bodies, serves as the fulcrum, or pivot point for motion. The disc is made of visco-elastic cartilage and can be compressed, stretched, rotated, and flexed and extended, defined by certain mechanical limits based on location in the cervical, thoracic or lumbar spine. The corresponding facet joints, paired left and right, move up and down to allow flexion and extension. Surrounding the facet joints, just like in the hip socket or knee, are joint capsule fibers and ligaments that serve to control and restrain in limits of motion.

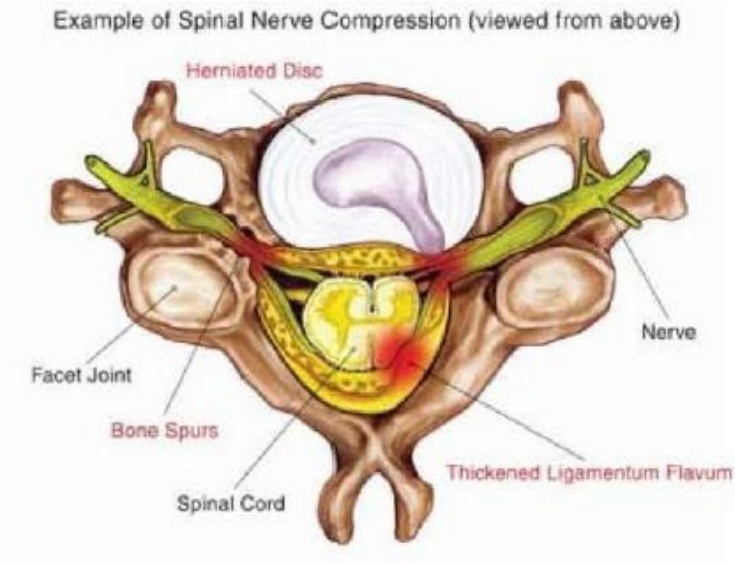
If you look back to our first drawing, showing the entire spinal column, you see that it is S-shaped. The cervical and lumbar curves match to some extent and the thoracic curve is directed in the opposite direction. Spine surgeons talk about the cervical and lumbar curves being “lordotic” or the thoracic curve being “kyphotic”. These curves actually serve several, very functional purposes. Muscles attaching to the spine and the effect of gravity generate tremendous forces to be dissipated in a very efficient manner. If our spines were perfectly straight, we would either fall on our faces or every vertebra in the volume would be crushed because of the compressive forces placed on the spine merely from standing and resisting gravity! Think of the Golden Gate Bridge in San Francisco as you ponder that last sentence. If the Golden Gate Bridge, or the arches in the Cathedral Notre Dame were not curved, or cantilevered, they would collapse under the forces placed on them! The combination of curvatures also places a plumb line dropped from under your chin exactly one centimeter in front of your sacrum, allowing for a perfectly balanced spine. If we didn’t have this, the effort in walking and daily living activities like lifting or carrying objects would be almost impossible!



The figure to the left shows a functional spinal unit and then the entire column of FSUs. The spinal column is usually described as having three columns, an anterior (front), middle and posterior (back) column. The anterior column is defined as the front half of the vertebral body and disc, along the front from one level to the next called the anterior longitudinal ligament (ALL). The middle column is the back half of the vertebral body and disc, along with a posterior longitudinal ligament (PLL). The posterior, or back column, is described as the pedicle, lamina, facet joint and spinous process. The facet joints have ligament capsules and running over the tips of the spinous processes and in between them are the supraspinous and interspinous ligaments. These posterior ligaments serve as major restraints to hyperflexion and protect the discs from rotational forces they can’t resist. When you think about the apparently complex interaction of these columns, think about that toy wooden snake with the interlocking wooden parts. No matter where you jiggle that toy snake, the individual wooden segments stay aligned to each other.

The middle and posterior (back) columns are attached to each other via the bony structures called the pedicles, shown in the drawing. The back of the vertebral body, the pedicle and then the arch of bone spanning from left to right define the spinal canal. The spinal canal is the protective chamber for the spinal cord and nerve roots. Many patients have the mistaken impression that the spinal cord and nerve roots run through the middle of the bony vertebral bodies and through the cartilage discs. The truth of the matter is that they run behind these structures. When we talk about “pinched” nerves or spinal cord, there are several structures that can cause this problem. The nerves pass behind the disc, around the pedicle and then underneath the facet join to exit and then travel down an arm or leg. Compromise at any of these locations can cause nerve irritation.

This figure shows this problem in a cross-sectional view of a spinal segment:



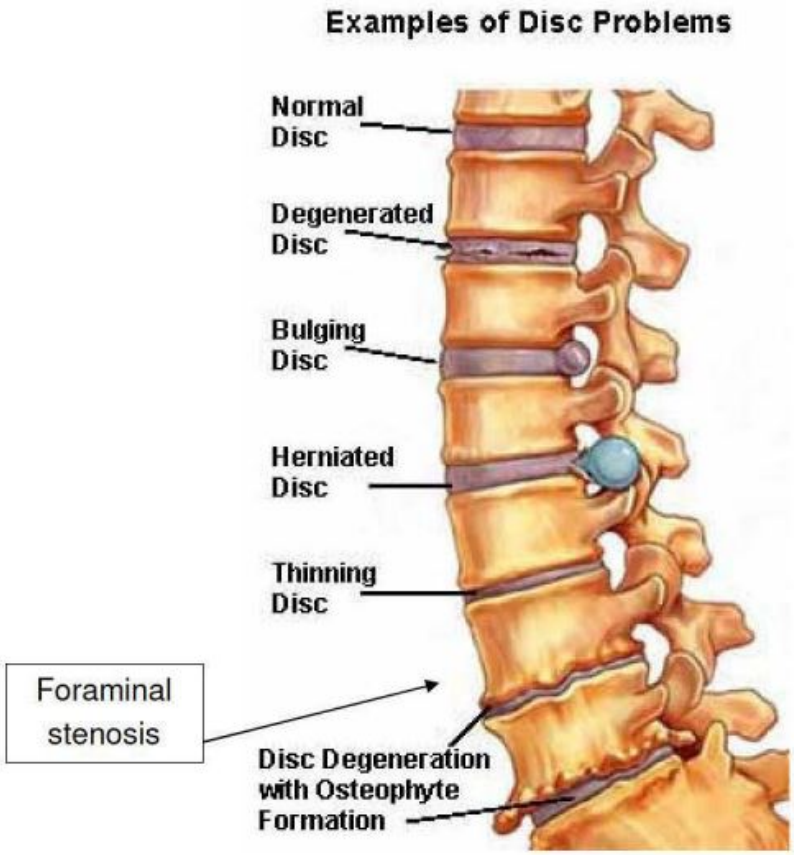
The picture above shows several things that can cause nerve irritation. First look at the facet joint on the left. Just like an arthritic hip or knee, arthritis can lead to cartilage damage and then inflammation and bone spurs. Bone spurs in the spine can get big enough to compress what is known as the foramen,, or exit zone of the nerve root. This is the location where the nerve root has already branched off the spinal cord, or in the lumbar spine, the spinal (dural) sac. This compression of the nerve causes irritation resulting in numbness, tingling, pain or weakness. A herniated disc can do the same thing, either in the canal or in the foramen. The figure above shows a herniated disc pushing up in what surgeons refer to as a "paracentral" location. These herniations can occur directly central, paracentral or lateral causing differing amounts of compression on various nerves along their path. Aging of the spine and abnormal repetitive motion can result in thickening of the ligaments. This too can lead to nerve compression. The figure above shows a thickened ligamentum flavum, a common cause of symptoms of leg pain, numbness and weakness.

Common Spinal Problems:

Degenerative disc disease and facet arthritis is a gradual process that eventually compromises the spine. It is a result of the normal wear and tear of the aging process. The intervertebral disc loses its elasticity and shock absorbing capabilities and the facet joints start to lose the smoothness of their cartilage surfaces and begin to form bone spurs. As this process evolves and matures, the disc and facet joints become stiff and limit movement. Pain usually occurs but can also be referred up or down the column several levels, or even into the pelvic area and upper thighs. This is called a "pseudo-sciatica", or false sciatica, to differentiate it from true sciatica that describes pain traveling down the entire thigh and leg. As an example, severe L4-5 facet arthritis frequently has a pain referral pattern into the buttocks and upper sides of the thigh, over the hips. Many of these patients will seek treatment for hip arthritis and bursitis, sometimes for many months without success, until it is realized that their real problem is in the back.

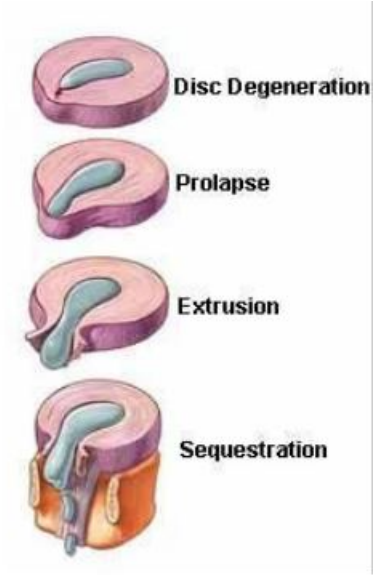
A disc herniation occurs when the central portion of the disc, the nucleus pulposus, bulges through the outer layer of the disc, called the annulus, and puts pressure on the spinal nerves. This type of problem is very common in the cervical and lumbar regions of the spine. The disc herniation can be described as bulging, extruded, or as a sequestered or free fragment. Bulging discs are still contained by the outer fibers of the disc, called the annulus, whereas extruded discs have a portion still attached to the inner fibers but have extended out past the annulus wall. Sequestered, or free fragments have lost all attachment to the disc and may even track out along a nerve root or the back of the adjacent vertebral bodies.

Spinal Stenosis, probably the most common spinal problems treated, describes a progressive narrowing of the spinal canal. The normal spinal canal is 10-15mm in front to back dimension and oval in shape, assuring plenty of room for the dural sac and the enclosed nerve roots to travel down the canal. The individual nerve roots exit the central canal at their respective vertebral levels. For example, the Left L3 nerve root branches off and exits the central canal at the L3 vertebral body through what is known as a foramen. The foramen is formed by the overlapping surfaces of the facet joints of adjacent vertebral levels. As the discs degenerate and the facet joints get arthritic, they bulge and generate osteophytes (bone spurs). In addition, the soft tissue capsules and surrounding ligaments enlarge as they try to resist the abnormal motion of the disc levels associated with aging. All of these contribute to a progressive narrowing of the available space, resulting in central canal and foraminal stenosis. This narrowing gets critical when the canal reduces to less than 8mm. in dimension from front to back or the foramen pinch off their respective nerve roots. In our clinics here at the Spine Center of Steamboat Springs, we often refer to the process of progressive spinal stenosis with symptoms as “angina of the spine”. Just as in coronary artery disease, when atherosclerotic plaques can block the blood flow through the coronary arteries, leading to chest and arm pain, and even a heart attack, progressive tightening of the spinal canal and foramen leads to nerve pain, numbness and weakness.



Why do discs degenerate or herniate?

This is the most commonly asked question posed to spine surgeons. Intervertebral discs are composed of fibrocartilage and are visco-elastic, which means they can be compressed, tensioned and rotated. The central or middle fourth of the disc is much more watery and viscous, and is referred to as the nucleus pulposus. This is the portion that herniates, pushing through the outer ringed annulus and irritating the nerves. The previous drawing showed a paracentral herniated nucleus pulposus. The outer 2/3 of the disc is called the annulus and is a thicker, stiffer cartilage that is very good at resisting compression. Looking from the top, down on a disc, the annulus looks like the swirling cross section of an onion. Each layer is laminated to the next with fibers criss-crossing like the fibers of a steel belted radial. The result is a structure very good at resisting compression forces. Unfortunately this design is not good at resisting torsion and shear forces. The result in the human spine is a tendency to degenerate and herniate. These herniations can be described as contained, extruded, or sequestered. The pictures below show the various forms and locations of herniated discs:



Discs degenerate over time because as we age the vertebra and their endplates become less permeable to water and proteins, so that these key nutrients cannot get to the disc. A healthy disc has a relative composition of water, made up of hydrogen and hydroxyl protein linkages, of up to 80-85%. As we age, this hydration status deteriorates significantly, resulting in stiffer, less elastic discs, eventually resulting in loss of disc height and bone spur formation. The loss of disc height affects the FSU, or functional spine unit, by increasing the pressure on the facet joints and decreasing the space available for the nerve roots to exit the spinal canal. This is a cyclical, bad, positive feedback loop, as the increased facet joint pressure leads to further deterioration of the disc. The process can go on and on until the disc space and facet joints collapse completely.

Discs herniate because shear and rotational forces are poorly tolerated. Unfortunately a lot of the bending and twisting we do in daily living activities exert precisely those kinds of forces on the discs. One potential weak spot is along the lateral, or outside margin of the posterior longitudinal ligament (PLL) and

its contact with the outer rim of the disc, the annulus. This is the paracentral location that is most common for herniated disc. Acute disc herniations are most common in the 30-45 year old age group, whereas degenerative discs and spurs with facet arthritis are more common in the older age groups. In summary, the functional anatomy and the relationship of the nerves and spinal cord and sac to the bony structures follows a common thread throughout the spinal column. Understanding the basic structures and their relationship to each other, i.e. understand the “functional spine unit” or FSU, allows you to understand why certain things happen. Why does my left arm hurt? Why is my right thumb numb? Why does my low back hurt when I extend and rotate to the right? All of these questions can be answered by understanding what is going on at specific functional spinal units.

Spondylolisthesis is a slippage of one vertebral level forward on an adjacent level. Because the spinal canal is simply made up of a stack of vertebra with space behind them, one level slipping forward can cut off the canal and pinch the nerve roots. This slippage can be the result of trauma, such as a pars fracture, which damages the linkage point between successive facet joint levels, or degenerative. The degenerative version is the most common.

Scoliosis is an abnormal curvature of the spine. There are several subtypes, but one of the most common is degenerative lumbar scoliosis. Asymmetric disc degeneration or uneven settling of degenerative facet joints can tilt, or tip, one level to the left or right. Then, like the leaning Tower of Pisa, the entire column follows suit. Our muscles and ligaments serve as restraints to this and the typical compensatory curve is noted higher up the spinal column. Degenerative scoliosis is usually associated with degenerative disc disease, facet arthritis and spinal stenosis.

Non-surgical treatments are the first and essential steps in managing these problems. The literature shows us that >85% of herniated disc patients improve with non-surgical treatment. Degenerative disc disease and facet arthritis are usually managed with a comprehensive core strengthening and general fitness program, as well as with cover the counter anti-inflammatory medications like Advil and Aleve. Spondylolisthesis, even is because of a pars fracture or defect, can be managed conservatively. Dr. Fabian has managed professional football and hockey players this way, as well as high level athletes in many other sports, including ski racers and PGA golf professionals. Physical therapy, chiropractic

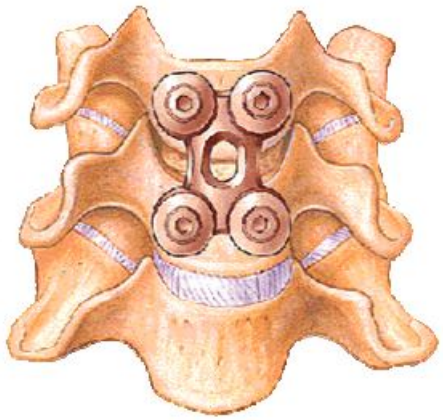
manipulation, massage therapy, acupuncture and spinal injection therapy, may all have a role in treating a particular problem.

Unfortunately, in some cases conservative therapy fails to achieve the desired results. Patients with progressive loss of function, including progression of weakness, numbness and pain that limits daily acitivities, may lead the patient and the surgeon to discuss and agree to surgical options.

Common Spinal Operations

The following are some of the most common surgeries performed in the spine. Your particular surgery will be determined by Dr. Fabian and his team depending on your particular situation and after consultation with you.

Anterior Cervical Discectomy and Fusion



This surgery is very common and is performed when a disc herniates, or a bone spur develops and compresses a nerve. Symptoms include neck pain and referred pain to the shoulder region and down the arm, including pain, numbness and arm and hand weakness. The surgery is performed from the front (anterior) side of the neck. This approach is considered very safe and results in minimal blood loss. The disc space in question is confirmed with an X-ray marker and then the disc and/or bone spurs are removed. The disc space is then filled with an allograft (banked bone) machined dowel or synthetic spacer filled with bone graft. At the Spine Center of Steamboat Springs, a unique hybrid technique is used to assure less pain to the patient with bone graft. Bone marrow and graft is harvested from the iliac crest at the pelvis with a small drill and then placed inside the prefabricated spacer/dowel. The bone graft grows into the adjacent vertebral bodies resulting in a fusion. An extremely low profile plate with screws is used to secure the segments being fused. This is so secure that for one and two level fusions, no postoperative bracing is required. For three level fusions or greater, a cervical collar is used for 4-6 weeks postoperatively. In some cases, the spinal cord compression may be so severe that an entire vertebra and the two adjacent discs have to be removed. This is called a corpectomy requires longer term bracing.

Posterior Cervical Fusion and Cervical Laminectomy

This surgery is performed from the back (posterior) side of the neck. The posterior cervical fusion is often performed in conjunction with an anterior cervical fusion when multiple levels need to be addressed. This then represents a circumferential fusion. The fusion from the back can be accomplished using wire or cabling techniques or the use of what is called a lateral mass/trans-facet fusion with rods and screws. Bone graft is placed along with the instrumentation to achieve the fusion. Cervical laminectomies are often performed when there is severe multi-level spinal stenosis. For a single or two level problem, a laminotomy, or partial removal of the lamina, can be performed. At a single level, this can be done with what is referred to as a “key-hole” foraminotomy.

Lumbar Micro-discectomy or Endoscopic Discectomy

This procedure is performed for herniated discs when they compress the spinal nerves and cause sciatica. Sciatica refers to the classic pain that radiates from the lower lumbar region down the thigh and leg, along the respective nerve level dermatome. A dermatome describes the regional distribution of a particular nerve root. The S1 nerve root for example, branching off at the L5-S1 disc level, supplies the lower, inside buttock, back of the thigh, the calf, and the heel, sole and 4th and 5th toes. The L5 nerve root supplies the upper outside buttock, the lateral (outside) thigh, the lateral leg below the knee, and then classically the instep and top of the big toe.

Microscopic or loop magnification, with or without endoscopic techniques, is used to remove the portion of the disc that is compressing the nerve. Any associated bone spurs (osteophytes) are also removed to insure the path of the nerve root is free. At Yampa Valley Medical Center, over 98% of these procedures are performed on an outpatient basis, with the procedure typically less than 60 min in duration.60-90 minutes after surgery, patients are ready to be discharged and walk out of the hospital! Dr. Fabian was one of the first surgeons in Ohio, as previous Director of the Ohio Spine Institute, to perform a microendoscopic discectomy in 1996. Minimally invasive techniques for this type of procedure continue to be refined. In these procedures, only a small portion of the overlying bone needs to be removed. The bony covering of the spinal is called the lamina. Partial removal of this one side is known as a hemi-laminotomy. Sometimes the outgoing channel for the nerve root needs to be widened in conjunction with this. This is known as a foraminotomy, or micro-foraminotomy. A related area of nerve compression is known as the lateral recess, this is opened by performing a partial facetectomy.

Lumbar Laminectomy

This is done when the stenosis, or compression of the canal is global, involving both sides, or when the herniated disc is so large that a bigger exposure is needed to safely remove it. This is also very commonly an outpatient procedure. When greater than two levels need to be removed at the same time, patients are kept overnight as short-stay in-patients.

Lumbar Fusion

Lumbar fusions are performed for several reasons, but the most common are instability of the segment, such as in a fracture or spondylolisthesis, and for degenerative disc disease with stenosis. In the case of the stenosis, sometimes so much of the lamina and facet joints need to be removed so that this in itself can create instability. There are several methods to achieve lumbar fusion. Over the past 10 years there has been increased use of interbody fusion. Interbody fusion involves removing as much of the disc as is feasible and then replacing it with a spacer that allows bone graft to grow through and around the device. Because 80% of the weightbearing axis of the spine is through the front of the vertebra and bone grows better in compression, the interbody region is the best place to fuse the spine. An interbody fusion can be accomplished from the front (anterior) or back (posterior). From the front this is known as an anterior interbody fusion (ALIF) and from the back as a posterior interbody fusion (PLIF). The anterior interbody technique involves an approach via the abdomen. A general surgeon assists in the approach. Both techniques continue to evolve with the use of minimally invasive surgery (MIS). Dr. Fabian has been a leader in the development of minimally invasive spinal instrumentation and the Spine Center is on the cutting edge of this rapidly progressive field. It is hoped that MIS techniques will allow for faster rehab, shorter hospital stays and less blood loss and incisional pain.

Although stand-alone ALIF and PLIF procedures can be done, in most cases the interbody fusions are supplemented with pedicle screw and rod instrumentation or transfacet posterolateral fusion. The posterolateral fusion is the oldest technique and is still widely used in multi-level fusions, particularly in elderly patients and those with curvatures. For most of these cases, bone graft is taken from the iliac crest, a portion of pelvic bone near the surgical site. Bone marrow aspirate and mesenchymal stem cells, both new technologies, are used by Dr. Fabian at the Center. In fact, in the Spring of 2011, the Spine Center of Steamboat Springs was only the third site in the United States where the new Pure-Gen™ mesenchymal stem cell thechnology was used. Along with these exciing new technologies, osteobiologic bone graft exapanders are sued, such as demineralized bone matrix (DBM) and calcium phosphate and calcium sulfate expanders. Allograft, or banked bone, is also used in selected cases. Dr. Fabian and his team discuss the use of such products prior to surgery.