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JOURNAL OF THE SPINAL RESEARCH FOUNDATION
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JOURNAL OF THE SPINAL RESEARCH FOUNDATION

Trauma and Tumors of the Spine

2011

THE JOURNAL OF THE SPINAL RESEARCH FOUNDATION
A multidisciplinary journal for patients and spine specialists

"I believe that knowledge is empowering. In addition to providing my patients with the most effective spine care available, I also strive to educate them. I take the time to teach them about their condition. My goal is to empower them to make any necessary lifestyle modifications which would benefit not only their spine health, but improve their overall quality of life."

SPINAL HERO

Najeeb M. Thomas, M.D.

Southern Brain and Spine

The Spinal Research Foundation recognizes our outstanding clinicians and researchers in the field of spine research and profiles them as Spinal Heroes. These dedicated spine care professionals embrace excellence in both research and education, contributing significantly to improvements in the diagnosis and treatment of spinal disorders. We recognize Najeeb M. Thomas, MD, of Southern Brain and Spine in Metairie, LA as a Spinal Hero.

THE JOURNAL OF THE SPINAL RESEARCH FOUNDATION
Volume 6, Number 2

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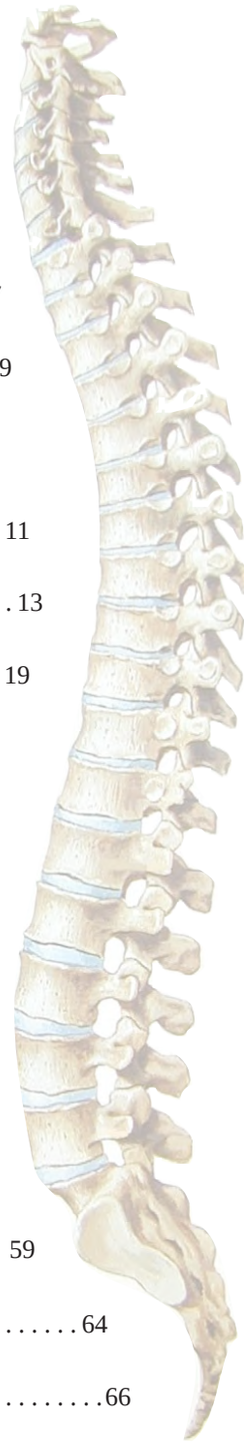


From the Editor

Brian R. Subach, M.D., F.A.C.S.

It is my pleasure to introduce this edition of the *Journal of the Spinal Research Foundation*. This Fall 2011 Issue is dedicated to both traumatic injuries and tumors of the spine and presents the work of experts from around the country. Often thought to be some of the most challenging areas of spinal intervention, traumatic injuries and tumors of the spine may cause significant pain as well as structural instability.

The most difficult problem in dealing with traumatic damage to the spine is the presence of other complicating injuries. Many times, there will be a hip fracture or a brain injury associated with a broken neck. Other times, there will be broken ankles associated with a broken lumbar spine. In these cases, the management of the patient requires a comprehensive approach to evaluate the patient as a whole person, as opposed to seeing them as an isolated spinal condition. In such cases, neurosurgeons, orthopedic spinal surgeons, and trauma surgeons often work together.

Similarly, in dealing with cases of tumor, many patients present with axial (spinal) pain that can be disabling or with progressive nerve damage in the arms or legs. When tumors involve the spine, they may originate in the spine itself (primary tumors) or may come from a distant site (metastatic) and spread through the bloodstream or lymph nodes. Many times, the presence of the tumor weakens the structure of the spine and can cause impingement (pressure) on the spinal cord or exiting nerve roots, causing significant pain and disability. In addition, many tumors may not be completely removed by surgery, requiring additional chemotherapy or radiation therapy to control the problem. In tumor cases, spinal surgeons often work in conjunction with oncologists and radiation oncologists.

I also need to briefly comment on this issue's *Spine Tale*. As you know, I will typically present the story of a patient who has overcome adversity, specifically related to spinal disease. Many times, a surgical or nonoperative intervention is performed, allowing that person to get back to his or her life. In this issue, the *Spine Tale* is actually told from the first person perspective. Joseph Merciez is a young man who endured significant pain and disability for a number of years until he was diagnosed and treated by his spinal specialist. It is a heartwarming story that shows how an individual's strength can overcome pain and disability.

I would like to thank all of the contributors to the *Journal* for their efforts in assembling the cases and insights. I would also like to thank the co-editors and proofreaders for their significant efforts. I hope you enjoy this *Journal* and are challenged by the cases presented.

From the President

Thomas C. Schuler, M.D., F.A.C.S.

Should I have spinal surgery?

This is a question that is frequently asked by patients. Many state that they have been told to "never have spinal surgery." Spinal surgery historically has developed a poor reputation because of decades of poor results. This created a misperception that if one has spinal surgery, his or her life would never be the same. This cannot be further from the truth when modern spinal surgery is performed by a qualified, competent spinal surgeon. The entire goal of modern spinal surgery is to minimize the trauma of the surgery on an individual, while maximizing the return to function. Most patients who undergo proper surgical treatment for one or two levels of spine pathology usually experience a full and complete return to their lifestyle. This is especially true in the motivated patient who is willing to perform a quality rehabilitation program and comply with the necessary exercise and fitness regimen to optimize their overall spine health.

To understand why spinal surgery has developed such a bad reputation, we must realize that the era of modern spinal surgery only began during the past fifteen to twenty years. It has only become common place nationally in the past decade. Prior to the early 1990s, the instrumentation that was available to treat spinal conditions was mainly first and second generation equipment. In the 1950s through 1970s, patients were frequently kept on bed rest for months at a time after spinal fusion in order to try to obtain a solid arthrodesis. Even with these prolonged periods of bed rest, a stable fusion was frequently not achieved. Minimally invasive surgery did not exist and every operation required major trauma to the body and major disruption of muscles. More recent implants have great technological improvement. Current instrumentation advantages include: lower profile, greater strength, and ease of use which allows smaller incisions and faster surgeries. These modern options allow patients to be mobilized immediately after surgery, eliminating debilitating bed rest. The main reason the national incidence of spinal surgery has increased over the past decade is because of improved knowledge combined with improved technology.

Through gradual technological developments in the 1980s, initial improvements were made thereby decreasing the failure rate of surgeries. All of the work that was performed in the 1980s led to great technological breakthroughs in the 1990s and into the early 2000s. Over the past decade, we have significantly improved upon these monumental gains. Now, spinal surgery is performed minimizing the trauma to the body, preserving maximum function, and optimizing a patient's return to his or her life. Many patients who have undergone minimally invasive discectomy or even major lumbar reconstructive fusion surgery have

returned to professional athletics, golf, running, work, and most importantly, their families. I feel truly blessed as a spinal surgeon to be able to help so many people recover from severe incapacitating pain and guide their return to full and complete lives. This is only possible because of monumental advances which modern surgery and true spine specialists bring to our patients.

In answering the question, "Should I have spinal surgery?", the answer is simple. If you need it, then yes, one should have spinal surgery performed by a spinal specialist. However, if one has reasonable non-operative options to improve their function, then by all means those should be completed prior to performing any surgery. I have had patients come to me and say that they were told by a physician that they should not have spinal surgery until urine was running down their leg. I could not disagree more with such a comment and feel that it is inappropriate for a medical professional to make such a dangerous statement. If one would wait until they were suffering from severe neurologic deficit to undergo surgery, then the ability to return them to a full and active lifestyle may be impossible at that point. Furthermore, they may suffer permanent neurologic dysfunction. One of the clear urgent indications for spinal surgery is progressive loss of nerve function. The symptoms of this may include numbness in an extremity, weakness in an extremity, or loss of bowel or bladder function. Even persistent radiating pain into an extremity that goes untreated can lead to permanent nerve damage and chronic painful conditions. If a patient experiences persistent or even recurrent radiculopathy from a spinal nerve impingement for greater than three months, then I would often recommend surgical correction. Surgery could be performed on it sooner if the patient's symptoms were not tolerable, or deteriorating, or the spinal imaging studies demonstrated pathology which, in the opinion of the spine expert, would not improve with additional non-operative care.

The bottom line is that spinal surgery, when done for the right reasons and in the proper fashion, can yield excellent results. Delaying treatment unnecessarily can often limit the results of the surgical procedure as well as impair the patient's recovery. In essence, delaying surgical treatment may compromise the success of surgery. For spinal surgery to accomplish the best results possible, it must be coupled with a quality rehabilitation program, a committed patient, and appropriate timing of surgery to optimize the body's ability to recover. The appropriate time is determined based upon the patient's symptoms, the patient's needs, their response to non-operative treatment, the pathology identified on the diagnostic studies, and the surgeon's experience and expertise. Understanding all of this, the answer to the question, "Should I have spinal surgery?" is yes, if the above criteria are met.

Ask the Expert

George A. Frey, M.D.
Colorado Comprehensive Spine Institute

What are the most common causes of spinal trauma?

Auto and motorcycle accidents are the leading cause of spinal trauma, accounting for more than 40 percent of new spinal traumas each year. As many as 15 percent of spinal traumas result from *violent encounters*, often involving gunshot and knife wounds. *Falls* are the main cause of spinal trauma after the age of 65, about one-quarter of spinal traumas. *Sports and recreation activities*, such as impact sports and diving in shallow water, cause about 8 percent of spinal traumas. *Alcohol* use is a factor in about 1 out of every 4 spinal traumas.

What are the symptoms of spinal cord injury?

Spinal cord injuries of any kind may result in one or more of the following symptoms: loss of movement; loss of the ability to perceive temperature; loss of bowel or bladder control; exaggerated reflex activities or spasms; changes in sexual function, sexual sensitivity and fertility; pain or an intense stinging sensation caused by damage to the nerve fibers in the spinal cord; difficulty breathing, coughing or clearing secretions from the lungs.

What causes spinal tumors to develop?

Spinal tumor cells often contain a number of abnormal genes, but in many cases, researchers don't know what causes these genetic alterations. They do know that in some cases, spinal cord tumors run in families and are associated with familial cancer syndromes such as *neurofibromatosis 2 and Von Hippel-Lindau disease.* In *neurofibromatosis 2*, noncancerous tumors develop on or near the nerves related to hearing, leading to progressive hearing loss in one or both ears. Some people with neurofibromatosis 2 also develop tumors in the arachnoid layer of the spinal cord or in the supporting glial cells. *Von Hippel-Lindau disease* is associated with noncancerous blood vessel tumors (hemangioblastomas) in the brain, retina and spinal cord and with other types of tumors in the kidneys or adrenal glands. It is also known that *spinal cord lymphomas* (cancers that affect lymphocytes, a type of immune cell) are more common in people whose immune systems are compromised by medications or disease.

What kinds of doctors treat people with spinal tumors?

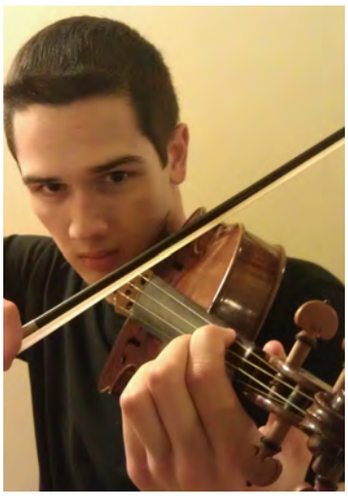
In most cases, surgical resection followed by chemotherapy and radiation therapy allows for the best treatment outcomes. Hence, spinal tumors are treated by a group of specialists: spinal surgeons, oncologists and radiation therapy specialists.

George A. Frey, M.D.

Dr. Frey is the Founder of the Colorado Comprehensive Spine Institute. Dr. Frey focuses his medical practice on the treatment of all complex spine problems affecting the cervical, thoracic, and lumbar regions in adult and pediatric patients. Dr. Frey is known for his extensive experience and training in complex spinal reconstruction, revision, and scoliosis surgery in children and adults. His practice reflects his strong expertise in the treatment of complex adult spine problems where deformity exists or revision surgery is necessary.

Spine Tale

Joseph R. Merciez



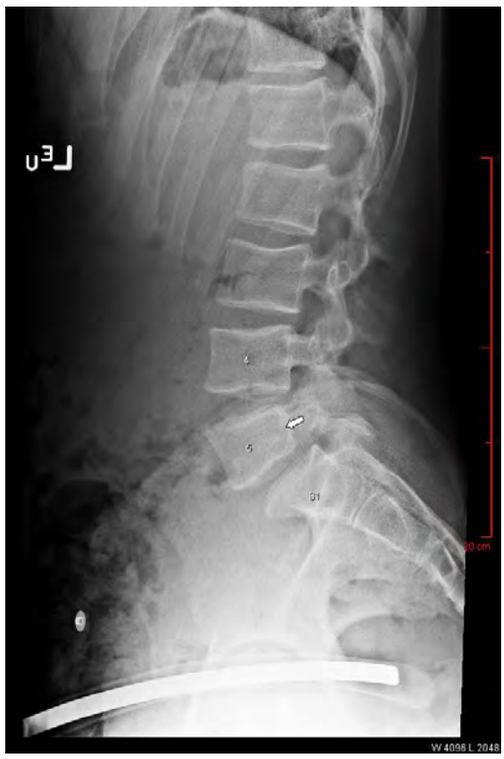
It's an understatement to say that Dr. Brian Subach has changed my life. My name is Joseph Merciez and I'm a sixteen year old high school junior who underwent a L5-S1 anterior interbody fusion (ALIF) with bone morphogenetic protein (BMP) and titanium cages in June 2010. Today, I am healthy and active, looking forward to my future, and living life without the incapacitating pain I had prior to meeting Dr. Subach.

As a young child, it was readily apparent that I had a variety of medical challenges. One of them was spinal pain and it happened to be one of my earliest memories. My father was a Naval Officer and I spent the first ten years of my life traversing the world according to his duty stations. Upon my father's military retirement in 2005, my family came to live in Northern Virginia. My mother proactively sought out medical care for me throughout my life, always seeking out the best doctors when possible. Shortly after we arrived to the area, I was diagnosed with Ehlers-Danlos syndrome, a connective tissue disorder that affects my entire body, causing significant hypermobility (flexibility) of the joints. I saw several orthopedists for my spine. Of growing concern was the instability and pain I was having throughout my body, most particularly in my spine. These visits to orthopedic doctors yielded little in terms of concrete plans to address the cause of my pain. As I was growing taller, the plainly evident scoliosis (curvature), spondylolisthesis (misalignment), spondylolysis (stress fracture), stenosis (narrowing around the nerves), and other findings on numerous X-rays, CT's, and MRI's began to cause pain that increasingly took over my life. I was interested in sports, played the violin, and was involved in advanced academic programs at school, but it was very difficult to do almost anything without substantial pain in my lumbar spine.

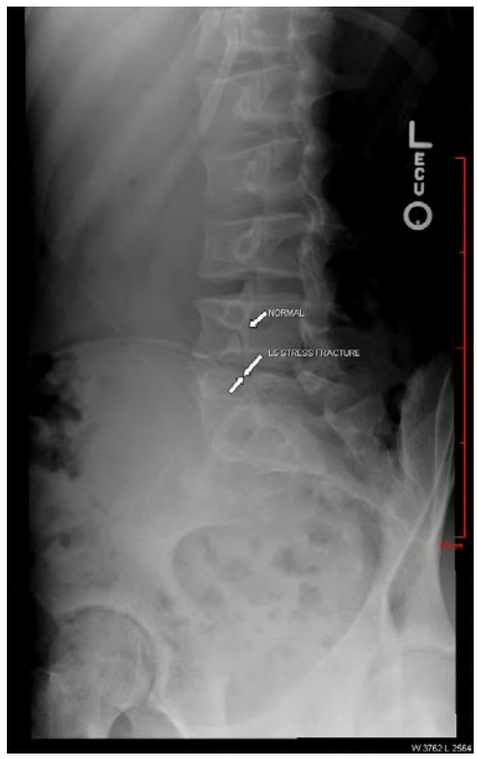
In 2009, my mother made an appointment for me with Dr. Subach. This was the first time I'd seen a neurosurgeon, let alone one who specialized in complex spinal disorders, such as Dr. Subach. I was having radiculopathy (sciatic nerve pain) in both legs originating from my lumbar spine, and increasing difficulty with normal everyday living. Immediately upon entering the exam room, my mother and I had a very good feeling about the extensive information collected by Dr. Subach and his physician assistant, Diana DeWolfe. It indicated to us that they were focused on me as a patient. Dr. Subach listened to what I was telling him about how I was feeling and how much pain I was in, and carefully solicited questions to further determine a course of action. I felt at ease and comfortable as he ordered some additional radiological tests and spoke to me in layman's terms about his diagnosis of what was going on with my spine. Over the next year or so, we followed the conservative course of treatment which Dr. Subach prescribed. Dr. Subach told us that with the pars defect (stress fracture) and spondylolisthesis (slippage), he clearly understood and validated that I had real pain. Finally, someone had pinpointed the cause of my pain!

In my 2009–2010 high school freshman year, the pain became increasingly debilitating for me. Every single aspect of my life was influenced by the terrible lumbar pain I was suffering. I was on restrictions in my physical education class and unable to do any sports. I couldn't even stand in line at lunch. Walking the hallways of school while carrying a backpack caused me terrible pain. I had trouble sitting in the chairs during class and walking home from the bus. Playing the violin was limited due to pain. My sleep was disrupted and I was having trouble coping, despite temporary, but slight relief from pain medications.

In the spring, most kids my age were enjoying activities outdoors, but I was restricted and desperate for relief from pain. My mother made another appointment with Dr. Subach. Dr. Subach clearly has seen many patients with severe spinal pain. He made me feel that he understood how "I" felt. The most recent images showed the slippage of my L5-S1 vertebrae, so Dr. Subach carefully explained how I was a good candidate for a spinal fusion surgery. After a detailed explanation and clear plan, we decided that surgery was the best option to alleviate my pain and stabilize my lumbar spine. Fusion would improve my leg pain



Pre-op lateral

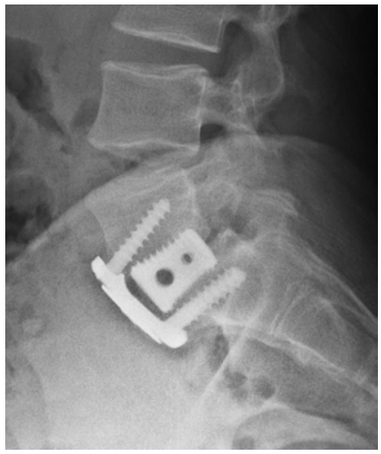


Pre-op oblique

X-rays before surgery.

and prevent nerve damage, while preventing further slippage of the vertebrae.

Leading up to the spinal fusion surgery scheduled for June 2010, I felt hope for the first time in a long while that I might have a life without pain. The relationship that had developed between Dr. Subach, his physician assistant Diana DeWolfe, and myself allowed me a level of comfort and confidence in the busy days leading up to surgery. I knew that it would take time to recover afterwards, but I approached the surgery with positive feelings and hope.



X-ray after surgery.

The day after Dr. Subach performed my ALIF surgery, I was still in the hospital and, despite being on heavy pain medication, it was clearly evident I had massive improvement in my pain level. Even though I felt weak and tired, my legs felt much better and I was amazed at the progression from day to day as I improved. I went home without any complications and on day seven post surgery, I was off all pain medications. I took a muscle relaxant for a few weeks, but rapidly tapered it off as I began physical therapy. Carefully adhering to not lifting, bending, or twisting, as well as wearing my back brace, I worked very closely with my physical therapist Jeff Menges to further stabilize my spine through strengthening my core muscles. There were occasional bouts of minor pain and soreness as I recovered, but I was so vastly improved and pain free in a short time.

It has been more than a year since Dr. Subach performed my ALIF surgery and I'm feeling great. It is very difficult to explain how much I was helped by this surgery because it is particularly hard to relay how much pain I was in prior to having a spinal fusion. I am so grateful for the scientists who developed BMP and the companies who made the titanium cages that are now a permanent fixture in my lumbar spine. Through the skill, great expertise, and compassion of my doctor, Brian Subach, I've been given the opportunity to focus on all the great things that life has in store for me. I look forward to finishing high school and heading off to college. From what seemed to be depths of despair from unremitting pain in my life before June 2010, I've found inspiration to study biomedical engineering and devote my own future education and career to try to help others through research and innovation. I hope that I might help someone in the future . . . and pay it forward!

"We've Got Your Back" Reston, Virginia Race/Walk Raises $100,000 for Spinal Health

Meghan J. McWilliams and Erin C. Orr, C.P.S.M.

The Spinal Research Foundation's fourth annual "We've Got Your Back" Race for Spinal Health was held on May 14th, in Reston, Virginia, and raised over $100,000 in support of the foundation's mission to improve spinal health care through research, education, and patient advocacy. "This is our signature event for raising awareness, and the money raised contributes directly to life-changing research and educational programs conducted by the Spinal Research Foundation," said Thomas C. Schuler, M.D., F.A.C.S, President of the Spinal Research Foundation.

More than 600 participants and 100 volunteers teamed up at the Virginia Spine Institute (Regional Sponsor and Host of the event) to raise awareness of spinal health care. The race festivities included live entertainment, refreshments, kids' activities, free giveaways, and door prizes. An on-site Spinal Health Fair educated attendees about their spine, provided scoliosis screenings, and demonstrated preventive measures for injuries, including proper workplace ergonomics, gait analysis, and proper stretching. The Virginia Spine Institute also offered complimentary bone density scans to screen for bone fractures or osteoporosis.

To honor Spinal Champions on race day, a VIP tent area was created to showcase success stories. A Spinal Champion is defined as someone who has suffered from back or neck pain and has overcome it through either nonsurgical or surgical treatments. These special individuals were recognized during opening ceremonies and by their commemorative Spinal Champion race shirts on the race course.

Special appearances were made by government officials and professional athletes. U.S. Congressman Jim Moran and Virginia Delegate Tom Rust spoke at the opening ceremonies about their support for the Spinal Research Foundation's mission, and Rust presented a Letter of Commendation on behalf of the Virginia House of Delegates. Two Spinal Champions, Rocky McIntosh of the Washington Redskins and James Thrash, a former Redskin, also appeared and spoke about their personal victories over neck and back pain and how spinal treatment helped them as football players.

"The Spinal Research Foundation is identifying the best treatments for spinal problems through a national network of research centers," Schuler said. "This network is expanding to all 50 states. We are challenging all of the Regional Research Partners to host 5K events to raise awareness of spinal treatment success, help individuals establish goals to improve their health, and to raise funds for further research."

The Spinal Research Foundation is proud to host the only run/walk event designed to celebrate the accomplishments of Spinal Champions as they continue to research new techniques to improve spinal healthcare for future generations. To learn more about the "We've Got Your Back" Race for Spinal Health series, visit wevegotyourbackrace.org.


Refreshments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WEVEGOTYOURBACKRACE.ORG

Issue Overview

Marcus M. Martin, Ph.D. and Anne G. Copay, Ph.D.

The current issue of the Journal of The Spinal Research Foundation explores two major causes of spine dysfunction: trauma of the spine and tumors of the spine. Trauma of the spine incorporates injury to the soft tissue, bones, or nervous tissue, whereas tumors of the spine are the result of aberrant cellular proliferation. In the current issue, we have brought together experts from both fields to provide insight into the nature of these conditions, their course, and treatment options.

Addressing the topic of spine trauma, we have contributions from three renowned spine surgeons: Dr. Najeeb M. Thomas, Dr. Christopher H. Comey, and Dr. Christopher R. Good. All three of these surgeons have extensive experience in treating traumatic spinal injuries. Dr. Thomas presents a succinct introduction to cervical spine injury which is geared toward patients and complete with illustrations of injuries. Dr. Comey presents an in-depth introduction to thoracic spine trauma highlighting anatomy, mechanism of injury, and treatment options for thoracic trauma injuries. His presentation is followed by three cases illustrating treatment and outcomes. Dr. Good presents an exceptional overview of lumbar spine trauma. He presents different forms of lumbar trauma and their clinical presentation. He introduces readers to the Thoracolumbar Injury Classification and Severity Score, providing a window into the evaluation of these injuries and the determination of an ideal treatment approach.

To address the topic of tumors of the spine, we have contributions from three separate research groups engaged in spine tumor related research. The lead authors are Dr. J. Cameron Muir, Dr. W. Lee Titsworth, and Dr. Arjun Sahgal. Dr. Muir gives an introduction to the different types of spine tumors, some of the outcomes of their growth, and their treatment options. Dr. Titsworth and Dr. Pincus present a comprehensive overview of tumors of the pediatric spine highlighting the usual presentation of the conditions, treatment options, and various types of tumors. Dr. Sahgal and Dr. Fehling present an overview of Stereostatic Body Radiotherapy (SBRT) in the treatment of spinal metastases. He explores the advantages of this form of therapy and presents his assessment of the future trajectory of its application.

The current issue of the journal also provides a robust case report section containing cases of spine trauma and tumors, medical decision making, and treatment outcomes. Karen Busse, M.S. provides a brief overview of the merits of spine research using the BRYAN® Cervical Disc System as an example of applied research improving the lives of spine patients.

The fall 2011 issue of the journal should act as an excellent introduction to readers into understanding spine trauma and tumors, as well as providing a window into the medical decision making process involved in treating these often multifaceted and challenging cases.

Marcus M. Martin, Ph.D.

Dr. Martin's research interests include virology, immunology and neuroimmunology. He is engaged in collaborative research through SRF, with the Medical University of South Carolina Children's Hospital, geared toward the development of neuroprotective and neuroregenerative compounds for the treatment of nerve pathology.

Anne G. Copay, Ph.D.

Dr. Copay studies the outcomes of surgical and non-surgical spine treatments. She published several articles on the outcomes of spine fusion. She has ongoing research projects concerning the effectiveness of new spine technologies and the long-term outcomes of surgical treatments.

Cervical Spine Trauma

Najeeb M. Thomas, M.D.

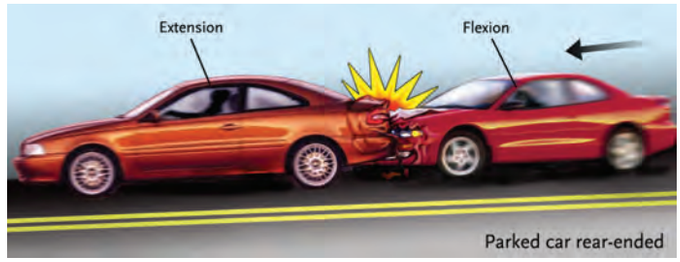
Cervical spine trauma encompasses a wide range of injuries to the cervical spine. These injuries range from a simple cervical sprain to a spinal cord injury with complete neurologic deficit including quadriplegia (inability to move the arms or the legs). It is estimated that in North America approximately 14,000 spinal cord injuries occurs each year. The incidence of minor cervical spine injury (sprains or neck pain secondary to trauma) is uncertain. The types of injuries vary from muscle strain to traumatic disc herniations, fracture dislocations and gross spinal instability. As the injury becomes more severe the risk of spinal cord injury becomes greater. Appropriate recognition contributes to accurate diagnosis and treatment which may also prevent spinal cord injury.

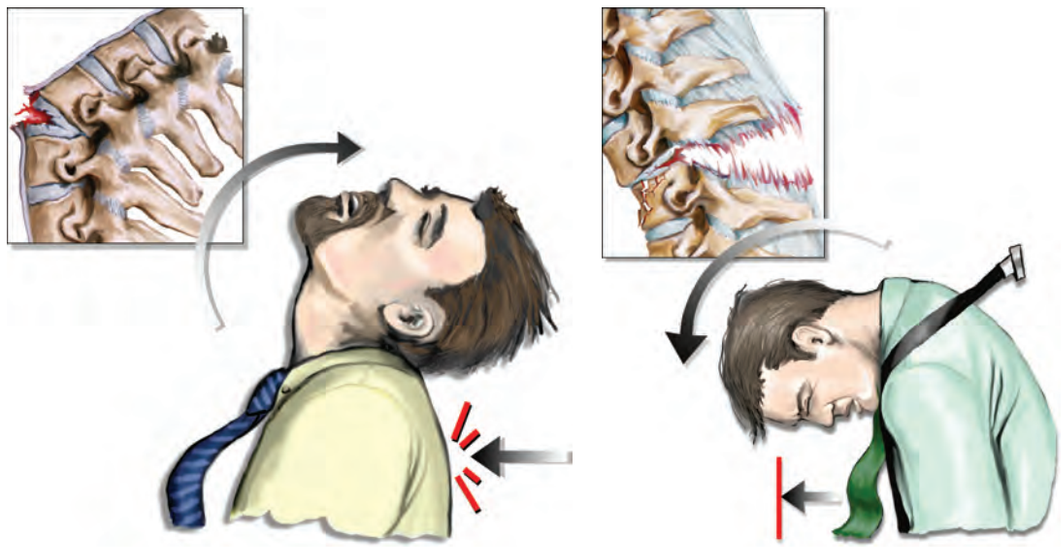
In an attempt to stratify cervical spine trauma, many classification systems have been formulated. While a detailed look at the classification systems is beyond the scope of this article, a simple approach may help the lay person understand these injuries. When cervical spine trauma has occurred, the first assessment a physician must make is to determine whether the injury has resulted in neurologic deficit. These neurologic injuries range from dense plegia (complete paralysis of the arms and legs), to small sensory disturbances, the inability to urinate, or have diminished sensation in the rectum. Once the determination of a neurological injury has been made, then appropriate radiographic studies are made to determine if the patient has sustained a musculoskeletal strain or perhaps something more serious such as a fracture.

No radiographic assessment of the cervical spine is warranted in a patient who is completely awake, does not have an altered mental status, and lacks neck pain. A patient who is asymptomatic must meet the following criteria: neurologically normal, no evidence of head injury or intoxication, no neck pain or tenderness, and no associated injury which may distract the patient from realizing they have a neck injury.

Imaging studies are required in patients who are symptomatic from cervical spine trauma (complaining of neck pain or tenderness, have symptoms of a neurologic deficit) and in patients who are believed to have a cervical spine injury but cannot be assessed secondary to head injury, intoxication, or other distracting injury. It is recommended that three views of the cervical spine be imaged with plain radiographs. Other studies including flexion/extension radiographs and MRI's may be performed as well. It is very important to make sure that an accurate neurologic exam is documented, as deterioration of neurologic function can underlie serious injury to the cervical spine.

After an accurate diagnosis of the cervical spine trauma is made, treatment modalities may be instituted. For patients who have neck pain without neurologic deficits and for whom no radiographic abnormality has





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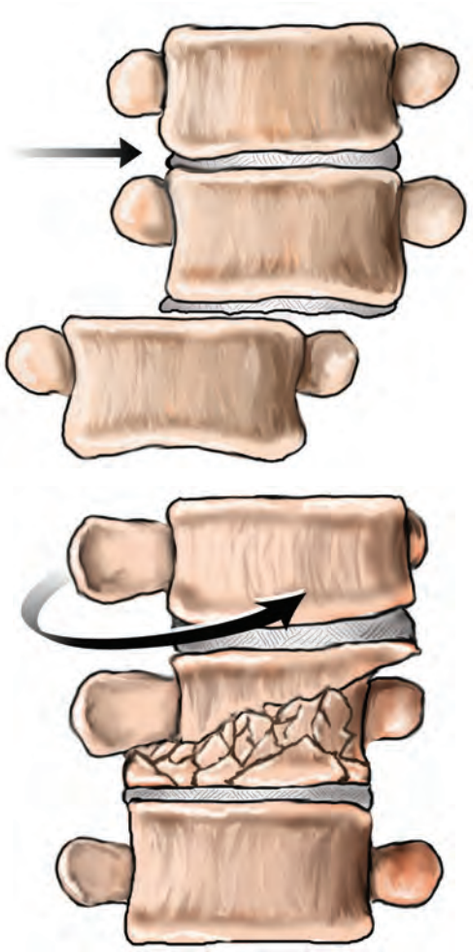

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been identified, treatment may involve symptomatic therapies. These include anti-inflammatories, rest, ice, and physical therapy. It is very important that patient athletes are not allowed to return to activities which could exacerbate their injury while any neck pain is present. Sufficient time must pass so that any sprain is completely healed before the patient begins to re-engage in contact sports.

There is a wide variety of treatments for those with radiographic abnormalities. For patients with more serious injuries, surgery may be necessary. The goal of surgery is generally to decompress the spinal cord and stabilize the segment of the spinal column which has been injured and may be unstable (unable to bear physiological loads). Surgery may include anterior procedures of the cervical spine (including discectomy and fusion), and may also include posterior procedures of the spine (including posterior fusion stabilization). Finally, a combination of both may be employed if it is necessary to stabilize and potentially decompress the spinal cord.

Depending upon the nature of the injury there may be intensive rehab and physical therapy involved. Patients with cervical spinal trauma and who have spinal cord injury are at high risk of certain complications. These complications include deep vein thrombosis, pulmonary embolism, infection, urinary retention, skin breakdown, and pressure sores. Not only must patients have appropriate nursing care to help prevent these complications, but proper nutrition and counseling are important as well.

It is important for patients to realize that persistent symptoms of cervical spine trauma ranging from persistent neck pain to neurologic deficits such as numbness, tingling and weakness must not be ignored. These signs and symptoms may be harbingers of underlying damage to the cervical spine or spinal cord itself. It is important to seek treatment from an experienced spine surgeon.

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Najeeb M. Thomas, M.D.

Dr. Thomas is a neurological surgeon at Southern Brain & Spine in New Orleans. He specializes in minimally invasive surgical techniques for the spine. He has lectured about spinal procedures on four continents and had interactions with hundreds of surgeons around the world. He is recognized as an innovator, continues to be active in the latest development of minimally invasive spine procedures so that his patients may receive the most advanced spinal care in the world.

Thoracic Spine Trauma

Christopher H. Comey, M.D.

Introduction

The thoracic spine consists of twelve vertebral bodies and is supported by twelve pairs of ribs. This system forms a protective container for the heart, lungs, and many other important structures. Because the system is connected by joints, ligaments, and muscles, this container also can be flexible, to accommodate body movements and the critical bellows function associated with breathing. Despite this ingenious reinforced design, the thoracic spine is still vulnerable to injuries, such as fractures or dislocations. Fractures may occur as a result of high energy injuries such as car accidents or falls. They may also occur with minimal to no trauma. This second type of fracture, also known as fragility fracture often occurs with osteoporosis and is seen more commonly in the elderly. Dislocations of the spine can occur with disruption of the supporting ligaments and the intervertebral disc. Some patients can suffer from a combination of a fracture and a ligamentous injury. Because they are much more common, the majority of this article will be dedicated to a discussion of thoracic fractures.

Anatomy of the Thoracic Spine

The human chest consists of twelve paired ribs which form a flexible bridge between the sternum, or breast bone, and the spine. The thoracic spine, or mid back region, consists of twelve rectangular or slightly wedge-shaped vertebral bodies (Figure 1).

While the cervical and lumbar spinal regions normally have a lordotic (backward curving) shape, the thoracic spine has a normal kyphosis (forward curving).

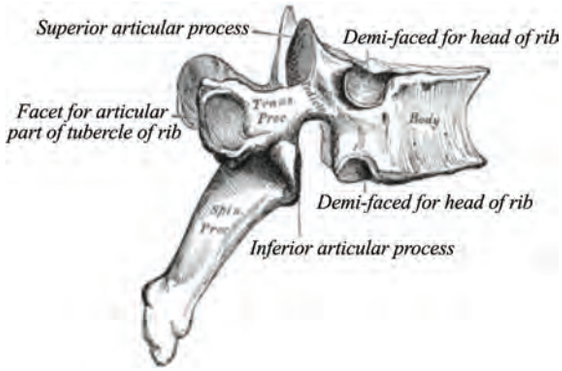

Figure 1. Image courtesy of Bartleby.com from Henry Gray's Anatomy of the Human Body.

This normal forward bend makes each thoracic vertebral body have to carry a greater proportion of load than its cervical or lumbar counterparts (Figure 2).

In the cervical and lumbar spines, as a result of their lordotic curves, a greater proportion of the weight is supported by the facet joints which reside in the back portion of the spine. In the normal, healthy thoracic spine, this increased load on the vertebral bodies is adequately compensated for by the intact rib cage. With trauma or osteoporosis, these forces can become more than the vertebral bodies can support, leading to fractures.

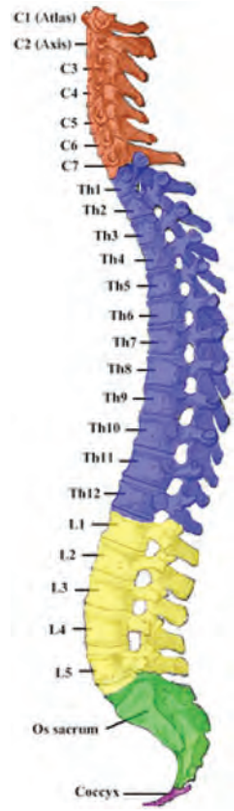

Figure 2. Image courtesy of Medtronic.

Each thoracic vertebra consists of a vertebral body, a pair of pedicles, and two facet joints which allow an interlocking connection between each of the twelve bones. There are also two wing-like transverse processes that project out from the base of each pedicle (Figure 3).

At the outer aspect of the junction between each pedicle and transverse process is a small, smooth surface. This is designed to accommodate a joint with each corresponding rib. These smooth areas are seen only in the thoracic spine as ribs do not typically exist in the cervical or lumbar spine.

The thoracic vertebral segments are numbered from top to bottom. The first thoracic vertebra (also called by the shorthand T1) forms a joint with the seventh

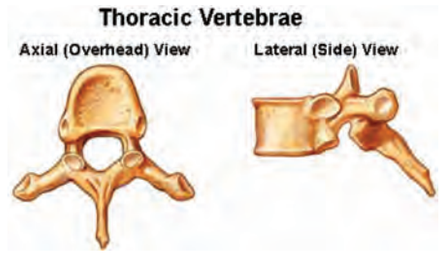

Figure 3. Images provided by Medtronic Sofamor Danek USA, Inc.

cervical vertebra (C7). In similar fashion, the twelfth thoracic vertebra (T12) forms a joint with the first lumbar vertebra (L1). The ribs of each thoracic segment actually form a joint with the spine at the level of the disk between two vertebral segments. For example, the tenth rib meets the spine at the disc between the ninth and tenth vertebral segments. Knowledge of this relationship is very helpful for surgeons to accurately determine where they are in the spine. As one might imagine, during surgery on the thoracic spine, it can be challenging to determine exactly which one of the twelve thoracic vertebrae one is looking at!

While it is tempting to think of each thoracic vertebral body as an inert block supporting the body, they are actually living and made of very functional tissue. The outer edge of each vertebral body is made of cortical bone, which forms a hard shell. The inner aspect of each vertebral body is composed of a softer, spongy bone called cancellous bone (Figure 4).

The cancellous bone forms a delicate, three-dimensional honeycomb. Bone marrow occupies the small spaces within this honeycomb. Although the cancellous bone is softer than its cortical counterpart, it still provides structural support. It is typically the cancellous bone that is most affected by osteoporosis, making it more prone to collapse and fracture.

In the human skeleton, in general, and in the spine, in particular, fracture occurs when the force applied to the spine is greater than the bone's ability to withstand that force. The stronger the bone, the greater the force needed to break it. For instance, in the most advanced cases of osteoporosis, it is not a car accident or a fall from a roof that produces a thoracic fracture. Rather, it is unfortunately something very trivial, such as coughing, lifting a suitcase, or even turning over in bed.

The other important aspect of thoracic spine trauma involves the mechanism of injury. Specifically the surgeon has to think in terms of "how did this injury occur?" As one might imagine, different forces on the spine will produce different injury patterns. The two most common scenarios are known as axial loading (Figure 5) and translational forces (Figure 6).

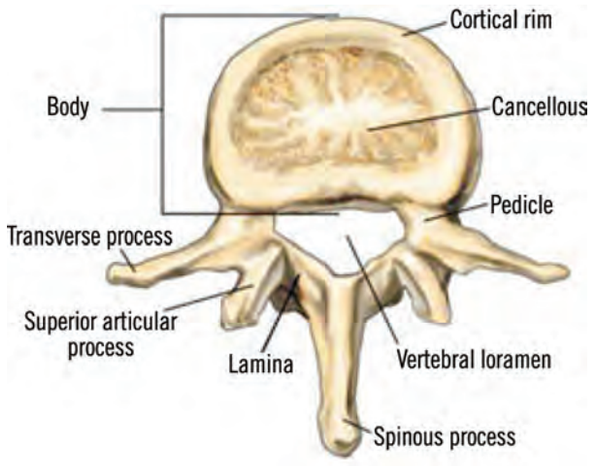

Figure 4. Images provided by Medtronic Sofamor Danek USA, Inc.

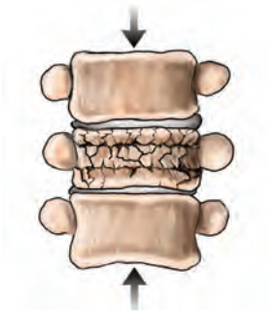

Figure 5. Images provided by Medtronic Sofamor Danek USA, Inc.

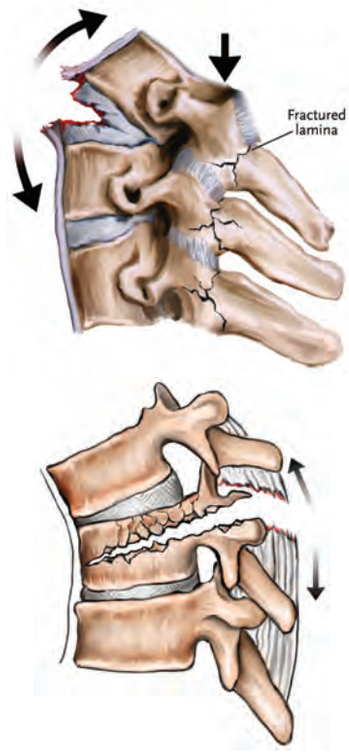

Figure 6. Images provided by Medtronic Sofamor Danek USA, Inc.

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Axial loading involves a direct top to bottom force on the spine. Examples of this injury pattern involve falling from a height and landing on ones feet or attempting to lift an extremely heavy object (e.g., a stuck garage door). Translational injury typically involves a rapid, uncontrolled deceleration. The most common example of this injury pattern is a motor vehicle collision where an occupant is not wearing a seat belt. In this scenario, upon striking an object, the car stops instantly while the unrestrained occupant continues forward striking the dash board, windshield, or even being ejected from the vehicle itself. Translational injuries are more commonly associated with ligament disruption and even dislocations of the spine. It is a common misconception that airbags are totally protective without seat belts. The above injury can easily occur in the presence of normally functioning airbags. The mechanism of injury is important to the surgeon as it will prompt him or her to look for other associated bodily injuries and come up with a sound treatment plan for dealing with the fracture.

Conditions which predispose a patient to fracture of the thoracic spine include: osteoporosis, tumors of the spine and bone marrow (such as multiple myeloma), and certain infections.

Treatment Options

Treatment for thoracic spine trauma should follow three basic principles: (1) preserve and protect neurologic function by minimizing the risk of spinal cord injury, (2) identify the injury and work to restore the structural integrity of the spine, and (3) accomplish the above with the least invasive means possible. Based on these principles, treatment can range from activity restriction, to bracing, to surgery. With advances in surgical techniques, there are minimally invasive treatment options as well as larger reconstructive surgical options. The minimally invasive surgical options have proven to be invaluable in elderly patients who are often too frail to be considered for larger reconstructive procedures. Prior to the advent of minimally invasive techniques about 10 to 15 years ago, the only treatment options available for the elderly involved bed rest and bracing. Unfortunately, these techniques were often not effective at controlling pain and carried a risk of deconditioning, bed sores, and even death. With present minimally invasive techniques, elderly patients can be out of bed within hours after surgery and do not require cumbersome spinal braces.

The two most common minimally invasive techniques used to treat thoracic fractures are vertebroplasty and kyphoplasty. Both techniques involve the placement of needles into the fractured vertebral body using the pedicles as an access corridor. The needle placement is accomplished under x-ray guidance. After inserting needles into the fracture, plastic bone cement is injected, also under x-ray guidance. The cement hardens in minutes, providing immediate structural support for the damaged vertebral body. The principle difference between vertebroplasty and kyphoplasty is that kyphoplasty involves the use of two balloons. These balloons are inflated within the fractured vertebral body to create a cavity. Bone cement, about the consistency of cookie dough, is then used to fill these cavities. In vertebroplasty, a slightly runnier version of the same cement is injected into the fine network of channels within the vertebral body. While there are vocal proponents of each technique, both have been shown to be similar in terms of effectiveness.

Larger reconstructive techniques involve the placement of spinal hardware and bone graft in an effort to restore the structural integrity of the spine and allow it to heal in a more normal alignment. These techniques are often used in conjunction with direct decompression of the spinal cord. Such reconstructive efforts can be carried out from the front of the spine through the chest, from the back of the spine, or a combination of both. The spinal hardware used is often titanium and is designed to provide an internal brace for the spine in order to create the best environment for it to heal. A frequent misconception is that after one has spinal hardware placed, one cannot ever have an MRI. Titanium spinal implants have the combined benefits of strength and MRI compatibility.

Osteoporosis

Any discussion of thoracic spinal fractures would be incomplete without some discussion of osteoporosis. This disease involves the progressive decline of bone mineral content and is most common in women beyond

the age of menopause. It should be noted that the disease can also affect men. Chronic steroid use, smoking, and certain hereditary conditions make certain individuals more susceptible to osteoporosis. Fractures of the thoracic and lumbar vertebral bodies, as well as the hips, are the unfortunate consequences of this disease. To get a sense of the scope of this condition, there are currently approximately 700,000 spine fractures annually related to osteoporosis in the United States. This compares with 300,000 hip fractures. Part of this disparity comes from the fact that we have only two hips, whereas each person has twelve thoracic vertebrae and five lumbar vertebrae. Recently, a greater emphasis on vitamin D deficiency as well as calcium deficiency has led to improvements in the medical management of this condition.

Elderly patients with fragility fractures of the thoracic spine often heal without intervention. In those cases where patients do not heal on their own, vertebroplasty and kyphoplasty have been shown to be quite effective in terms of improving pain and returning patients to activity. Unfortunately, patients who have required one of these treatments, have a 10–15% chance of developing an additional fracture.

Illustrative Cases: Patient One

Patient one is a healthy 56 year old woman who was enjoying her vacation in South America until she slipped down about ten steps while touring some ruins, landing on her back and buttocks. She was able to grab a hand rail to ultimately stop her fall. At the time, she felt more embarrassed than injured and continued her vacation with some new mid back discomfort. Unfortunately, for weeks after her return home, she experienced increasing pain between the shoulder blades. As time went on, she began to experience pain radiating around to the front of her chest on the left greater than the right side. This pain became her constant, unwanted companion. She was ultimately found to have a fracture of her T6 vertebral body. She was initially treated with a brace and only had a progressive increase in her pain. Her subsequent x-rays showed progressive collapse of the T6 vertebral body (Figure 7). At this point a CT scan (Figure 8), and an MRI (Figure 9) showed dramatic loss of bone in the vertebral body, with a

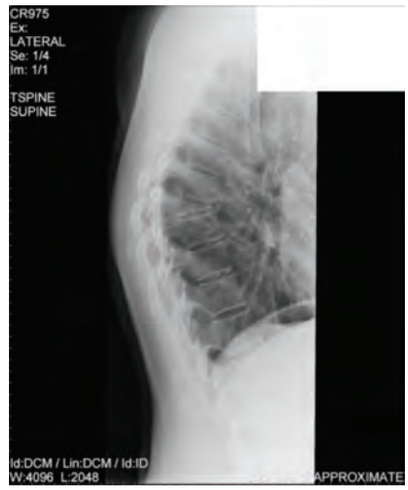

Figure 7. X-ray showing collapse of T6.

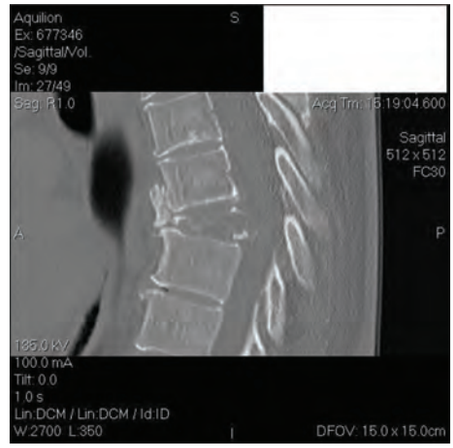

Figure 8. CT scan showing bone loss at T6.

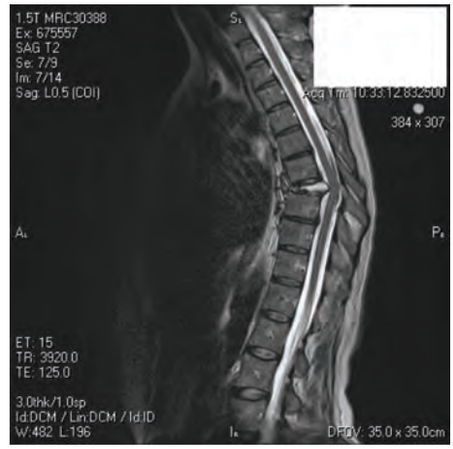

Figure 9. MRI showing compression of the spinal cord.

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significant loss of the normal vertebral body height, and an abnormal increase in the forward angulation of the spine. Also of particular concern was the degree of compression and distortion of her thoracic spinal cord. This latter finding was particularly concerning as it potentially threatened the use of her legs.

As a result of the almost complete loss of the structural integrity of the T6 vertebral body and the concerning presence of the significant spinal cord compression, a decision was made to proceed with direct reconstruction of the front of the patient's thoracic spine. With the help of a thoracic surgeon, the patient's left chest was entered. With the left lung deflated, the remnants of the T6 vertebral body were removed, and the spinal cord was decompressed. The spine was then reconstructed using an expanding titanium cage supplemented by a plate and four screws. A section of one of the patient's ribs was removed by the thoracic surgeon so that it could be used for bone graft. Ribs tend to make excellent bone graft as they are one of the few bones in the body that can heal while exposed to the constant chest motion associated with breathing. X-rays of the patient from after surgery are seen in Figures 10 and 11. She has made an excellent recovery and looks forward to future travelling. Pathologic analysis of the T6 bone removed at surgery revealed no evidence of infection or tumor.

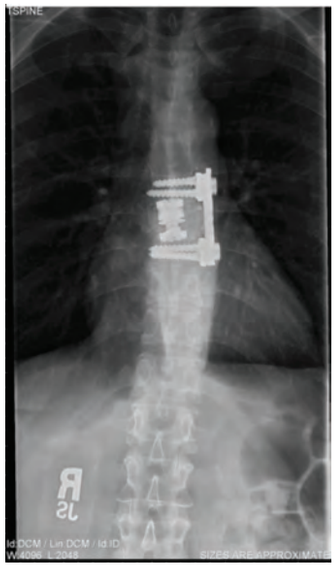

Figure 10. Post-surgery x-rays.

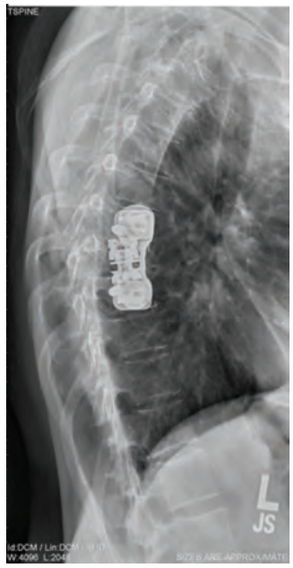

Figure 11. Post-surgery x-rays.

Illustrative Cases: Patient Two

Patient two is a 58 year old man with a history of seizures. After skipping several doses of his medication, he had a severe grand mal seizure. After recovering from his seizure, he complained of persistent pain between the shoulder blades. An MRI showed a fracture of the T7 bone (Figures 12 and 13).

The patient was initially treated with a brace and pain medication, but failed to have improvement in his pain. Due to his ongoing pain, a decision was made to proceed with kyphoplasty of the T7 fracture. Front and side views of the treated fracture are seen in Figures 14 and 15. The patient had immediate improvement in his pain and was able to resume his normal activities shortly after surgery.

Illustrative Cases: Patient Three

Patient three is a 63 year old man who fell in his yard while raking leaves. He was found to have a fracture of T9 on MRI (Figure 16). He was treated with a brace.

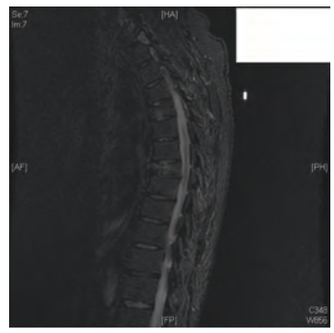

Figure 12. MRI showing T7 fracture.

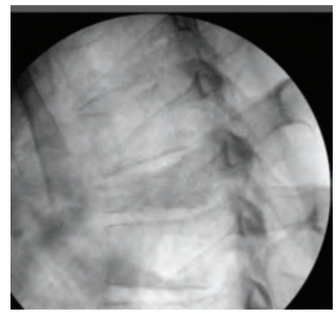

Figure 13. MRI showing T7 fracture.

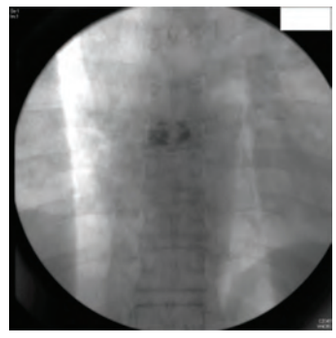

Figure 14. MRI after kyphoplasty.

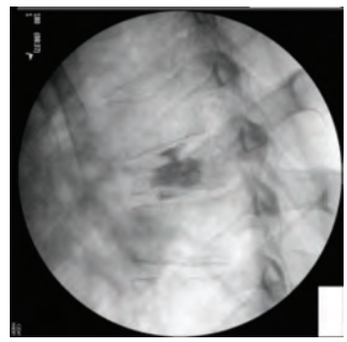

Figure 15. MRI after kyphoplasty.

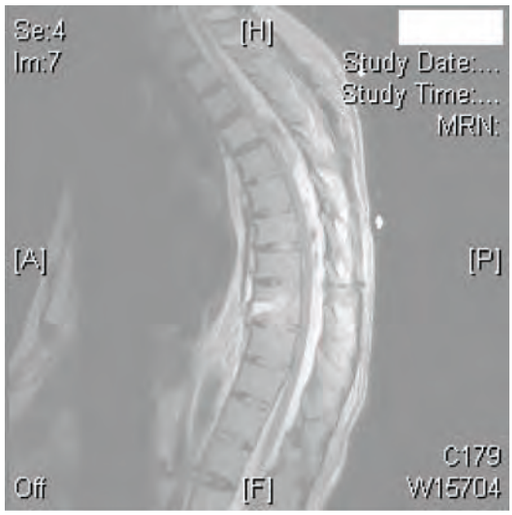

Figure 16. MRI showing T9 fracture.

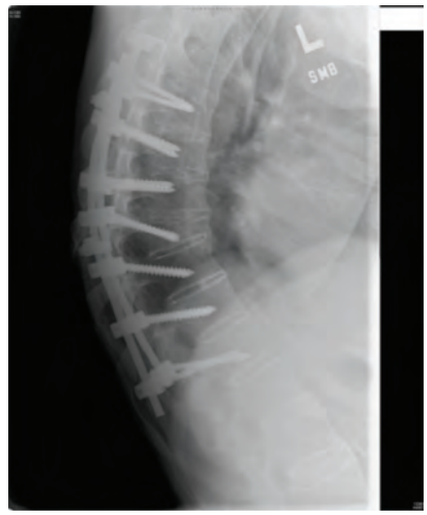

Figure 18. Post-surgery x-ray.

After initially doing well, he developed progressive dislocation of his spine, consistent with both a fracture and ligament injury. He also began to experience some heaviness in his legs. A follow-up CAT scan shows that the spine has slipped out of alignment, threatening the spinal cord (Figure 17).

An extensive reconstruction was performed from the back of the spine in order to realign and stabilize the spine in the area of injury (Figure 18). He has made a complete recovery.

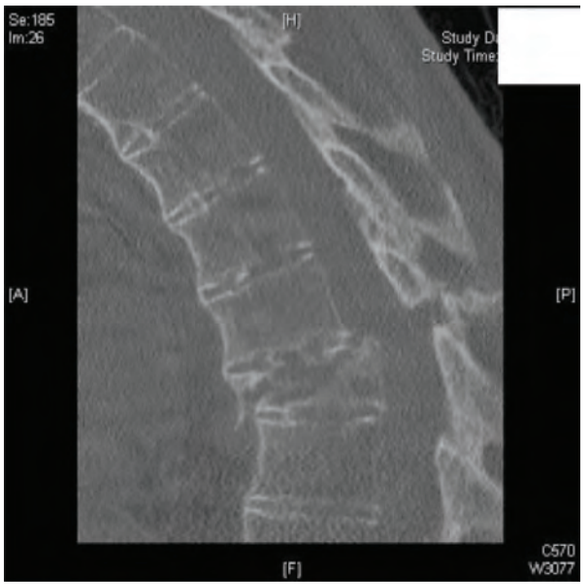

Figure 17. MRI showing T9 fracture.

Conclusion

The thoracic spine is part of a complex system of bones, joints, muscles and ligaments. It is well designed and well protected, but unfortunately is not immune from injury. Fractures and ligamentous injuries can damage the structural integrity of the spine, produce terrible pain, and place the spinal cord at risk. With a thorough knowledge of the anatomy of the spine, as well as the typical injury patterns affecting it, the spine surgeon can work to restore the integrity of the spine, relieve pain, and return an injured patient to activity.

Christopher H. Comey, M.D.

Dr. Comey is Chief of Surgery at Holyoke Medical Center. His practice encompasses all aspects of neurosurgical care with a special emphasis on minimally invasive surgical techniques and the treatment of complex spinal disorders. Despite his commitment to his patients, he also finds time to pursue his research interests and to lecture to surgeons around the country. Dr. Comey has authored dozens of peer-reviewed publications as well as contributed to a number of textbooks on diseases of the spine. Dr. Comey is an active member of the American Association of Neurological Surgeons, the Congress of Neurological Surgeons, the North American Spine Society, the Joint Section on Disorders of the Spine, the Massachusetts Medical Society, and the Hampden District Medical Society.

Thoracolumbar Spine Trauma

Christopher R. Good, M.D., F.A.C.S.

Thoracolumbar spine injuries are commonly related to high energy accidents including falls or motor vehicle accidents. Patients with thoracolumbar injuries commonly have other injuries including injuries to the abdomen, chest, extremities, or other spinal injuries. The typical "ABC" (airway, breathing, and circulation) evaluation is needed for all patients seen in the emergency room after a thoracolumbar spine trauma. Appropriate evaluation of the thoracolumbar spine trauma requires complete and thorough clinical and radiographic examination, which begins only after ensuring the patient's other vital organ systems are intact.

Examination of the spine includes careful visual inspection as well as palpation of the spine and a complete neurologic evaluation including assessment of the patient's strength, skin, sensation, and reflexes.

Careful evaluation can be performed in patients who are awake and are comfortable enough for the examination. For patients who are sedated or have changes in mental status, there is a need for additional imaging modalities including CT scan and MRI scan to look for other injuries. In these patients it is critical to perform repeat evaluation as the patient's condition stabilizes. It is not uncommon for additional injuries to be identified once the patient is able to report.

Neurologic Evaluation

Assessment of a patient's strength and sensation at and below the level of spinal injury is critical, including evaluating the function of each of the nerves at the specific level injured. "Spinal shock" is a condition where paralysis may occur as a result of disruption of spinal cord function. This typically occurs at or just below the level of an injury. Spinal shock typically resolves within 48 hours after an accident. It is important to realize that full assessment of a patient's neurologic status can only be made when a patient has recovered from spinal shock. Resolution of spinal shock is confirmed when certain reflexes that are mediated through the spinal cord return, particularly the bulbocavernous reflex.

Thoracolumbar spine trauma and fractures may be associated with neurologic injuries. A "complete" neurologic injury signifies the complete absence of any sensation or motor function below the level of the injury. An "incomplete" neurologic injury means that there is some residual spinal cord and nerve function below the level of the injury and has better prognosis for potential recovery. Spinal cord injury has been classified by a level of injury as defined by the American Spinal Injury Association (ASIA). Incomplete spinal cord injuries may fit into one of four typically described patterns, and the type of neurologic deficit usually correlates with the location of the injury within the spinal cord (Figure 1).

Central Cord Syndrome

Central cord syndrome is the most common spinal cord injury pattern. Patients with central cord syndrome typically have greater loss of motor function in the hips and thighs with relative sparing of the function in the feet and ankles. Prognosis for some recovery after this injury is good with approximately 75% of cases having some improvement.

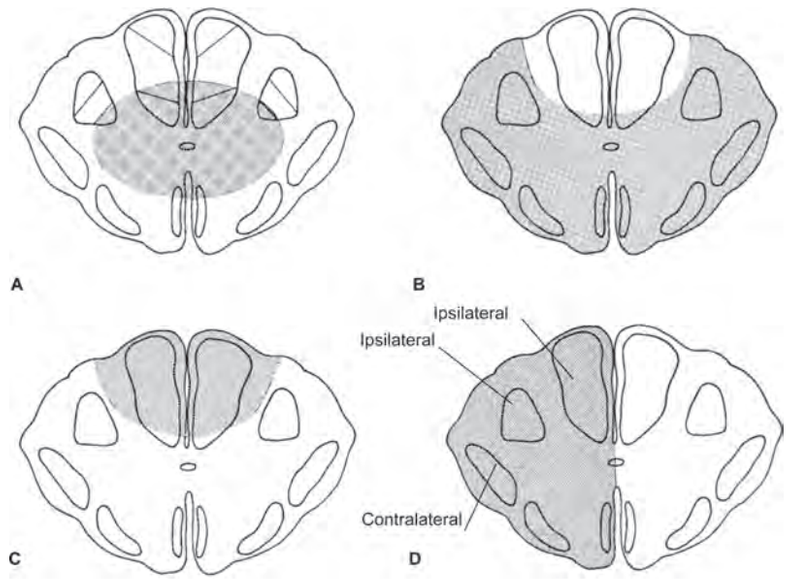

Figure 1. Types of spinal cord injury (shaded zones) that produce the four main incomplete injury patterns seen clinically. (A) Central cord syndrome. (B) Anterior cord syndrome. (C) Posterior cord syndrome. (D) Brown-Séquard syndrome. © 1995 American Academy of Orthopaedic Surgeons. Reprinted from the *Journal of the American Academy of Orthopaedic Surgeons,* Volume 3(6), pp. 345–352 with permission.

Anterior Cord Syndrome

Patients with anterior spinal cord syndrome usually have complete loss of muscle function as well as loss of pain and temperature sensation below the level of the injury. In this situation, the nerves that provide the sensation of vibration and light touch are spared. The prognosis for recovery in this situation is unfortunately very poor, with approximately 10% of patients having significant recovery.

Posterior Cord Syndrome

Posterior cord syndrome is the least common spinal cord injury pattern. In this situation there is typically a decrease in sensations such as vibration and light touch, but muscle function is usually preserved.

Brown-Sequard Syndrome

Brown-Sequard syndrome is an unusual situation where function in one half of the spinal cord is disrupted. Patients with Brown-Sequard syndrome find that the sensations of touch and vibration are lost on one side of the body while sensation of deep pain and temperature are lost on the opposite side of the body. While this is rare, the prognosis for recovery is good in over 80% of patients.

All patients with acute thoracolumbar trauma require full evaluation in order to rule out injury inside the abdomen or chest, including the possibility of major bleeding, bowel rupture or other abdominal injuries. Patients with thoracolumbar spine injuries may also suffer from "neurogenic shock." This is a state of low blood pressure that results in the loss of normal function of the sympathetic nervous system. When the nervous system is not functioning properly, the patient will typically have low blood pressure as well as a decreased heart rate. This is a different type of shock than seen in most traumas where a high heart rate is seen with low blood pressure.[1]

Patients with thoracolumbar spine injury require radiographic evaluation to start with x-rays of the spine from the front and side. Other evaluation is based on the presence of additional injury and trauma. Most patients also get x-rays of the chest as well as pelvis, in this situation. CT scan has proven to be very valuable for the evaluation of thoracolumbar injury. A CT scan provides the best possible understanding

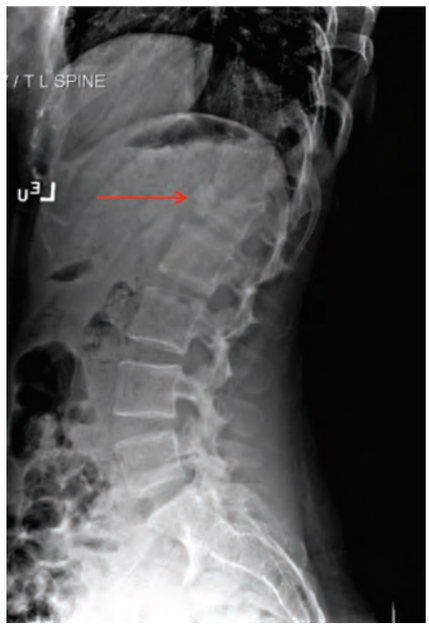

Figure 2. X-ray of the thoracolumbar spine in a 24 year old woman after falling off a bicycle. Her x-rays show a fracture at L1 (red arrow). The bone at the first lumbar vertebra (L1) is compressed down, compared to the square shape seen at the other vertebrae.

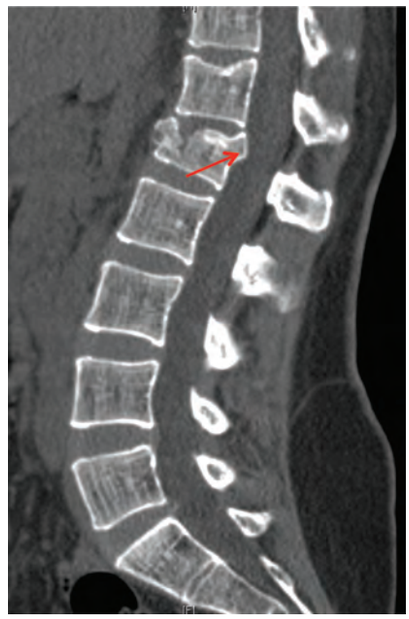

Figure 3. CT scan of the same patient showing the broken bone at L1. A small amount of buckling can be seen at the back edge of the bone (red arrows).

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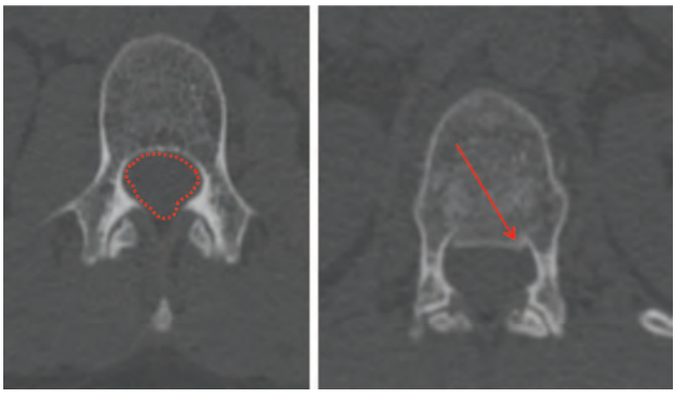

Figure 4. Cross sectional CT scan on the same patient. On the right, a normal amount of space exists around the spinal cord (red dots). On the left view, a small amount of bone has retropulsed back into the spinal canal (red arrow).

of the anatomy of the bones and location of fracture. MRI is another form of spine imaging that allows for visualization of the "soft tissues" including the spinal cord, intervertebral discs, as well as the ligaments. An MRI scan is indicated in all patients with neurologic deficit after trauma in order to evaluate for spinal cord compression or other neural injury. An MRI scan can also be used to look for bruising of the spinal cord or the possibility of bleeding or hematoma around the spinal cord that may occur as a result of a fracture.

It is important to realize that at some point imaging must be used for the entire spine for patients with thoracolumbar injury. Patients with thoracolumbar fracture have been noted to have fractures at other levels of the spine in 5% to 30% of cases. There should be a high index of suspicion in these situations in order to avoid missed or delayed diagnosis of injury.

Thoracolumbar Spine Trauma Classification

Thoracolumbar spine trauma is one of the most common musculoskeletal injuries in the world. However, there is a wide variability in the management, largely because of a lack of an accepted classification system. Spine fractures account for a large portion of musculoskeletal injuries. Approximately 70% to 90% of spinal fractures occur in the thoracic or lumbar spine, most of which occur at the junction between the two (T10 to L2).

Thoracolumbar spine trauma has been classified using multiple schemes over time. At this time, the Thoracolumbar Injury Classification system seems to

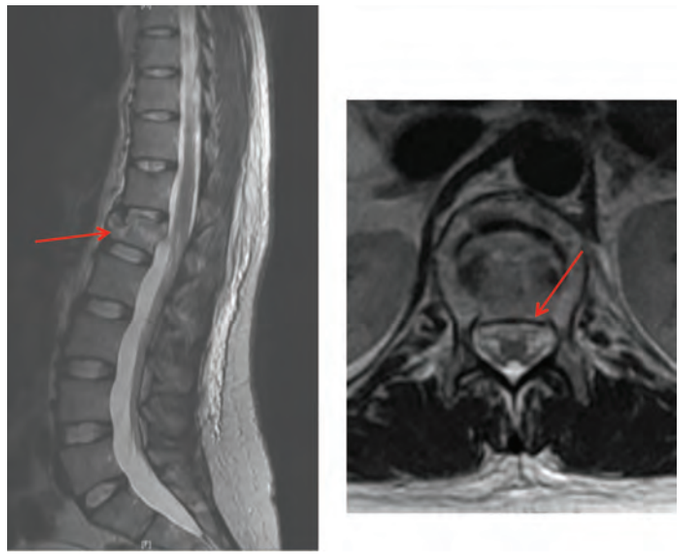

Figure 5. MRI scan shows the fracture at L1 with no evidence of compression of the spinal cord.

be the best classification available to guide decision making for patients with thoracolumbar spine injury. Although a number of classification systems have been used to aid surgeons in treating patients, only the Thoracolumbar Injury Classification and Severity Score (TLICS) has been evaluated by a rigorous process where clinical experts have worked to form a classification system which uses prospective protocols.

TLICS was developed by an international team of spine surgeons by the name of Spine Trauma Study Group. In this system, the patient's injury is given a score based on the spinal injury severity score (ISS). The injury is classified based on (1) the mechanism and type of injury, (2) the presence or absence of neurologic deficit, and (3) the stability of the ligamentous complex that supports the spine.[2]

1. Injury morphology is divided into three types, compression, rotation/translation, and distraction. Compression injury is defined by the loss of height of the vertebral body including compression and burst fractures. Rotation/translation is defined as horizontal movement of one vertebral body on top of another, typically noted with dislocations or fracture/dislocations. Distraction is defined as disassociation of the vertical access, commonly seen with ligamentous

rupture and hyperextension injuries with widening distraction of the spinal elements.

2. Neurologic injury is an important indicator of the severity of the spinal injury. The presence of a neurologic deficit is a strong indicator for surgical intervention. In the TLICS classification system, the neurologic status is described from better to worse prognosis, that is, from neurologically intact to nerve root injury, complete spinal cord or cauda equina injury and incomplete spinal cord or cauda equina injury.
3. Rupture of the posterior ligamentous complex (PLC) has been associated with increased spinal instability which may indicate the need for surgical intervention, as these structures have poor healing ability. In the TLICS, the PLC is categorized as intact, indeterminate, or disrupted. Patients with obvious rupture or gapping of the posterior structure are given the highest score.

The three factors within the TLICS are all given a score and then the scores are totaled to help guide final treatment. A score greater than 4 suggests the need for surgical treatment, indicating significant instability, whereas a score of less than 4 suggests the need for nonsurgical treatment. Patients with a score of 4 could be treated with either surgical or nonsurgical treatment. For patients with multiple fractures, the area with the highest severity score is utilized to guide treatment.

The thoracolumbar injury classification seems to be the best system available to guide decision making at this time. However, ongoing studies are needed to determine if the use of classification leads to better agreement among surgeons or better outcomes for patients.[3–5]

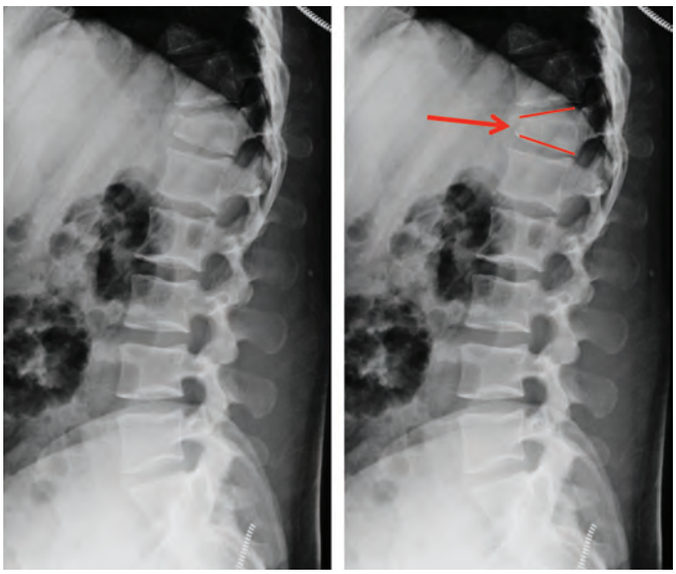

Figure 6. X-ray of the thoracolumbar spine in a 26 year old man after a severe car accident. He complained of back and leg pain but did not have any other neurologic abnormality. His x-rays show a fracture at T12 (red arrow). The bone at the twelfth thoracic vertebra is compressed down compared to the square shape seen at the other vertebrae (red lines).

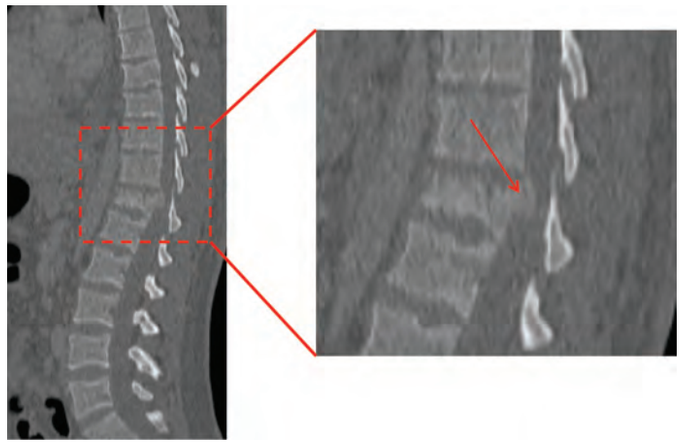

Figure 7. CT scan of the same patient showing the broken bone at T12. On the magnified view, buckling of the bone can be seen into the spinal canal (red arrows).

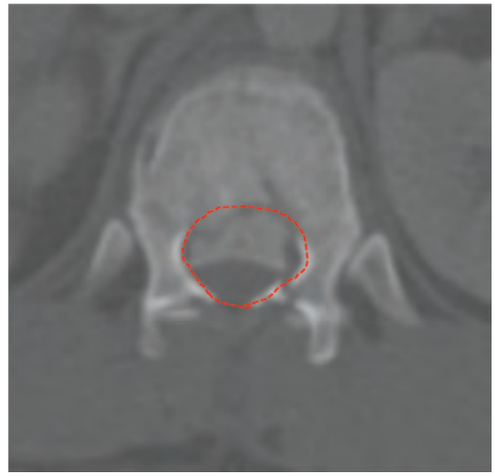

Figure 8. Cross sectional CT scan on the same patient. Bone has retropulsed back into the spinal canal causing compression of the spinal cord (red arrow). The normal space for the spinal cord has been outlined in red to highlight the amount of compression (red line).

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Initial treatment for patients with thoracolumbar trauma involves immobilization of the spine. The goal is to limit further damage to the injured spinal cord during the early stages of recovery. Bed rest with log rolling may be used. In some patients traction has been deemed desirable to achieve additional spine immobilization. Medical stabilization of a patient with thoracolumbar trauma is of paramount importance through the management of blood pressure and other injuries which may be immediately life threatening.

In some centers, high dose steroid (methylprednisolone) is routinely administered to all patients with spinal cord injury. When steroid is used in this situation, it is administered as a bolus of 30 mg per kilogram of body weight followed by 5.4 milligram/kilogram/hour for a total of 23 hours. The efficacy of this treatment has only been shown when treatment is started within eight hours of the injury and, at this time, considerable debate exists as to the efficacy of the treatment. Higher rates of complication have been noted in patients treated with steroids including postoperative infection, gastric ulcers, and pulmonary complications.[6]

Nonoperative treatment in patients with thoracolumbar trauma is used for injuries that are considered to be stable without potential for progressive neurologic compromise or spinal deformity during the healing period. Injuries are classified as either stable or unstable. In most cases a stable injury is treated with a rigid cast or removable orthosis which is maintained until the fracture has healed. Healing typically takes place between eight and twelve weeks. For fractures involving the lower thoracic spine and lumbar spine, additional treatment may be required based on the level of injury and time toward healing. Non-operative treatment is typically not recommended for patients with significant instability or neurologic compression.

Operative management of thoracolumbar injuries is usually considered for fractures that are unstable or have the potential for further neurologic deficit. For patients with significant neurologic compromise, early intervention and stabilization can lead to improved patient mobilization and potentially allow for higher rates of neurologic recovery. For patients with significant compression of the spinal cord or neural elements, any surgical intervention needs to achieve full decompression of any bone or soft tissue that is intruding upon the spinal cord. Decompression of the spinal cord may lead to improved recovery and afford functional benefits for patients long term.

For patients with spinal instability, the use of instrumentation and fusion of the spine at the level of fracture is warranted. Surgery is typically delayed until the patient is medically stabilized to allow the active bleeding or trauma to be managed. Surgery is performed emergently

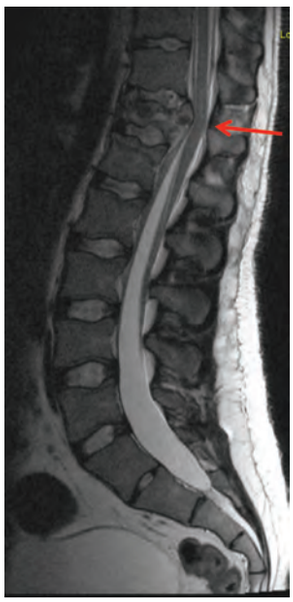

Figure 9. MRI scan shows the fracture at T12 with evidence of compression of the spinal cord (red arrow).

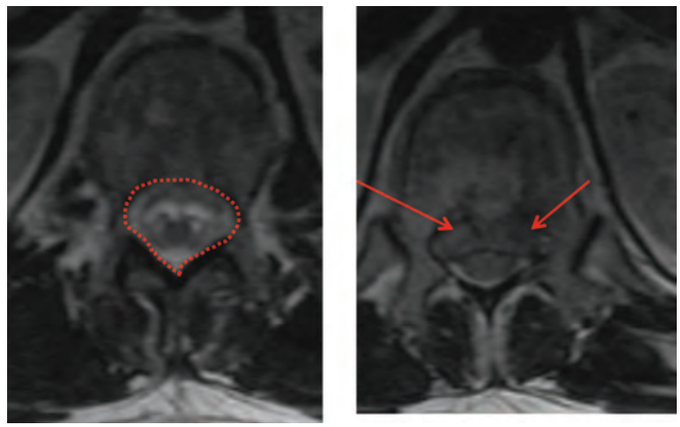

Figure 10. Cross sectional MRI scan on the same patient. On the right, a normal amount of space exists around the spinal cord (red dots). On the left view, bone has retropulsed back into the spinal canal causing compression of the spinal cord (red arrow).

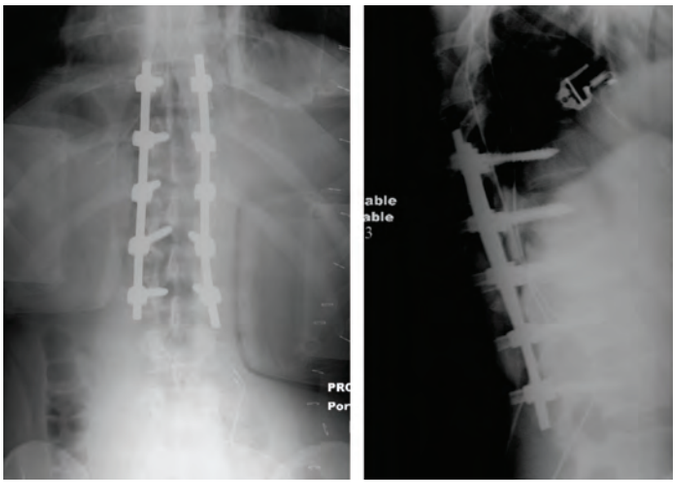

Figure 11. The patient has been treated with spinal instrumentation and indirect reduction of the fracture fragment. His symptoms improved and he returned to full activity including working in construction.

only in cases where progressive neurologic deterioration occurs, which is uncommon. The choice of instrumentation depends on the type and location of the fracture, as well as the presence or absence of neurologic compromise. Many injuries can be treated through all posterior surgical techniques including screws, rods, hooks, and wires to allow for reconstruction. In some cases, surgical approach to the bone and discs in the front part of the spine is warranted to achieve spinal stability, as well as removal of neurologic compression in that area. Sometimes, the anterior instrumentation alone can obviate the need for posterior surgery. Otherwise, a combination of approaches performed through an anterior and combined posterior approach is recommended.

For patients with neurologic deficits after thoracolumbar trauma, extremity motion exercises and strength training are useful during the postoperative period to maintain flexibility and maximize functional potential for recovery. For patients with paraplegia or significant weakness, additional training can help facilitate mobility and transfers, as well as return to independent living. Assistive devices and occupational therapy training can help patients get maximal functional independence.

Summary

The goal of management of thoracolumbar spine injuries is to prevent further deformity and neurologic deficit while achieving a stable spine. Most patients with thoracolumbar fractures are treated with nonoperative treatment, i.e., a cast or brace and ambulation. Recommendations vary based on the type and location of the fracture as well as the presence or absence of neurologic injury. Operative treatment to decompress neural compression and stabilize the spine is most commonly recommended. Details of the surgical procedure are based on the location of the fracture and neurologic compromise.

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Management of Spinal Tumors

J. Cameron Muir, M.D., F.A.A.H.P.M.

Introduction

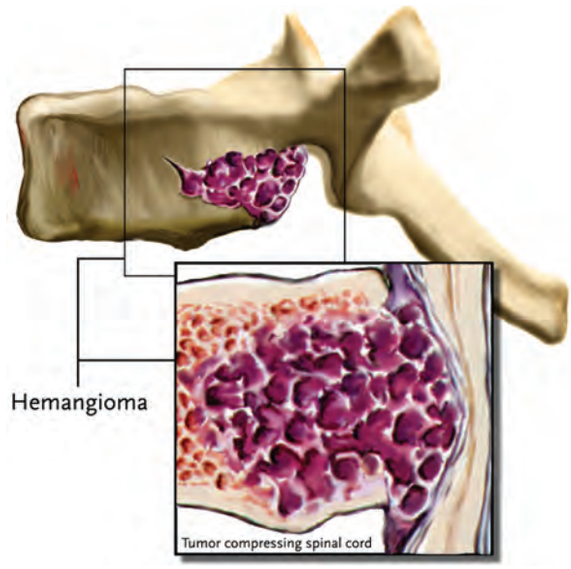
The spine is one of the essential structures in the human body, providing functional mobility, support of muscles and organs, and protection of the central nervous system. Preservation of spinal health and function can improve an individual's quality of life and control a growing economic burden on our nation's healthcare system. When considering oncologic conditions, the spine is the third most common site of abnormal cell proliferation, therefore, prompt evaluation and appropriate management of spinal pain and dysfunction is important.[1] The following review will focus on spinal tumors, including an overview of primary and secondary lesions of the spine, as well as the clinical manifestations and common complications of spinal tumors, the various disease directed treatment modalities, and finally, therapies for palliative symptom management. As the impact of spinal tumors can affect many different aspects of a person from function, to treatment, rehabilitation, and potentially decreased survival, it is important to have a multidisciplinary approach to maximize a patient's chance of survival, function, and overall quality of life.

Primary Spinal Tumors

Primary spinal tumors arise from the intradural-extramedullary and intradural-intramedullary regions of the central nervous system and account for approximately two to four percent of all CNS tumors. Vascular tumors, chordomas, epidermoids, and neurilemmomas generally present as extramedullary lesions in 70 to 80 percent of all spinal cord tumors, with the most common being benign meningiomas. The most common intramedullary lesions include astrocytomas and ependymomas, while oligodendrogliomas, gangliogliomas, medulloblastomas, hemangiomas, and hemangioblastomas are less common. The overall prevalence of primary spinal cord tumors is 0.74 per 100,000 persons. Of all primary spinal tumors, the majority (50 percent) involves the thoracic spinal canal, while the remainder affects the lumbosacral spine and cervical spine (30 percent and 20 percent respectively). Most spinal tumors present insidiously with symptoms including pain, unilateral motor weakness, sensory loss, and autonomic dysfunction. Spinal cord compression can present with intradural lesions (i.e., ependymoma, neurilemmomas, and paraganglioma), however this occurs most commonly in cases of extradural spinal metastasis. The relatively slow growing nature of primary spinal cord tumors results in an overall favorable prognosis with 64 percent of patients diagnosed with primary spinal cord tumors alive at least ten years.[2–4]

Secondary Spinal Tumors

Ninety five percent of all secondary spinal cord tumors are classified as extradural lesions and result from metastasis of a primary site. The incidence of spinal metastasis according to primary site is as follows: lung — 31%, breast — 24%, GI tract — 9%, prostate — 8%, lymphoma — 6%, melanoma — 4%, kidney — 1%. Seventy five percent of patients diagnosed with a primary cancer site will develop bone metastasis. Only ten percent of patients with spinal metastasis are symptomatic, and in many cases the disease is incidentally discovered during autopsy. As with primary spinal lesions, the thoracic area of the spine is the most affected (70%), followed by lumbar (20%) and cervical (10%). However, metastatic spinal tumors occur in multiple sites in more than half of the



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cases, while primary spinal tumors are more commonly a single primary lesion. Survival rates with secondary (metastatic) lesions are poor, with a median survival of 10 months (for all tissue types); and this number drops precipitously to 3 months if spinal cord compression occurs.[1–3]

Spinal Cord Compression

Over 20,000 cases of spinal cord compression are identified in the United States each year, affecting approximately five to ten percent of all patients diagnosed with cancer. The median interval between diagnosis of metastatic disease and spinal cord compression ranges from six to 12 months and most commonly occurs at the level of the thoracic spine. Incidentally, individuals diagnosed with metastatic lung or breast cancer have the highest tendency for thoracic metastasis and, therefore, are the tumor type that most often present with cord compression.[2,3]

Pain, the primary presenting symptom, can be classified in three categories: local, mechanical, and radicular. Local pain is a result of tumor growth in the affected spinal segment, and can be aggravated by coughing, sneezing, or the Valsalva maneuver. Mechanical pain usually is affected by movement or change in position, therefore pain that spontaneously awakens an individual from sleep, while relaxed in a recumbent position, is an ominous sign of spinal cord compression. Radicular pain is caused by nerve root irritation and results in muscle spasms or sharp, stabbing sensations in the extremities. It is likely that patients with cord compression will experience one or more of these pain symptoms. Motor weakness, sensory impairment, and bladder dysfunction are the primary neurologic symptoms that ensue in cases of rapid onset or delayed diagnosis, therefore prompt evaluation and work-up is essential in cases of new onset back pain. Magnetic resonance imaging is the preferred modality to establish prompt diagnosis.[2,3]

Treatment Options

The goal of treatment can either be curative in many cases of primary tumors, but in cases of secondary metastatic spinal disease, the goal is primarily palliative (i.e., non-curative). “Disease-modifying” therapy can decrease the size of the lesion by surgical and/or nonsurgical means. This may help to preserve, or in some cases improve, the patient’s functionality and ability to ambulate, to prevent further progression. In addition, primary palliative therapy should always be a part of treatment to reduce pain, increase function, and to improve the quality of life.

Surgical Interventions

In addition to the above mentioned goals of treatment, surgery has been used specifically for reducing tumor volume especially in cord compression. Other indications for surgery include acquisition of histological or diagnostic tissues, pain relief not achieved by nonsurgical measures, stabilization of the spine specifically for impending pathologic fractures and for metastatic tumors that are radioresistant (i.e., lung, colon, renal cell and sarcomas).

In a study conducted by Landmann et al.,[5] a combination of radiation with laminectomy showed the best outcome for cases of cord compression by regaining ambulation (82%), restoring sphincter function (68%) and providing pain relief (88%).

For patients that cannot tolerate open surgery, vertebroplasty can be a very important alternative procedure in providing pain relief due to compression fractures and providing vertebral stability for weakened vertebrae. The injection of a bone cement, liquid methylmethacrylate, to the vertebral body, solidifies the bone and offers stability. Kyphoplasty is a variation of vertebroplasty wherein a balloon is inserted into the vertebral body, which then is subsequently injected with methylmethacrylate.

Radiation Therapy

Different types of radiation have been used to treat malignant disease: external beam radiation therapy (EBRT), stereotactic radiation, bracytheraphy, and radioisotope therapy. For spinal tumors, ERBT and stereotactic radiosurgery (SRS) are used. Using radiotherapy, alone or in combination with surgery, has been proven to offer pain relief beginning in as little

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as 24 hours, but most commonly the peak benefit is experienced two to three weeks. The early pain relief has been attributed to the decrease of chemical pain receptors released from the tumor after the initiation of radiation; however, more commonly seen in the clinical setting, patient's pain may be exacerbated initially at the start of radiation therapy (attributed to the inflammation of the tumor and its surrounding tissues) before achieving pain relief days to a few weeks after completion of therapy (once tumor volume decreases). The likely radiosensitivity of a tumor should be taken into consideration. Lymphomas and germ cell tumors are highly sensitive while epithelial cell tumors are only moderately sensitive and thus needs high dosing. As mentioned, the radioresistant cancers like melanoma and renal cell cancers are usually addressed with surgery.

When planning for radiation dosing, there are many potential considerations: whether the patient is currently undergoing chemotherapy; the patient's ability to tolerate the procedure; and the timing of radiation with respect to any potential surgery. The standard palliative radiation treatment for spinal disease is commonly multiple fractions over two weeks (i.e., 10 fractions of 30 Gy). However, recent literature and consensus recommendations suggest that a single dose of radiation (i.e., 6–8 Gy) may provide similar levels of pain relief as multiple fractions. Thus, consideration of patient quality of life might suggest single dose radiation therapy in metastatic disease—especially when survival is limited as in the advanced disease setting.

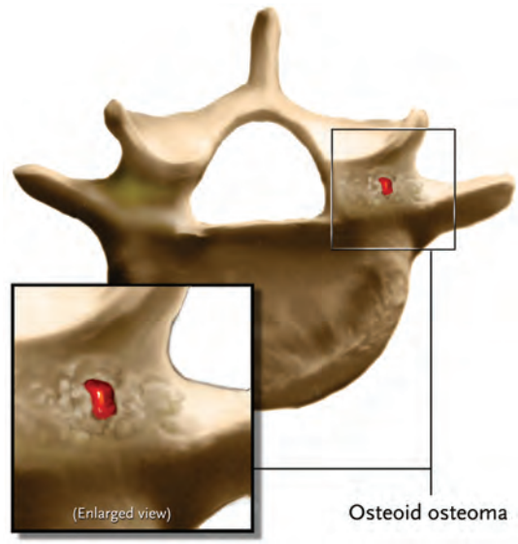
Side effects of the radiation are usually based on location relative to the external beam field. Radiation to the pelvic area or spine tends to cause nausea and diarrhea, while radiation to the upper spine can result to mucositis of the upper GI tract. Fatigue is common and can be a debilitating side effect. Patients can exhibit fatigue as early as a few days into therapy and can persist for weeks after the therapy is completed.

Chemotherapy

Based on the patient's ECOG performance status and the patient's goals, chemotherapy is used for spinal tumors: as a "neo-adjuvant" therapy, to shrink the tumor *prior* to surgery; or as an "adjuvant" treatment *after* surgery to address the remaining cancer cells. In general, chemotherapy is the mainstay of primary therapy for malignant disease, however, studies have shown that it has limited benefit for spinal cancer. Thus, a balanced discussion about the benefits and burdens of chemotherapy specifically with regard to the impact on spinal metastatic disease is warranted.

Corticosteroids

Steroids are used for its many benefits including anti-inflammatory properties, anti-nausea benefits, as well as for its analgesic properties. Its analgesic effect is achieved by its inhibitory effect against prostaglandin and leukotriene. As an adjuvant for opioids, a range of doses of dexamethasone can be used from 4–20 mg PO once daily. However, for significant symptoms and/or cord compression, a regimen of dexamethasone 20 mg IV stat, followed by 20 mg po/iv once daily is indicated, followed by a subsequent taper as indicated by the clinical scenario. Given the long half-life of dexamathasone (36–54 hours) and the relative absence of mineralocorticoid effect (little salt and water retention compared, for example to prednisone), once daily dexamethasone is pharmacologically and clinically recommended. In the case of



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cord compression, a surgical and/or radiation oncology consult is likewise imperative.

Bisphosphonates

Use of bisphosphonates is another effective adjuvant therapy to reduce both pain and the incidence of pathologic fractures, specifically for bone metastatic lesions that have high osteolytic activities. Its prophylactic use in breast cancer and multiple myeloma has proven beneficial. Its mechanism of action is through the natural uptake of osteoclasts for which the bisphosphonates then interferes with the osteoclasts' activity and/or triggers their apoptosis. Its preventative benefit has mostly been seen in patients treated for more than six months, showing a reduction of vertebral fracture. Some institutions do consider its use on patients whose prognosis is 3–6 months provided the predominant symptom burden is bone metastatis. As an adjuvant analgesic, its effect is usually seen within 2–3 weeks and mainly with the use of IV bisphosphonate. Duration of treatment is unclear and usually continued as tolerated by the patient or until significant functionality decline is noted. Its most common side effect is a flu-like symptom seen within 2 days of IV infusion and usually resolves within 24–48 hours. The other notable possible side effect of bisphosphonate is osteonecrosis of the jaw, usually seen in patients under treatment for years.

For pain associated with spinal tumors, opioids are a mainstay of therapy for both the nocieceptive and neuropathic components of pain. Morphine is the gold standard for pain therapy, however, other opioids have similar efficacy when dosed appropriately. Opioids should be dosed according to both the WHO analgesic ladder as well as the NCCN Cancer Pain Guidelines (www.NCCN.org). Opioid rotation is indicated when there are side effects or toxicities to the initial opioid prescribed. In addition, all patients receiving opioid therapy should have a concomitant bowel regimen prescribed to reduce or prevent constipation—the only side effect of opioid therapy that the body does not accommodate to over time. Finally, for radicular pain suggestive of nerve damage, neuropathic analgesics should be considered. In addition to dexamethasone (described above), tricyclic antidepressants (amitriptyline, nortriptyline, and others) and anticonvulsants (gabapentin, pregabalin, and others) are a mainstay of therapy.

Summary

Tumors of the spine are predominantly secondary or metastatic in nature, and the symptoms are brought about when the tumor occupies a constricted space of the spine. Different types of treatment modalities are available for the patient, but mostly as a form of palliative treatment and symptom management, offering the most benefit when used in combination. The challenge for practitioners lay on a complex decision making regarding which modalities or interventions should be suggested to the patient; in which, the decision should be based from an honest discussion with patients about their case, their prognosis and goals; in conjunction with a constant coordination and communication between different departments involved in a patient's care.

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Primary Pediatric Spinal Column Tumors

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Primary tumors of the spine are rare entities in children. The management of these lesions is quite complex and may involve radical excision, complex reconstruction, chemotherapy and radiation. In this article we are limiting our discussion to tumors of the mobile spine as the management of sacral tumors merits an article of its own. We have also excluded information regarding clival tumors because, while many of the pathologies involving this region are the same as those of the mobile spine, the clivus is part of the skull. We will provide an overview of spinal tumors in children and will include case examples from our own series. Clinical series of pediatric spinal tumors are rare; therefore, much of the data summarized is from adult or mixed adult and pediatric series. The cases presented do not include all pathologies and are for illustrative purposes of clinical management.

Epidemiology

Compared to spinal metastasis, which has 90,000 new cases a year, primary tumors of the vertebral column are relatively rare with only an estimated 7,500 new cases per year in the United States. The overall prevalence of primary spinal tumors is 2.5–8.5 cases per 100,000 person years and they compose only 10% of all tumors of the spine. In children, the most common benign vertebral tumors are osteoid osteoma, osteoblastoma, aneurysmal bone cyst, and eosinophilic granuloma.[1,2] Overall, there is a slight male predominance for primary vertebral tumors. Osteoid osteoma, osteoblastoma, chordoma, and chondrosarcoma all occur more frequently in men than women, with a general ratio of 2:1. Aneurysmal bone cysts and giant cell tumors have a slight female predominance.[3,4] Osteosarcomas are equal between sexes.[5,6]

Generally, pediatric spine tumors are functionally divided into three classes based on their behavior. The benign tumors of the pediatric spine are eosinophilic granuloma, osteoid osteoma, aneurysmal bone cyst, and chondroma. Benign but locally invasive tumors include giant cell tumor and osteoblastoma, while malignant tumors are chordoma, chondrosarcoma, and osteosarcoma (Table 1).

Table 1. Primary Tumors of the Adult and Pediatric Spine

	Adult	Pediatric
Benign	Hemangioma Osteoblasma Osteochondroma	Osteoid osteoma osteoblastoma Aneurismal bone cyst Eosinophilic granuloma Chondroma
Malignant	Plasmacytoma Chondrosacrcoma osteosarcoma	Chordoma Chondrosarcoma Osteosarcoma Ewing Sarcoma

Presentation

The classic presentation of primary spinal tumors is pain at night and spinal pain that is not affected by activity. Fenoy, et al.[1] looked at the presentation of 56 patients with age younger than 18, who were later determined to have primary spinal neoplasms. Back or neck pain was the most common presenting symptom (78%), followed by weakness (67%), radiculopathy (34%), paresis and bladder dysfunction (13%), paresthesia (10%), and torticollis (5%). Compression fractures may also accompany lytic lesions such as hemangioma, giant cell tumor, eosinophilic granuloma, and plasmacytoma. Deformity represents another presentation of certain spinal tumors

Evaluation

The patient suspected of having a primary spine tumor should undergo a thorough local and systemic work-up to complete staging. Imaging studies include CT and magnetic resonance imaging of the tumor with and without contrast. In addition, the physician may consider contrasted CT of the chest and abdomen, magnetic resonance imaging of the rest of the spinal column, and bone scan. More recently, positron emission tomography scan may complete the systemic imaging. A differential diagnosis should be established before biopsy.

Surgical Treatment

Importance of Biopsy

Needle biopsy of spinal masses should be performed whenever possible and the diagnosis is not absolutely

certain based on imaging. Open biopsy or laminectomy and piecemeal resection may render a potentially curable tumor fatal. This is crucial even in the setting of cord compression and neurological deficit. Based on the results of needle biopsy, neoadjuvant therapy may be indicated and may ameliorate neurological compromise. Corticosteroids may also be administered to allow short term relief of neurological deficit until biopsy results are obtained. The results of the biopsy may mandate *en bloc* excision and spinal column reconstruction rather than simple decompression. The tract of biopsy should be in line with the definitive surgical incision and tract marking should be employed when possible to insure minimal contamination of neoplastic cells into surrounding tissues after resection. This is crucial since, as a general rule, violation of the tumor margin greatly worsens prognosis. Permanent marking of the biopsy site is recommended and a closed CT-guided biopsy is more oncologically sound than open biopsy. Although fine needle aspiration provides cytomorphological features that may yield a diagnosis, a trocar and core biopsy may improve accuracy by analysis of all histologic features of the tissue.[7,8]

Evolution of Spinal Surgery

Over the last 50 years, tremendous advances in the surgical treatment of primary spinal tumors have been made. Traditionally, surgeons used various management styles that have followed orthopedic and neurosurgery principles of decompression. As surgical methods improved, stabilization was added to allow more aggressive resections and reduce delayed deformity. Spinal oncology surgery has now progressed from initial laminectomy for decompression of the spine, to piecemeal resection with stabilization, and finally *en bloc* resection with reconstruction. This advance has occurred as practitioners embrace the principles of musculoskeletal oncology developed by Enneking.[9]

Intralesional vs. En bloc *Resection*

En bloc resections were previously thought to be impossible in regards to many spinal tumors. However with the advancement of operative techniques and development of sophisticated reconstructions, this is a possibility in selected tumors. To evaluate the effectiveness of intralesional versus *en bloc* resection one must first clearly define the terms (Table 2).

"*En bloc*" refers to the surgical removal of tumor in a single piece, fully encased within a layer of healthy tissue or margin.[10] Use of the *en bloc* is not helpful unless the resection is followed by a pathological analysis of the margins. Depending on careful gross and histologic inspection of the resected specimen, margins may be "intralesional," "marginal," or "wide." Intralesional means that the surgeon has cut within the tumor mass. Marginal means that the surgeon has operated along the layer of reactive tissue that surrounds the tumor (pseudocapsule). Many *en bloc* resections in the spine are marginal along the dura, unless it is resected along with the specimen. While dural resection may be possible, it is not clear that it provides an oncologic advantage. Further, dural resection is associated with increased morbidity including cerebrospinal fistula and neurological deficit. "Wide" describes a resection that occurred outside of the pseudocapsule (i.e., removal of the tumor with a continuous shell of healthy tissue). "Radical" margins are impossible in the spine because this indicates an *en bloc* resection along with the whole compartment of tumor origin. The epidural space compartment extends from the

Table 2. Enneking Principles of Resection

Type	Plane of Dissection	Result
Intralesional	Piecemeal debulking or curettage	Leaves macroscopic disease
Marginal	Shell out *en bloc* through pseudocapsule or reactive zone	May leave either "satellite" or "skip" lesions
Wide	Intracompartmental *en bloc* with cuff of normal tissue	May leave "skip" lesions
Radical	Extracompartmental *en bloc* entire compartment	No residual

Adapted from Enneking.[9]

skull to the coccyx; therefore, the compartment is not removed even if the spinal cord is sectioned above and below the tumor. This term is usually reserved for surgery of the extremities.

In general, intralesional resections involve a piecemeal removal with violation of the capsule and with margins defined by the tumor itself. This is an acceptable method for metastatic tumors and some benign tumors. The advantage of this method is that it allows spine surgeons to utilize familiar approaches and techniques. It is also technically less demanding than *en bloc* resection and carries lower morbidity. However, there is an increased risk of recurrence with violation of the capsule in many tumor types. In contrast, *en bloc* resections involve no violation of the capsule with clearly defined normal tissue as margins. This method is ideal for primary malignant or locally aggressive tumors. While risk of recurrence is reduced, surgical complexity and morbidity tend to increase.

An example of the oncologic benefit of *en bloc* resection has recently been published by the Spinal Oncology Study Group (SOSG). They reviewed 6 case series and retrospective reviews to determine the effect of incisional biopsy or intralesional resection performed before definitive *en bloc* resection in patients with chordoma or chondrosarcoma.[8] Three hundred eleven cases were included in these series[11–16] which showed a recurrence rate of 21.4–45.4% with either wide marginal or *en bloc* resection compared to 75–100% with intralesional excision.[12–14]

Weinstein-Boriani-Biagini Staging System

The Weinstein-Boriani-Biagini (WBB) classification[10] was devised to stage spinal tumors while recognizing the anatomic complexities of the spine. This simple staging system helps identify whether *en bloc* resection is possible. The WBB grade determines which tumors should not be attempted due to the increased difficulty and morbidity associated with these procedures. The WBB system divides the anatomy of the vertebra into 12 transverse "zones," which define the borders of the tumor (Fig. 1A). The axial space occupied by the tumor, extending from the intradural space to the adjacent soft tissues, is also determined.

The WBB system provides the surgeon with a guide as to the type of surgery that may be necessary. For example, if the tumor primarily involves the anterior zones of the system (i.e., zones 4–8 or 5–9), vertebrectomy is indicated (Figure 1B-D). Should the tumor involve zones 2 to 5 or 7 to 11, a sagittal resection is suggested. Finally, tumor that is isolated to zones 10 to 3 requires removal of the posterior elements.

Fisher et al.[17] performed the only prospective study to address the achievement of disease-free margins based on preoperative staging. In their study, 26 patients (age 16 to 70) were prospectively graded using the WBB system and then compared to the pathological results. The WBB staging accurately predicted the margins in 19/26 cases (73%). However, if the general goal is redefined as attainment of a wide or marginal margins, the success rate increased to 23/26 cases (88%).

Complications Associated with En bloc

A review of multiple series utilizing *en bloc* resection was performed to determine the rate of complication.[11,13–15,17,18] The mortality in these series ranged from 0–7.7%. The main complications of *en bloc* resection include spinal cord injury, nerve root injury,

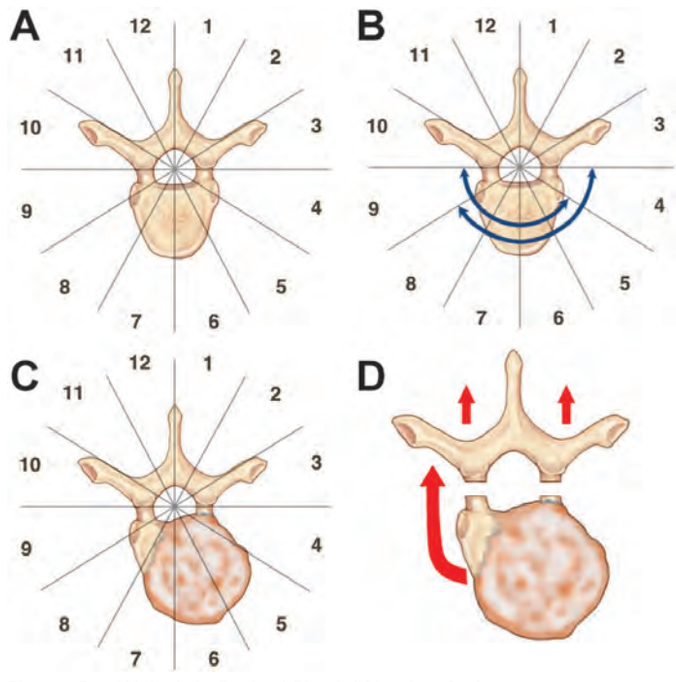

Figure 1. Weinstein-Boriani-Biagini Staging System.

CSF leak, pneumo/hemothorax, vascular injury, tumor margin violation, massive epidural venous bleeding.

Bandiera et al.,[18] in the largest study written specifically to address the issue of complications of *en bloc* resection in the spine, reported results of 134 consecutive surgeries including both pediatric and adult patients and metastatic and primary spinal disease. There were 43 major complications in 27 patients and 29 minor complications in 28 patients. Among 35 patients previously treated at another center, 48.5% had at least 1 complication. The most relevant complications were one intraoperative death caused by injury to the vena cava and 2 late dissections of the aorta wall, one of which was fatal. Among the 99 previously unoperated cases, 31% suffered complications. The authors suggested that both a higher rate of complications and recurrence was associated with treatment prior to arrival at a tertiary care center. In particular, the risk of a major complication was observed in 72% of the previously treated group versus 20% in the new presentation group.[18]

There is a wide range of incidence in morbidity reported. Fisher et al.,[17] in a series of 26 cases (age 16 to 70) reported 24 complications, including 11 cases with massive intraoperative blood loss (>5000 mL, 43%). Other complications included wound infection (14%), nonunion (7%), epidural abscess, unintended durotomy, dysphagia, decubitus ulcers, septic shock, myocardial infarction, subarachnoid pleural fistula, and neurologic deterioration. Only 1 patient died during hospitalization, due to septicemia and multiorgan system failure.

In contrast, Boriani et al.[14] case series of 52 patients mentions only 1 intraoperative complication of ureter injury, 2 patients with cardiovascular complications, and 6 delayed complications including hardware failure. However the mortality of 7.7% was high compared to other series. These differences may reflect demographic variability as well as the experience and level of aggressiveness to pursue *en bloc* resection among centers.

Treatment Recommendations by Tumor Type

Due to the rarity of neoplasms of the spinal column, there is little hope of randomized control trials for these diseases. Rather, the literature is filled, at best, with large case series and occasionally with nothing more than scattered case reports. Additionally, most of the case series, when they are present for a given tumor type, include both adult and pediatric subjects and often result in generalizations that may not hold true.

Aneurysmal Bone Cyst

Case example. This was a 16 year old male who presented with low back pain. MRI showed typical imaging consistent with an aneurysmal bone cyst (ABC), which includes multiple fluid filled cysts with fluid levels, hemosiderin, and destruction of the pedicle (Figure 2).

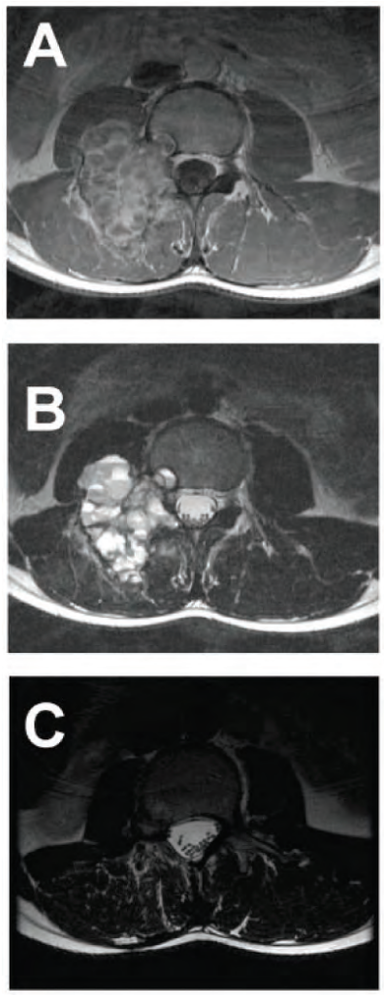

Figure 2. Aneurysmal Bone Cyst. (A) T1 weighted MRI. (B) T2 weighted MRI. (C) Post resection T2 weighted MRI showing complete resection.

These lesions are composed of thin walled, blood filled cystic cavities and comprise 1.4% of all bone tumors and 15% of all primary spine tumors.[19,20] The age of presentation is 1st through 3rd decade of life and are most common in the lumbar spine.[6] While these lesions are non-neoplastic, because of expansion, they merit consideration in surgical discussions. Rarely these lesions will become quiescent or undergo spontaneous regression but progression is the most common course. In this example the lesion was preoperatively embolized in an attempt to reduce intraoperative blood loss. We then proceeded with intralesional resection without instrumentation. No other adjuvant therapy was required. The patient remains free of disease 8 years following treatment. He is pain free without deformity.

Treatment options for ABCs include simple curettage with or without bone grafting, complete excision, embolization, radiation therapy, or a combination of these methods. Seven clinical series exist in the literature that addressed completeness of surgical excision and local disease recurrence and almost all patients were within the pediatric population.[3,20–25] Garg et al. presented a retrospective review of 12 cases of children with spinal ABC. They utilized a four-step approach of intralesional curettage, high-speed bur, electrocautery, and bone grafting which they felt had significantly reduced rate of recurrence (0/8 cases) compared with traditional intralesional curettage and bone grafting (4/4 cases).[25] *En bloc* resection has only rarely been reported in ABC and appears to be unnecessary. Rather, complete excision through an intralesional approach showed no recurrence in the 45 patients reviewed. Incomplete excision with or without radiation therapy showed a recurrence rate from 6–23%. Radiographic evidence of cure is manifested by shrinking of the lesion and reossification of the cystic areas. Recurrence of an ABC is unusual after 2 years and rare after 4 years. SOSG strongly recommend intralesional gross total resection.[26]

Radiation therapy has only rarely been used as a standalone treatment option in patients too ill for surgery or with inoperable lesions. Rather, use of adjuvant radiotherapy can be evaluated by current case series. It shows that the use of radiotherapy decreased the aggregate recurrence in incomplete resection from 19% to 4%. However radiation must be avoided in patient with spinal fractures, neurological compromise, or spinal deformity.[27] Feigenber et al. investigated the role for megavoltage radiotherapy for recurrent ABC tumors or for which surgery would result in significant functional morbidity. Nine patients received local radiotherapy doses between 20 and 60 Gy. No patient experienced a local recurrence (median follow-up, 17 years) and all patients who had significant pain before radiation therapy had relief of their symptoms within 2 weeks of completion of therapy. Complications included only one patient who required stabilization of a dorsal kyphosis.[28]

The use of preoperative embolization with medium sized particles of polyvinyl alcohol has been reported to reduce intraoperative blood loss.[29,30] Although successful treatment with embolization alone has been reported for ABCs of the pelvis and long bones, its role as the sole mode of therapy in the spine is more limited. Boriani et al. reported 4 cases treated with embolization alone with 1 recurrence.[3] The benefits of embolization must be weighed against potential swelling that may result in cord compression. In a separate series, 17 pelvic and 6 spinal ABCs (age 3–60 years) were treated with embolization alone. Thirty-nine percent required more than one embolization and 5% had complications including 2 cases of skin necrosis and 1 of transient paresis.[31]

Giant Cell Tumor

Case example. This 18-year old female presented with chest pain and shortness of breath. CT and MRI showed a T3 compression fracture with a large thoracic mass (Figure 3). The tumor invaded both the posterior and anterior chest wall and was not felt to be amenable to *en bloc* excision due to near circumferential involvement of the vertebra. The mass was biopsied and found to be a giant cell tumor (GCT). The appearance on histopathology was that of abundant osteoclastic giant cells with spindle-shaped cells and regions of fibrous tissue, rich in collagen content.[32] These tumors are derivatives of the osteoclastic giant

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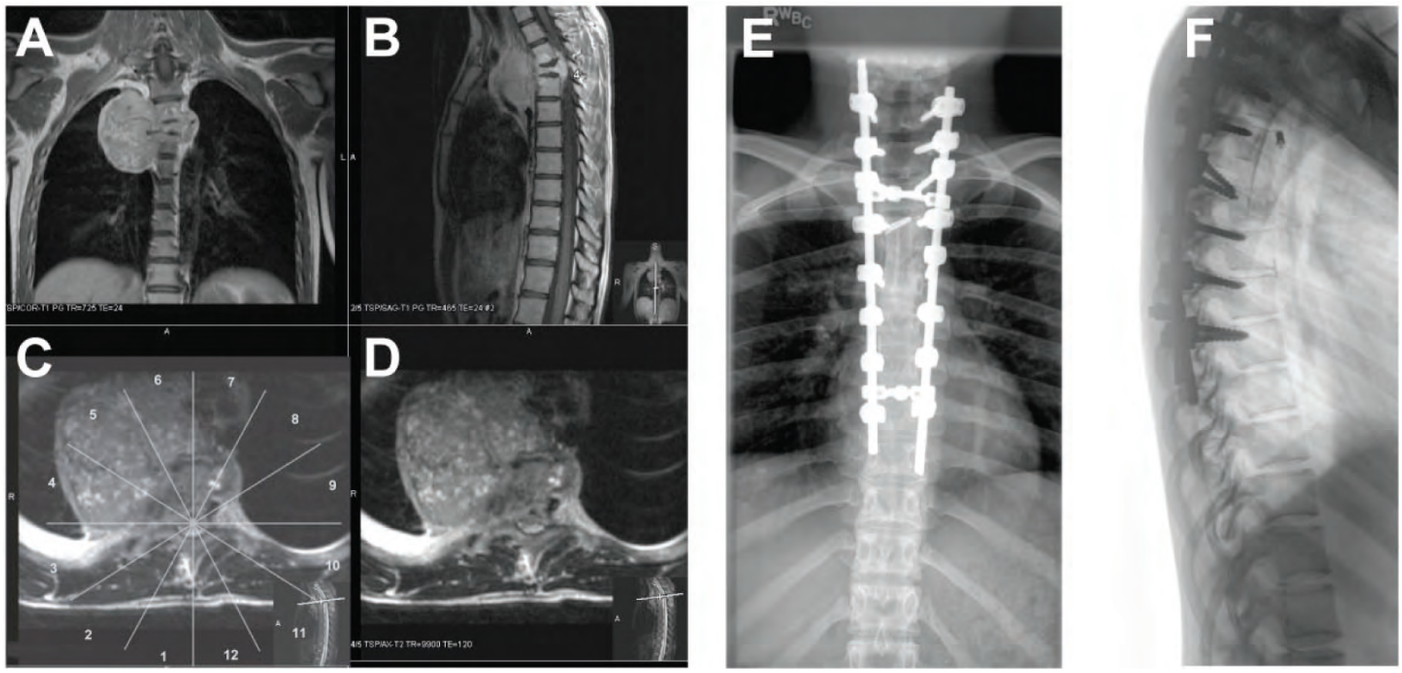

Figure 3. Giant Cell Tumor. (A) Coronal, (B) sagittal, (C) Axial T2 with the WWB coordinates overlay (D) Axial T2 weighted MRI of GCT prior to resection. (E&F) Post operative films showing stabilizing hardware with anterior rib grafts.

cells and most commonly occur in the 2nd and 3rd decades of life. GCTs tend to occur in the sacrum and thoracolumbar spine. These tumors are slow growing but are also locally invasive and have a high local recurrence rate and therefore merit treatment.[6] Additionally these tumors can have lung metastasis in up to 9% of cases.

A variable incidence of spinal involvement has been reported in GCTs, with some series demonstrating up to 10% of these tumors occurring in the spine and sacrum.[33] Spinal GCTs have a considerably poorer prognosis than those in the appendicular skeleton with recurrence rates of up to 80% after intralesional resection. These lesions are uncommon before adolescence or after 50 years of age and are found most commonly in the second to fourth decades of life. There is a slight female predominance.

In our case, preoperative tumor embolization was employed. This was followed by a staged resection. The first stage consisted of posterior resection with a C7 to T6 stabilization. The second stage was an anterior resection with T3 to T5 corpectomy and rib graft. The patient had high intraoperative blood loss and suffered from a DVT postoperatively. Postoperatively, conformal radiotherapy was used to deliver 45 Gy at 1.8 Gy per fraction using 25 fractions. The patient remains tumor free, 6 years following resection.

Surgery is the current mainstay of GCT treatment. Leggon et al. found a recurrence rate of 49% for patients who had radiation therapy alone, 47% for patients who had surgical resection with intralesional margins, 46% for patients who had intralesional margins and radiation therapy, and 0% for patients who had surgery with wide margins.[34] There is generally a high incidence of complications and functional limitations has been described after total sacrectomy and reconstruction[35] but significantly lower morbidity is found in resection of lumbar and thoracic GCT.[36]

Martin et al. reported 23 cases of GCT in the spine and sacrum. Ten lesions occurred in the sacrum with an average age of 31 years (range of 13–49) and 13 occurred in the mobile spine with an average age of 39 years of age (range of 13–64). Treatment with preoperative arterial embolization and intralesional surgical resection lead to recurrence in 2/6 while *en bloc* resection had none (0/2). *En bloc* surgical resection in

the spine resulted in recurrence in 2/11 cases and intralesional resection resulted in recurrence in 2/2. The authors concluded that giant cell tumors of the spine and sacrum should be managed with *en bloc* resections.[37]

Junming et al. reported 22 cases of GCTs of the cervical spine which underwent surgical treatment (age 17–66; mean = 35). The choice of surgical intervention was based on the Weinstein-Boriani-Biagini grading system. Eight patients underwent subtotal resection, 13 cases received total spondylectomy, and one received "*en bloc*" resection. Postoperative radiation therapy was given in 18 cases, as an adjunctive therapy method. The symptom of radicular pain almost disappeared and patients suffering from spinal cord compression recovered well. Local recurrence was detected in 5 of 7 cases (71.4%) that underwent subtotal resection, but in only 1 of the 13 cases (7.7%) for total spondylectomy. A strictly "*en bloc*" resection is often not a feasible option in the cervical spine (unlike in the thoracic and lumbar spine) because of the involvement of critical neurovascular structures. However, total spondylectomy with radiation therapy can be used to treat the cervical spine.[38]

Ozaki et al. reported 6 patients with GCT of the spine in the sacrum (3), thoracic spine (2), and lumbar spine (1). Two patients were treated with cement implanted after curettage of a sacral lesion with one patient having local relapse. Three patients had marginal excision with no relapse. One patient had a subtotal resection and received postoperative irradiation without relapse. These authors argue that planning an *en bloc* seems beneficial for vertebral lesions above the sacrum, while total sacrectomy of a sacral lesion seems to be too invasive when cement implantation can control the lesion. An *en bloc* surgical resection is considered to be the optimal treatment of thoracic and lumbar tumors and reduces the rate of local recurrence. Several adjuvant treatments to the wall of the cavity of the tumor are advocated including cryotherapy, phenolization, or application of methyl methacrylate cement.[39]

Radiotherapy to supplement surgery has been used in the treatment of local recurrences and following incomplete excision. However, it is not always successful and there is the long-term risk of a radiation-induced sarcoma. Chakravarti et al. reported 85% of the tumors treated with megavoltage radiation treatment had not progressed. Additionally, no cases of malignant transformation occurred in a median of 9.3 years follow-up.[40] Despite these data, radiation does comes with the risk of malignant transformation. Radiation-induced sarcoma occurred in at least 11% of patients in the combined pelvic and sacral group who received radiation therapy for a primary or recurrent lesion with a follow-up of 5 years or more.[34]

Caudell et al. investigated the utility of radiotherapy on GCT, with or without surgical resection. Twenty-one cases of axial skeleton GCT were presented (age range 11 to 69 years, median 32 years). Thirteen had primary and 12 had locally recurrent disease. The actuarial 5-year overall and disease-free survival rate was 91% and 58%, respectively. In the case of primary disease radiation therapy was inferior to surgical resection. However the radiation therapy should be considered an adjuvant to surgery or as alternative therapy, in cases of GCTs that are unresectable or in which excision would result in substantial functional deficits.[41]

A recent study evaluated the use of therapeutic embolization as a primary therapy in 9 patients with sacral GCTs. This intervention was successful in 7 patients without adjuvant radiation or surgical therapy at a mean 8-year follow-up.[42] However, 2 patients required radiation therapy; one had a successful outcome while the other developed pulmonary metastases and eventually succumbed to the disease. Lin et al. further reported a series of 18 patients who underwent therapeutic embolization. Their Kaplan-Meier analysis of this series demonstrated a 31% risk of recurrence at 10 years after treatment.[43]

Chordoma

Case example. This 18 year old female presented with difficulty breathing. Imaging revealed a large spinal and paraspinal mass with tracheal compression (Figure 4). CT guided biopsy was performed which demonstrated chordoma. As was seen in this biopsy, histopathology shows physaliphorous (bubble-bearing) cells and immunoreactivity for S-100 and EMA. Chordomas have a proclivity for the sacrum and coccyx (50%), followed

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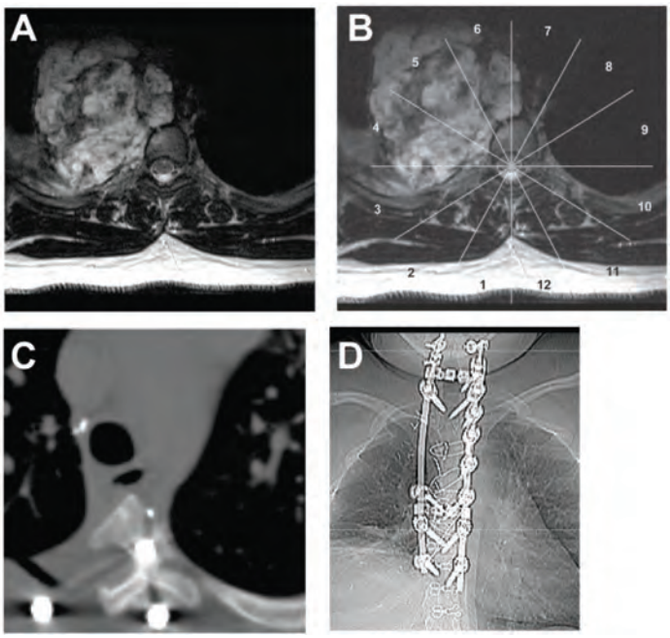

Figure 4. Chordoma. (A) Preoperative axial T2 weighted MRI. (B) The overlay of the WWB classification. (C) Post resection CT showing parasagittal osteotomy and rib resection on the left side. (D) Postoperative radiograph.

by the skull base (35%) and the mobile spine (15%).[2] They are remnants of the notochord and are most common in the 4th through 6th decade of life. While slow growing they tend to be locally aggressive.[6]

In our case, WBB staging indicated that the mass was amenable to *en bloc* resection. A tracheal stent was placed preoperatively. A multistage approach was used to ensure that the mass was dissectible from mediastinal structures without violation of margins. A trap door thoracotomy and tumor dissection from mediastinal structures was initially performed. At a second stage, a right lateral extracavitary approach was employed with complete laminectomy of T3 to T5 followed by parasagittal osteotomies through the vertebral bodies. Involved ribs were resected as part of the *en bloc* specimen. C5 to T7 posterior fixation and allograft arthrodesis was then performed. At a third stage, anterior tumor resection was completed and discectomies and interbody grafting was performed. Complications encountered included 1500 cc blood loss intraoperatively. Clear margins were obtained. She did not receive additional therapy and has remained free of disease for 4 years.

Unfortunately there are no case series of spinal chrodoma exclusively in pediatric population. Bergh et al. analyzed 30 sacral and 9 mobile spine chordomas (median age 55 years). The final surgical margins were wide in 23 patients and marginal or intralesional in 16, with a mean follow-up of 8.1 years. Seventeen patients (44%) developed local recurrences and 11 patients (28%) developed metastases. The estimated 5-year survival rates were 84%. Larger tumor size, performance of an invasive morphologic diagnostic procedure outside of the tumor center, inadequate surgical margins, microscopic tumor necrosis, Ki-67 > 5%, and local recurrence were found to be adverse prognostic factors.[11]

Boriani et al. analyzed a consecutive series of 52 chordomas of the mobile spine, observed over a 50-year period and including both adults and pediatric patients. When *en bloc* resection was not feasible, intralesional extracapsular excision was combined with radiation therapy. All patients having radiation alone, intralesional excision alone, or a combination of both had recurrences in less than 2 years. Intralesional extracapsular excision with radiation had a high rate of recurrence (12 of 16 at average 30 months). Twelve of 18 patients having *en bloc* resection are disease free at an average of 8 years. The authors concluded that the only treatment protocol associated with disease free status at follow-up longer than 5 years is margin-free *en bloc* resection.[14]

Cervical resection holds some limitation to *en bloc* resection of sacral tumors. Choi et al. reported two cases (aged 7 and 10) of cervical chordoma, subtotally removed in an attempt to improve the success of adjuvant proton beam radiotherapy. At one year, both children were alive with evidence of decreased tumor mass in the resection cavity. Although *en bloc* resection is the ideal modality for treatment of chordoma, such a procedure is often associated with a significant risk of surgical morbidity due to the tumor location. Therefore, piecemeal resection followed by postoperative adjuvant radiotherapy, including proton radiotherapy or radiosurgery, should be considered in such cases.[44]

Similarly, sacral resections of chordomas have an increased level of morbidity that must be taken into account preoperatively. Samson et al. reported the resection of 21 sacrococcygeal chordomas (median age

55 years; range 6–78) through a posterior approach exclusively. In this series, 4 patients died and 15 were free of disease at follow-up (mean 4.5 years). Of the 7 patients in whom both second sacral roots were the most caudal nerve-roots spared, 4 had normal bladder control and 5 had normal bowel control. Of the 4 patients in whom the most caudad nerve-roots spared were the first sacral or more cephalic roots, all had impaired bladder control, 1 had impaired bowel control, and 3 had a colostomy.[45]

Potluri et al. investigated the role of high-dose radiotherapy after surgical debulking for chordomas and chondrosarcomas of the spine in 19 patients including both adults and children. The 5-year cause-specific survival for radically treated patients with chordomas was 92% and the 5-year local control rate was 83%. A gross total volume threshold of 30 cm^3 distinguished local failures from the 15 patients with local control. The authors concluded that although surgical debulking is essential, a small residual tumor volume may still be controlled with high-dose photon radiotherapy.[46] Noel et al. reported 100 consecutive patients with chordoma of the base of skull or upper cervical spine treated by fractionated irradiation combining proton and photon beams (median age of 53 years and range 8–85 years). With a median follow-up of 31 months, 25 tumors relapsed locally. For chordomas of the base of the skull and upper cervical spine treated by surgery and irradiation, these authors confirmed that the role of surgical resection remains paramount.[47] In general, recurrence and survival rates of patients with skull base chordomas treated with radiotherapy are similar to spinal chordomas (Table 3).

Chondrosarcoma

Chondrosarcomas of the spine constitute only 4% to 10% of all chondrosarcomas.[50] These tumors originate from chondrocytes and are found most commonly in the thoracic spine.[12] They present during the 3rd through 5th decade of life and tend to be locally destructive. Their survival is greatly dependent upon WHO classification (Table 4). On imaging they are lytic with a classic "ring and arc" calcification and tend to enhance. They are generally chemo and radiation insensitive and have a very poor survival.[6]

In the oldest case series, Shiver et al. reported 20 patients (age 18–70) diagnosed as having chondrosarcoma of the spine and treated surgically. All patients had a surgical biopsy of the lesion, often combined with decompressive laminectomy. Five patients received postoperative radiation therapy in various dosages. No patient received adjunctive chemotherapy. All but five patients died of local progression of the disease. The five-year survival rate was 55 percent with a median survival of six years.[51]

Later series showed much improved survival. Boriani et al.[12] retrospectively reviewed 32 cases of chondrosarcoma within the mobile spine (mean age 37, range 13–78). The patients underwent a total of 33 procedures, including management of recurrences. The average follow-up period was 81 months (range 2–236 months). Recurrences occurred in 3 of 14 patients treated by *en bloc* resection, compared with 100% of 18 patients treated with intralesional curettage.

Two other studies looked at *en bloc* resection of chondrosarcomas as well as other diagnoses, most commonly chordomas.[15,16] Hsieh et al.[15] retrospectively reviewed 20 consecutive patients who underwent *en bloc* sacral resections for chordoma and chondrosarcoma (both adult and pediatric). *En bloc* resection was achieved in 70% of cases. With respect to continuously disease-free survival, patients who underwent an *en bloc* resection experienced 51 months of disease-free survival at the end of the study, compared to only 17.5 months for patients who had contaminated tumor margins.

Table 3. Recurrence and survival rates of chordomas of the skull base treated with radiotherapy

Series	Recurrence	Survival (5-yr)
Hug et al.	24%	79%
Ares et al.	19%	62%
Noel et al.	31%	80.5%

Table 4. The effect of grade on chondrosarcoma survival

Grade	10 Year Survival (%)
I	90
II	65–80
III–IV	30–40

Similarly, Saravanja et al.[16] recently presented an analysis of a multicenter cohort of patients who underwent intralesional or *en bloc* resection of 150 primary spine tumors, of which 35 (23%) were chondrosarcoma (both adult and pediatric). *En bloc* resection with acceptable margins was carried out in 17 chondrosarcomas. Open biopsy significantly increased the likelihood of intralesional margins. A decrease in local recurrence was observed in patients who received wide or marginal *en bloc* resection. In patients with local recurrence, there was increased risk of mortality.

There are no case series that analyzed pediatric chondrosarcomas of the spine individually. Extrapolation from the above case series and isolated case reports[52–57] indicate that surgical management is the optimal treatment with adjuvant radiation treatment or radiation at the time of recurrence.

Mesenchymal Chondrosarcoma

Case example. A 13-year old girl presented with back pain and bilateral lower extremity pain as well as gait difficulty. She was paraparetic with a thoracic sensory level on exam. MRI demonstrated a left vertebral and paravertebral mass measuring 9 × 9 cm with spinal cord compression from T7 to T10 (Fig. 5). She also had multiple small pulmonary metastases. CT guided needle biopsy provided diagnosis of mesenchymal chondrosarcoma. While conventional chondrosarcoma (CCS) make up 85% of all chondrosarcomas in general, the remaining are composed of dedifferentiated, mesenchymal, and clear cell chondrosarcoma.[58] Mesenchymal Chondrosarcoma (MCS) differs from conventional chondrosarcoma in its young age of onset (20's vs. >50 years old), its poor prognosis, and a high proportion of extraskeletal tumors.[50] The prognosis of mesenchymal chondrosarcoma is usually poor with a tendency for late local recurrence and distant metastasis, most commonly pulmonary.[59–61] Ten-year survival rates for patients with mesenchymal chondrosarcoma are reported between 28% and 58%.[60,62,63] Spinal mesenchymal chondrosarcomas typically presents in late teens with a 3:1 female predominance and can be found in any part of the spine but mostly occurs in the lower thoracic, lumbar and sacral spine.

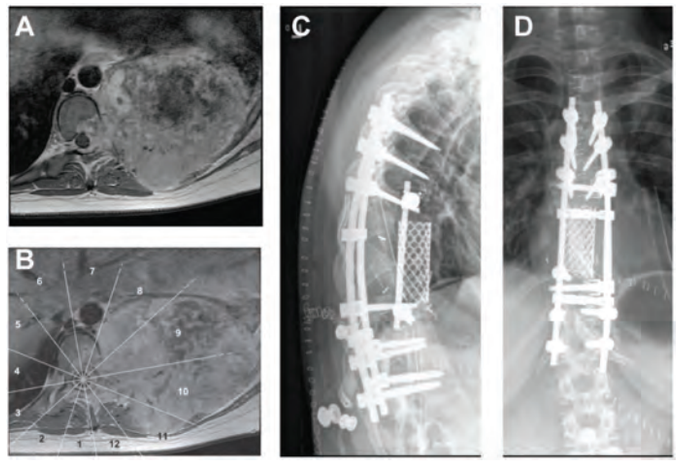

Figure 5. Mesenchymal chondrosarcoma. (A) Axial T1 weighted MRI before neo-adjuvant chemotherapy. (B) Same image with WWB classification overlay. (C&D) Postoperative radiographs.

We treated our patient with neoadjuvant chemotherapy. This resulted in resolution of her neurological compromise and slight regression of her epidural disease. There was little if any change in the component outside the spinal canal (Figure 5). While the tumor was already metastatic and the WBB stage indicated that *en bloc* resection was not possible (Figure 5B), an aggressive approach was agreed upon with the family. The goal was to minimize local recurrence, preserve neurological function and to attempt control of her

Table 5. Effects of Intralesion and Wide resection on Chordoma and Chondrosarcomas

Tumor	Resection	Recurrence (%)	Survival (%)
Chordoma	Intralesional	78	58
	Wide	26	86
Chondrosarcoma	Intralesional	49	59
	Wide	7	88

Based on pooled data of 153 chordomas and 94 chondrosarcomas treated at 6 centers.

Table 6. Gross recurrence and Survival Rates for Chordomas and Chondrosarcomas

Tumor	Recurrence	Survival
Chordoma	47	50
Chondrosarcoma	100	100

Hug et al. MGH proton beam experience, tumors not involving sacrum or skull base.

additional disease with resection of lung lesions, chemotherapy and radiation therapy. A two-stage resection was performed. First, a left lateral extracavitary approach was used for release of the posterior component. T7-10 laminectomies and rib resections were performed with T5-12 fixation and arthrodesis. Next, a left thoracotomy, anterior T8-9 vertebrectomies, and tumor resection were performed with chest wall reconstruction (Figure 5C–D). Ipsilateral pulmonary lesions were resected at the same time. Intraoperatively, substantial epidural bleeding was encountered. This is a common problem when circumferential spinal resection is performed. Postoperatively the patient underwent multiple chemotherapy regimens with little success. She was eventually discovered to have metastasis to her hips, spine, lungs, liver, and adrenals. Palliative radiation therapy was administered to her hip metastasis. She remained ambulatory for greater than 13 months following surgery. She was eventually rendered paraplegic from new epidural disease at T2. She was died 14 months postoperatively.

The largest case series of 111 cases of mesenchymal chondrosarcomas from all locations was performed by Nakashima et al.[60] Only 8 studies on the topic include more than 10 patients with sufficient clinical data and follow-up.[59–62,64–67] The consensus of these series indicates that surgical resection with wide margins is the accepted gold standard of treatment and curettage alone or incomplete excision leads to a high rate of local recurrence.

Although chondrogenic tumors are assumed relatively radioinsensitive due to lower cellular turnover, mesenchymal chondrosarcoma is an exception with a higher fraction of dividing cells which can benefit from radiotherapy.[65] Harwood et al. reported response of mesenchymal chondrosarcoma to irradiation and recommended a combination of chemotherapy and radiotherapy with inadequate safe margins.[65] Additionally, Ranjan et al. suggested that postoperative local radiotherapy may reduce local recurrence rates.[68] Radiotherapy utilized in spinal mesenchymal chondrosarcoma ranged from 25–60 Gy in the reported literature. Radiotherapy was explicitly used in 19 of 24 reported cases of spinal mesenchymal chondrosarcoma.[69–74]

Several authors have suggested that chemotherapy, with or without radiotherapy, may aid in local control although no direct evidence of this has ever been established.[67,71,74–78] The chemotherapeutic agents used to date include Ifosfamide, Doxorubicin, Cisplatin, VP-16, Carboplatinum, Epirubicin, Cyclophosphamide, Adriamycin, Methotrexate, and Actinomycin D.

Ewing's Sarcoma

Case Example. An 18 year old boy with presented with back and arm pain. CT guided biopsy was performed which showed Ewing's sarcoma (Figure 6). First described in 1921 by James Ewing, Ewing's sarcoma (ES) is a malignant, poorly differentiated, small round cell tumor that arises in the bone and soft tissues. Overall, it is the fourth most common malignancy of bone and the second most common primary malignant bone tumor in children.[79] Classically, ES is very responsive to both chemotherapy and radiation with surgical resection reserved for the extremities. In our case, treatment with chemotherapy and radiation therapy was pursued. Six years post treatment the patient has no evidence of disease (Figure 6). Chemotherapy has increased the 5-year survival from 5–10% 20 years ago to 65–70% today.[80,81] However, there exists a high rate of systemic relapse. Factors that herald a poor response are metastasis at diagnosis, large tumor size, and axial tumors.

In 1996, Ozaki et al. reviewed the outcomes of 244 patients with ES from all location who were registered in the Cooperative Ewing's Sarcoma Studies and who underwent surgical treatment.[82] Analysis revealed that relapse rate after surgery with or without irradiation

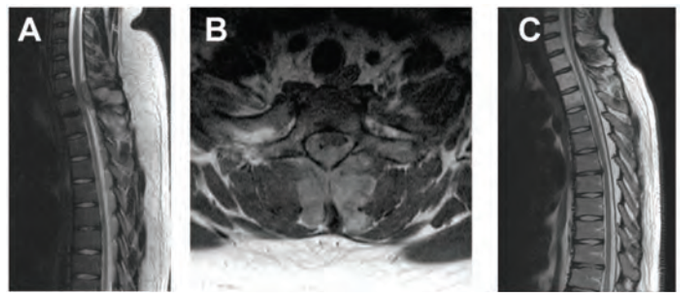

Figure 6. Ewing's sarcoma. (A) Pre-resection T2-weighted MRI. (B) Pre-resection T1 weighted MRI. (C) follow up MRI showing no disease after treatment with chemotherapy alone.

was significantly lower compared with that after irradiation alone (7% vs. 31%). In addition, relapse rate after complete resection (radical or wide margin) with or without irradiation was less, compared to incomplete resection (marginal or intralesional margin) with or without irradiation (5% vs. 12%). Interestingly, however, the 10-year overall survival for each of the margins showed no difference. Similarly, in 2001, Sluga et al. reported 142 patients treated for ES of any location with a median follow-up of 8.5 years. The 5-year overall survival after radical or wide resection was 60.2%, in comparison to 40.1% after marginal or intralesional resection.[83] Bacci et al., in 2006, reviewed the outcomes of 512 patients with Ewing's sarcoma family tumors of any location.[84] The outcomes of surgery alone or surgery followed by radiotherapy were compared to radiotherapy alone. They found that local control (88.8% vs. 80.2%) and 5-year disease-free survival (63.8% vs. 47.6%) were significantly better in surgically treated patients if adequate margins were obtained. However, these results were observed only in extremity tumors and not in core or spinal tumors.

Several series have looked at ES of the spine in isolation. Indelicato et al. reported 27 patients with spinal or paraspinal ES. In this series, 21 patients (median age 17 years) were treated with radiotherapy alone and 6 with surgery plus radiotherapy. The 5-year actuarial overall survival, cause-specific survival, and local control rate was 62%, 62%, and 90%, respectively. The local control rate was 84% for patients treated with radiotherapy alone vs. 100% for those treated with surgery plus radiotherapy. Of patients with Frankel C or greater neurologic deficits, 78% experienced a full recovery.[85]

Venkateswaran et al. reviewed 33 vertebral ES of the 344 identified in their institution over 30 years. The median age at diagnosis was 13.3 years of age. The primary sites were sacral (13), thoracic (10), lumbar (8), and cervical (2) vertebrae. All patients received combination chemotherapy and local radiotherapy without surgery. With a median follow-up of 9.7 years, 5-year survival and event-free survival estimates were 48.1% and 35.6%, respectively. Outcomes are similar for primary ES of the spine and primary ES in other sites suggesting generalizability of the whole body literature to the spine.[86]

Finally, Paulino et al. conducted a retrospective review of patients with localized ES (76 total, 11 spine) comparing survival of patients treated with radiotherapy, surgery, or a combination of surgery, radiotherapy and chemotherapy.[87] Multivariate analysis showed that only chemotherapy was a prognostic factor for local control. Accordingly, the SOSG strongly recommends that neoadjuvant chemotherapy offer significant improvements in local control and long-term survival for spinal ES. However, SOSG only weakly recommends that *en bloc* resection might provide local control but will not improve overall survival. Therefore surgery should be considered in all cases where complete resection of the tumor is possible. However, local therapy should not take precedence over, nor interfere with, systemic chemotherapy.

While no large case series exist that have looked at ES of pediatric spine, indications from individual case reports are similar.[88–93]

Osteoid Osteoma and Osteoblastoma

Osteoid osteomas and osteoblastomas are most common in the 1st and 2nd decades of life. They are commonly found in posterior elements of the lumbar and cervical spine. Several authors have suggested scoliosis as a common presentation of occult osteoid osteomas.[94,95] On imaging, they typically have a sclerotic rim and demonstrate slow growth.[6] Osteoid osteoma and osteoblastoma, although histologically similar, are treated very differently. Osteoid osteoma can be treated with NSAIDs and, if pain persists, percutaneous ablation techniques and incomplete resections. There is only one reported case suggesting progression of a radiographically diagnosed osteoid osteoma that later showed progression and proved to be a osteoblastoma.[96] However, several cases of incomplete resection of osteoblastoma have resulted in malignant degeneration into osteosarcoma.[97–104]

Osteoblastomas have a reported incidence between 10% and 25% of primary osseous spine tumors.[105] These lesions share a similar demographic profile with osteoid osteomas with a male predominance. Osteo-

blastomas are distributed equally through the cervical, thoracic and lumbar spine.[32,106,107] Osteoblastomas typically involve the posterior elements of the spine, but due to their larger size may extend into the anterior vertebral body and canal. Of the radiology techniques, computed tomography (CT scan) is the preferred imaging modality, since it can identify the lesion, degree of sclerosis, and extent of bony involvement.[106] MRI has a limited role in primary osseous tumors because it poorly visualizes the bone marrow and the lesion is thus obscured. In addition, visualization of the margin between the osseous and soft tissues is less defined resulting in inaccurate diagnosis of aggressive or malignant lesions.[108,109]

A recent article by Harrop systematically reviewed the treatment paradigms for osteoblastoma.[27] A cumulative review of the isolated spinal osteoblastomas showed recurrence rates of intralesional or biopsy were 93% (14/15), 15% (2/13) for marginal resection, and 20% (1/5) for *en bloc* resection. However, these recurrence rates are skewed, in that, the *en bloc* recurrence was in the field of a previous resection. Therefore, an *en bloc* resection of osteoblastoma should be performed when not restricted due to anatomic constraints since this method has the lowest risk of recurrence.[110] Kaner et al. reported 6 patients, with a mean age of 21 years (range 16–31) diagnosed with osteoid osteoma or osteoblastoma of the cervical spine. The most common symptom was local neck pain in the region of the tumor. Only one patient showed a neurological deficit. All patients were treated with surgical resection. Two patients underwent tumor resection, one patient underwent tumor resection and fusion, and 3 patients underwent tumor resection, fusion and spinal instrumentation. There was no tumor recurrence during the follow-up period.[111]

The SOSG final recommendations were a strong recommendation, based on very weak literature for intralesional resection for nonaggressive osteoblastoma (Enneking 2) and *en bloc* resection for Enneking 3 when anatomically feasible. Unfortunately, due to anatomical constraints such as neurological structures and dura matter, spinal osteoblastomas have the highest recurrence rates of all locations.[112]

Only a minority of cases suggest any effectiveness of radiation following resection. Janin et al. reported that 2 of 7 osteoblastoma patients received radiation therapy after complete resection without a recurrence. Therefore, the absence of recurrence may be the direct effect of the resection. Marsh et al., in his review of 197 osteoblastoma cases, stated that radiotherapy does not alter the course of the disease and appears to be contraindicated.[110] Tonai et al. followed a series of incomplete excised osteoblastoma treated with re-excision and noted no recurrence at 2 years. They proposed this as the optimal treatment strategy rather than radiation therapy.[113] Chemotherapy, similarly, has only been used after surgical resection. Berberoglu[114] reported the use of cisplatin and doxorubin after failure of radiation. Camitta[115] used the same agents with the addition of methotrexate with excellent response. The lack of evidence merited only a weak recommendation for radiation in the setting of recurrent lesions or incomplete resections and a limited role for chemotherapy in recurrent lesions by the SOSGS.

Burn et al., reported thirty pediatric cases of osteoid osteoma (32%) and osteoblastoma (68%) in which 22 were treated surgically and 8 were managed nonsurgically. The patients' mean age at presentation was 13 years (range 3–17 years). 97% of patients presented with pain; 23% had scoliosis at presentation. Outcomes were generally good with 40% experienced relief with nonsteroidal antiinflammatory medication. Pain freedom without medication had been achieved in 73% of those undergoing surgery but only 38% of the 8 nonsurgically treated patients.[116]

The relatively benign nature of these lesions, their typical posterior position, and their distinctive radiographic imaging allowing for certainty of diagnosis has opened the door for new technologies in their treatment (most notably, videoendoscope,[117] CT guided thermocoagulation,[118] and radiofrequency ablation). Use of radiofrequency ablation in 24 patient had a success rate of 79%, suggesting that this could be an alternative to patients without neurological deficits.[119–122] Hoffman et al. presented similar results in a series of 39 patients with a 98% success rate.[120]

Osteosarcoma

Osteosarcoma (OS) is the most common type of malignant bone cancer, accounting for 35% of primary bone malignancies. It arises from osteocytes in a bimodal distribution of the 4th decade and post 6th decade of life. Paget's disease is a major risk factor. On imaging, these lesions are lytic and enhancing. They are generally considered to be chemo and radiation sensitive.[6]

There is only one high quality study in regards to the surgical treatment of osteogenic sarcoma. Link et al. performed a randomized controlled study of 36 patients who underwent definitive surgical resection of limb osteosarcomas and then were randomly assigned to adjuvant chemotherapy or to observation without adjuvant treatment.[123,124] In this study, the authors found that, at 2 years following treatment, the actuarial relapse-free survival was 17% in the control group and 66% in the adjuvant chemotherapy group ($p < 0.001$).

Sundearesan reported 24 patients with osteogenic sarcoma of the spine treated over a 35-year period (age 13 to 71 years old). Prior to 1977, patients typically underwent limited tumor resection and external radiation therapy. In this report, 11 patients underwent more aggressive surgical resection and received combination chemotherapy as well as local radiation to the tumor bed. There were 5 long-term survivors and only 1 patient developed metastatic disease while on therapy. Complete surgical resection of the tumor by spondylectomy and combination chemotherapy offer the best prospect for cure of osteogenic sarcoma of the spine.[125]

Two more studies that addressed spinal OS bear mentioning. In 2002, Ozaki et al. reviewed 22 patients with OS of the spine (15 with tumors of the sacrum and 7 with tumors at other sites) who received chemotherapy, according to the Cooperative Osteosarcoma Study Group protocol.[126] There was a significant improvement in the overall survival of patients who underwent either wide or marginal surgery compared to intralesional surgery or no surgery ($p < 0.033$). DeLaney et al. retrospectively reviewed 41 adult and pediatric patients with OS of the spine who underwent gross total resection or subtotal resection with positive margins and then underwent RT with external beam photons and/or protons.[127] The 5-year local control rate according to the extent of resection was 78.4% for gross total resection, 77.8% for subtotal resection, and 40% for biopsy only ($p < 0.01$). The overall-survival rate according to the extent of resection was 74.45% for gross total resection, 74.1% for subtotal resection, and 25% for biopsy only ($p < 0.001$). Additionally, local control rate was 71% for patients receiving doses high dose radiation vs 53.6% patients receiving <55 Gy.

Accordingly the SOSG strongly recommends neoadjuvant chemotherapy to improve local control and long-term survival for spinal OS and *en bloc* resection for improved local control and potentially improved overall survival for spinal OS. Current standard treatment is to use neoadjuvant chemotherapy followed by surgical resection. Standard therapy is a combination of limb-salvage surgery when possible (or amputation in some cases) and a combination of high dose methotrexate with leucovorin rescue, intra-arterial cisplatin, adriamycin, ifosfamide with mesna, BCD, etoposide, muramyl tripeptide.[128]

Again, given its rarity, only individual case reports directly address OS in the pediatric spine but treatment modalities follow that used in the older population.[129–131]

Conclusions

Spinal oncology is a rapidly developing field. Recent advancements in surgical techniques, chemotherapy and radiation appear to be improving outcomes. For aggressive and malignant tumors, the literature clearly demonstrates the benefit adherence to the Enneking principles of *en bloc* resection. CT-guided needle biopsy and careful pretreatment planning by an experienced team is critical. Unfortunately, given the rarity of these tumors, most data is retrospective and based on small sample size and heterogeneous pathology Therefore, at best, most treatment strategies are based on expert opinion only. Future directions include a better understanding of the benefits of less invasive strategies including proton beam radiotherapy and stereotactic radiosurgery (SRS).

Table 7. Summary of Spinal Oncology Groups Recommendations

Pathology	Recommendation	Recommendation Strength	Literature Quality
Aneurysmal bone cyst[27]	Intralesional gross total resection because local recurrence is influenced by the completeness of resection.	Strong	Very low quality
	We suggest selective arterial embolization as a standalone modality, but it requires close serial observation.	Weak	Very low quality
	We recommend the use of selective arterial embolization as it facilitates resection by reducing intraoperative blood loss.	Strong	Very low quality
	We suggest embolization as the preferred treatment strategy, with limited use for other methods.	Weak	Very low quality
Osteoblastoma[27]	We suggest radiation in recurrent lesions or incompletely resected aggressive osteoblastomas (Enneking 3) as a treatment option.	Weak	Very low quality
	There is a limited role for chemotherapy in recurrent aggressive osteoblastomas (Enneking 3).	Weak	Very low quality
Giant Cell[27]	Thoracic and lumbar spine; When feasible based on staging, *en bloc* resection is recommended for both primary (Enneking 3) and recurrent GCTs of the thoracic and lumbar spine.	Strong	Very low quality
	Sacrum; When feasible based on staging and predicted surgical morbidity (not sacrificing sacral neural function), *en bloc* resection of sacral GCTs is recommended.	Weak	Very low quality
	For managing incompletely resected GCT, serial clinical and radiographic observation is recommended for residual GCT.	Weak	Very low quality
	We suggest radiation therapy as a treatment option for recurrent GCT.	Weak	Very low quality
Osteosarcoma[128]	Neoadjuvant (before surgery) chemotherapy offers significant improvements in local control and long-term survival for spinal OS and is essential in multimodality management.	Strong	Moderate
	En bloc resection provides improved local control and potentially improved overall survival for spinal OS.	Strong	Very low

Table 7. Summary of Spinal Oncology Groups Recommendations (*Continued*)

Pathology	Recommendation	Recommendation Strength	Literature Quality
Ewing Sarcoma[127]	Neoadjuvant (before surgery) chemotherapy offers significant improvements in local control and long-term survival for spinal ES and is essential in multimodality management.	Strong	Moderate
	En bloc surgical resection provides improved local control, but not improved overall survival for spinal ES. Radiation therapy may also be used for local control either alone or to supplement incomplete resection.	Weak	Very low evidence
Chordoma and Chondrosacroma[128]	CT-guided trocar biopsy is preferable to open biopsy to minimize risk of tumor contamination When there is a suspicion of primary spine tumor, the surgeon who performs the definitive surgery should ideally perform or direct the biopsy so the biopsy tract can be included within the subsequent resection margins.	Strong	Low quality
	En bloc resection of primary spine tumors with disease-free margins is achievable if staging determines that it is feasible. The adverse event profile is high (even at experienced centers). Therefore, these surgeries should be performed by experienced, multidisciplinary teams.	Strong	Low quality

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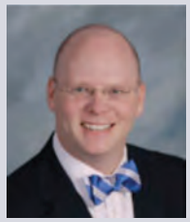

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Dr. Titsworth graduated Summa Cum Laude from Samford University with a degree in Psychology and Biology where he was awarded the Janice Teal award for outstanding graduate. He then spent two years as a missionary in Lesotho Africa where he worked as an AIDS/HIV educator and developed youth programs in the Baptist Church. Dr. Titsworth then entered the combined M.D./Ph.D. program at University of Louisville receiving the Hays Threlkeld Memorial Scholarship. His graduate work focused on blocking phospholipase activity after spinal cord injury. His work was subsequently awarded an NIH pre-doctoral fellowship. He also was an invited speaker at the National MD/PhD conference and the Kentucky Spinal Cord and Head Injury Research Trust Symposium. He was a junior inductee into AOA and graduated Cum Laude in 2010. He is scheduled to complete his residency program at University of Florida in 2017. Dr. Titsworth plans to pursue a career in academic pediatric neurosurgery fostering his love of teaching and desire to work with pediatric neuropathology. His research interests center on the use of Quality Improvement efforts among Neuro ICU patients.

David W. Pincus, M.D., Ph.D.

Dr. Pincus is the Chief of Pediatric Neurosurgery. He was born in New Haven, CT in 1963. He grew up in Massachusetts where he attended high school at Deerfield Academy. After graduating from Yale College with a B.S. degree in biology, Dr. Pincus obtained M.D. and Ph.D. degrees from Cornell University. His Ph.D. thesis work focused on the development of precursor cells (stem cells) in the nervous system. He then pursued a neurosurgical residency at the Neurological Institute of New York at Columbia-Presbyterian Medical Center. During his residency training he continued his work with neuronal precursor cells, now with human brain samples, and received the Congress of Neurological Surgeons' Resident Award in 1996. After completing his chief residency at Columbia, Dr. Pincus served as a pediatric neurosurgical fellow at Children's National Medical Center in Washington, DC. He then accepted a position as an attending at Children's where he remained for one year prior to being asked to join the Department of Neurological Surgery at the University of Florida. As the primary pediatric neurosurgeon at the University of Florida, Dr. Pincus takes care of all neurosurgical problems in children. Dr. Pincus is board certified by both the American Board of Neurological Surgeons and the American Board of Pediatric Neurosurgeons and is a member of the American Society of Pediatric Neurosurgeons. He cares for patients from birth through 21 years of age.

Stereotactic Body Radiotherapy (SBRT) for Spinal Metastases: What is it and why should we do it?

Arjun Sahgal, M.D. and Michael G. Fehlings, M.D., Ph.D., F.A.C.S.

Introduction

Spine stereotactic body radiotherapy (SBRT) is an emerging treatment for patients with spinal metastases. The aim of spine SBRT is to deliver high doses of radiation that would be considered locally "curative", in a single or up to 5 treatments (fractions) focused only on the involved vertebrae.[1] Although conventional palliative radiotherapy also delivers dose in a few fractions, it does so using lower dose per fraction radiation as the technique does not permit sparing of the normal tissues in the beam's path, which is required to escalate the tumor dose. Figure 1 highlights the fundamental difference between SBRT and conventional spine palliative radiotherapy. Therefore, the intent of spine SBRT is to escalate the dose to the tumor safely by sparing the surrounding normal tissues in order to achieve long-term local disease and pain control. These goals are becoming increasingly important in the patient with metastatic disease, as many of these individuals are living longer than previously expected due to the availability of more effective systemic agents.

Typically, clinicians have been focused on short term pain relief and local control in patients with bone metastases, which explains why traditional conventional low-dose and low-tech radiation have been the norm. This is reflected by most of the randomized studies evaluating radiation response for bone metastases being focused on the 3-month pain control rate.[2] It is only recently, with reported long-term local control outcomes based on imaging follow-up following conventional radiation, that we confirm sub-optimal control rates in selected spine metastases patients at one and two years.[3] Although there has yet to be reported a randomized controlled trial comparing spine SBRT to conventional radiation, the literature shows promise and high rates of efficacy.[1]

Spine SBRT is still considered an emerging practice as it is only with recent advances in radiation technology that this treatment option has become possible.[1] It requires sophisticated radiation delivery units equipped with beam shaping devices, immobilization systems to keep the patient in a reproducible position during treatments that can range from 30 to 90 minutes, and image-guidance to ensure visualization of the target prior to (and during) actual treatment delivery.[1,4,5] We have reported the University of Toronto approach with details for practice.[4] Furthermore, we have evaluated the precision of our technology to be within 1.2 mm and 1 degree with 95% confidence.[6] Spine SBRT is one of the most technically demanding practices in radiation oncology and requires a multidisciplinary effort with both spinal surgeons and dedicated spine SBRT radiation oncologists caring for the patients.[1]

Patient Selection

The indications for treatment span three main groups of patients[1] (i) *re-irradiation* SBRT, (ii) *de novo* SBRT, and (iii) *post-operative* SBRT. The outcomes for spine SBRT have been predominantly reported in cohorts consisting of mixtures of the above three indications.[1] Based on a mixed cohort, we have observed 809 tumors treated with 88% local control given a median follow-up ranging from 6–21 months.[1] Evidence based indications of inclusion and exclusion criteria have also been recently reported by an international consensus effort led by the American Association of Therapeutic Radiation Oncology for the interested reader.[7]

Re-Irradiation SBRT

Spine SBRT is most often practiced in patients to salvage conventional radiation failures (*re-irradiation* SBRT), as few efficacious treatment options are available for these patients.[1] A second course of conventional radiation is possible, although, limited to an even lower dose than the first course in order to respect the cumulative radiation tolerance of the spinal cord. The consequence of overdosing the spinal cord is radiation myelopathy, which can leave a patient with increased neurological morbidity, an undesirable risk in the palliative patient where the aim is to preserve quality of life. As spine SBRT allows shaping of the radiation to the diseased vertebral segment while sparing the spinal cord (Figure 1), we are still able to deliver high therapeutic doses to the tumor.[8] A recent analysis of the published literature specific to this indication reports 94% local control in 65 tumors treated given a median follow-up ranging from 6–15 months.[1]

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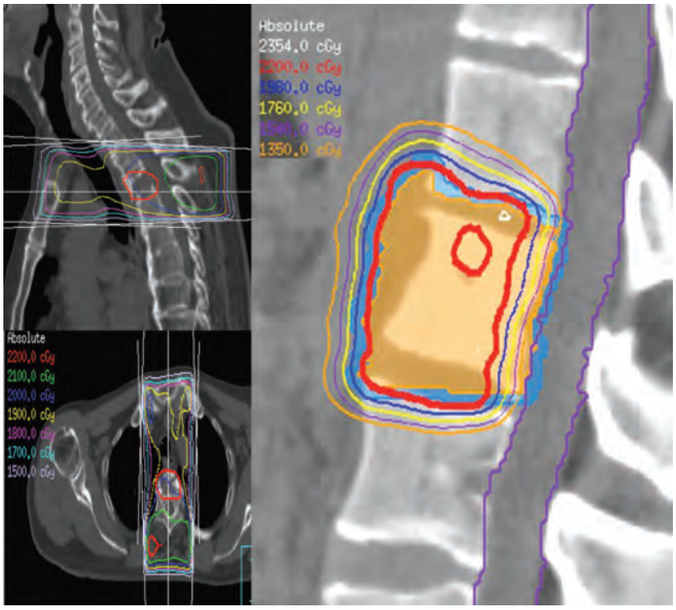


Figure 1. The left top and bottom images represent sagittal and axial representations of a T2 lung metastases treated with conventional radiation. A two beam approach is used (anterior and posterior beams), and with limited beams and traditional technology we include a healthy vertebrae above and below the target in order to physically deposit the required dose into the tumor. All the normal tissues in the beam's path are exposed to the prescribed dose and in this case the patient was treated with 20 Gy in 5 fractions. On the right is a sagittal view of an L2 hepatocellular metastases treated with SBRT, where we deposit very high doses of radiation (24 Gy in a single fraction) only to the affected vertebrae and spare the surrounding tissues to a low tolerable dose. We typically use nine beams and intensity modulated radiotherapy to generate the highly complex dose distribution.

De Novo Spine SBRT

The practice of spine SBRT in *de novo* patients (those where the spinal metastases to be treated have not been exposed to radiation) evolved into current practice with the intent to ablate tumor in those patients expected to have a prolonged survival. As a result, patient selection has been typically oriented to those with oligometastatic disease (fewer than 5 sites of metastatic tumor), disease confined only to the spine, good performance status, and patients eligible for further systemic therapies.[7] Other patients where the approach is justified are those with radioresistant histologies such as sarcoma (Figure 2), renal cell carcinoma, and hepatocellular cancer, and patients with bulky paraspinal disease. In these patients, we do not expect durable local control with low dose conventional radiation.

Currently, there is a randomized study led by the Radiation Therapy Oncology group (RTOG 0631) evaluating 16 Gy in a single fraction delivered with SBRT to 8 Gy in a single fraction delivered with conventional radiotherapy. This study is currently in the recruitment stage and will take time before we can hopefully confirm superiority of SBRT practice. In the *de novo* cohort, current data indicates excellent local control at 90% in 197 tumors treated given a median follow-up ranging from 6–15 months.[1]

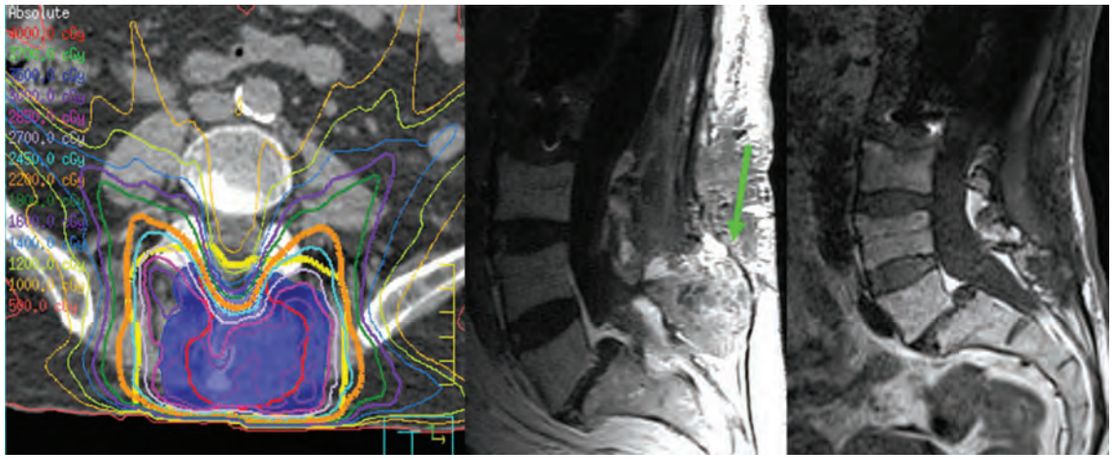


Figure 2. This patient with telangiectatic osteosarcoma has an L5 spinous process metastases that extended into the posterior soft tissues. We treated him with 30 Gy in 3 fractions with spine SBRT, and now 2 years later we confirm a durable complete response in a tumor that is considered to be radioresistant. On the left is an axial CT image illustrating the radiation dose distribution, and the planning target volume is in blue color wash. The middle image is the pre-SBRT sagittal T1 MRI with gadolinium that shows the tumor bulk (green arrow), and the right-most image indicates the 2 year follow-up sagittal T1 MRI with no residual tumor.

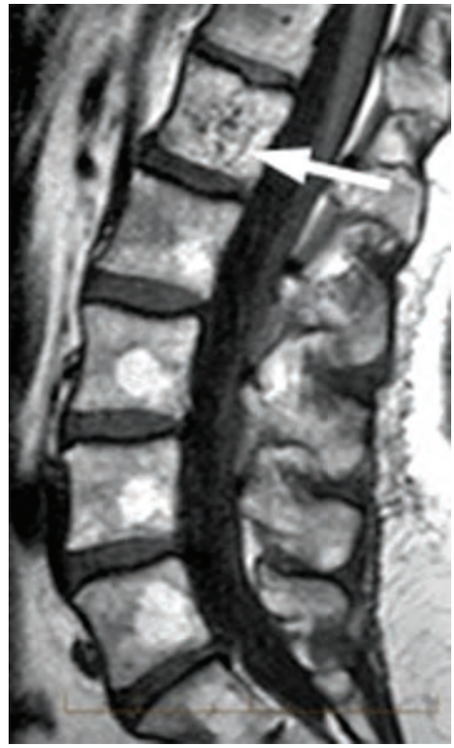
Post-operative SBRT

Surgery is the primary treatment for patients with single level symptomatic cord compression, and has been shown in a randomized trial to provide superior outcomes to conventional radiation alone.[9] In addition, surgery is indicated for patients with mechanical instability, as radiation does not palliate this type of pain. Following surgery, patients still need radiation for tumor control as surgery on its own is not locally curative. Typical practice has been conventional radiation, and spine SBRT has naturally evolved as an alternative to treat post-operative patients. In particular, for patients previously radiated, post-op spine SBRT allows for higher doses than otherwise would be delivered conventionally. Overall there is limited evidence in this cohort, however, outcomes are promising with 89% of 65 tumors treated achieving local control given a median follow-up ranging from 7–16 months.[1]

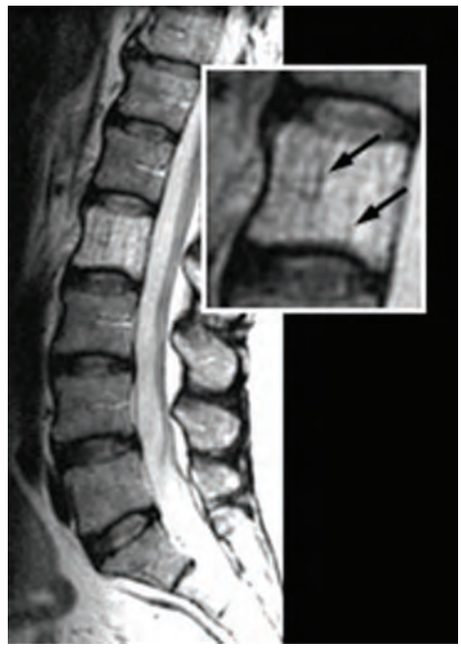
Current Issues to Consider for Safe Practice

What Target Volume to Treat?

As the practice of spine SBRT is still evolving, there are major areas that require consensus in an effort to standardize the approach for safe, consistent practice. One of the major areas is target delineation. Currently, the approach varies from treating the gross disease as visualized by CT and T1 MRI imaging with no applied margin, outlining the gross disease plus an arbitrary margin of 3–5 mm beyond the targeted tumor, or expanding the target volume to include the gross disease plus an anatomic margin to encompass the relevant anatomy at risk of microscopic disease extension.[1,5] The latter approach was described by Ryu et al., and represents the philosophy we practice at the University of Toronto. Essentially, if the vertebral body is involved, then we treat the entire body; if disease has extended into the ipsilateral pedicle and/or lamina, then the spinous process is taken into the target volume; and if bilateral pedicle and/or lamina are involved, then the entire vertebral segment is treated. Alternatively, if the disease involves the posterior elements alone, then we may exclude the vertebral body. An example of such a metastatic tumor treated with SBRT is shown in Figure 2.



The T1-weighted sagittal image demonstrates an atypical hemangioma within the L1 vertebral body (arrow) with coarse trabeculae, but with relatively little typical fat signal within the lesion.



The T2-weighted sagittal image shows a lesion of increased signal intensity replacing the entire L2 vertebral body. Coarse vertically oriented trabeculae are present (arrows).

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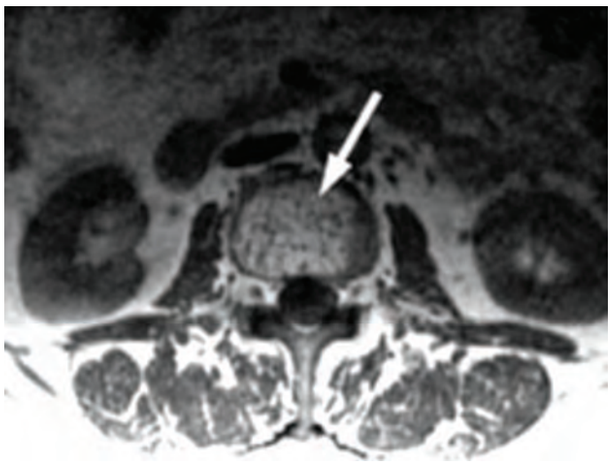
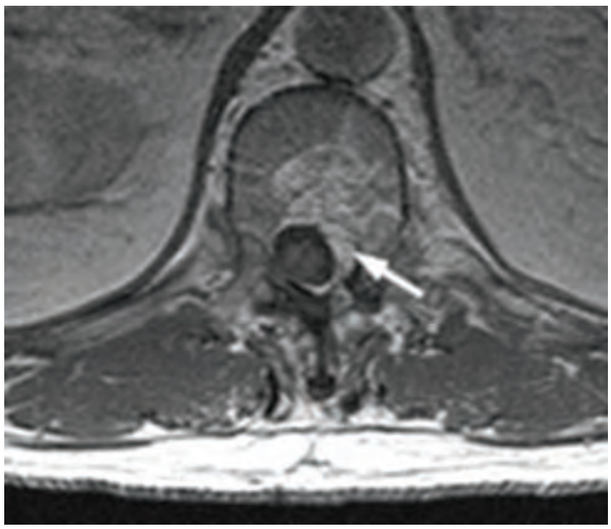


The T1-weighted axial image demonstrates the coarse trabeculae on end surrounded by fat signal, resulting in a "salt and pepper" appearance (arrow).



A contrast-enhanced T1-weighted axial plane image through the hemangioma confirms the epidural extension, and demonstrates the enhancing stroma within the left side of the spinal canal (arrow), displacing the thoracic cord.

One of the most important issues in spine SBRT practice requiring consensus is the appropriate target volume when the epidural space has been breached. The margin required within the epidural space to treat potential microscopic disease is unknown. Some follow the idea of treating only disease within the epidural space, while others provide margin to include the entire circumferential space. At the University of Toronto, we tend to take the entire circumferential epidural space, as epidural failure is the most common site of failure post-SBRT.[1,10] Furthermore, the consequence of epidural tumor progression is cord compression, and can result in the patient requiring major invasive surgery. This pattern of failure is due to either (i) relative under-dosing to respect cord tolerance, (ii) disease biology that is simply aggressive and resistant to treatment, or (iii) lack of targeting due to the conforming of the radiation to what we think is the target volume. It is the latter that we do not take chance with at the University of Toronto, and we feel it is safest to take the entire epidural space into the treatment volume. As we learn more from pattern of failure analysis post-spine SBRT, we will have further insight into appropriate target volume delineation.

What Dose to Give?

There are no standards as to the optimal dose to prescribe and number of fractions for spine SBRT. Initially, several centers adopted single fraction treatment as their standard of care[11,12] as this was largely based on the brain radiosurgery experience. Stereotactic radiosurgery for brain metastases is a one-day treatment which is necessary due to the need for an invasive head frame to not only immobilize the head, but to provide the stereotactic coordinates for tumor localization.[13] This is not required for spine (or brain anymore) SBRT as we have the ability to immobilize patients in a non-invasive near-rigid body device, and with image guidance we can visualize the target prior to treatment for day-to-day reproducibility and accuracy.[4] Therefore, several centers developed their practice on a fractionation premise, where it was felt that dividing the total dose into a few daily treatments would still maintain efficacy, but be safer on the normal tissues.[8,14] Therefore, current practice ranges from single treatments ranging from 16 to 24 Gy, to total doses ranging from 24–35 Gy in 2–5 fractions.[1] Although it is challenging to compare outcomes without a randomized study, the efficacy in all the reported series have been roughly equivalent despite the variation in prescription practice.[1] Although some data support higher single fraction doses,[15] others report no dose response within the SBRT treatment range[8,16–18] and ultimately we will need a single versus fractionated spine SBRT randomized study to determine optimal treatment.

What Are the Safety Considerations?

The two major late complications secondary to spine SBRT that must be discussed with the patient in order to ensure informed consent are vertebral compression fractures (VCF) and radiation myelopathy. A recent series from the Memorial Sloan Kettering Cancer Centre reported new or fracture progression in 39% of treated tumors.[19] This is high as compared to other series, and may reflect their high dose practice of 24 Gy in a single fraction. The consequence of VCF can be significant for patients, as they may require salvage procedures such as kyphoplasty, vertebroplasty, minimally invasive percutaneous instrumentation, or even major open invasive surgery to provide structural support with hardware. With new spine stability scoring systems,[20,21] we may be able to select patients at highest risk for VCF and prophylactically stabilize, however, at this point it is an area of active research and development.

Radiation myelopathy is the other major toxicity that patients must be made aware of, as the risk of radiation myelopathy is zero with conventional radiation. This is a delayed side effect that typically occurs years post-radiation, however, we have recently observed this toxicity as early as five months post-spine SBRT.[22,23] Radiation myelopathy is devastating to the patient as it can leave the patient paraplegic. The resurgence of this toxicity as a consequence of spine SBRT practice reflects the need to better understand the normal tissue tolerance of the spinal cord given the high dose per fraction radiation delivered, and the need for rigorous quality assurance in treatment delivery to ensure safe practice. Recent guidelines based on a dosimetric comparison of cases of radiation myelopathy to controls have resulted in suggested dose limits for safe practice.[22,23]

Future Directions

The ability to safely deliver locally curative doses within the spine has opened up an area of research to potentially minimize the morbidity of major spine surgery. As spine SBRT is limited with respect to dose within the epidural space to respect spinal cord tolerance, the role of surgery may shift to decompression, epidural tumor resection, and stabilization. Therefore, the bulk of the tumor mass can be left to be treated with SBRT, and the morbidity associated with radical resections is lowered.[24] Moreover, there is potential to minimize the post-operative stay and duration of rehabilitation required post-op by limiting the surgical extent. One approach developed at the University of Toronto combines minimally invasive surgery through a tubular retraction system with spine SBRT.[25] The uniqueness of this surgery is that it is an outpatient day procedure, so patients are admitted in the morning and discharged home that same day. We recently reported our preliminary outcomes on our first ten patients.[25] Our rates of local control are within those expected based on the published literature, and we observed improvements in pain, disability, and quality of life outcomes.

Conclusion

Spine SBRT is an emerging practice and preliminary data indicates local control that exceeds that expected from conventional radiotherapy. We still require prospective studies with standardized outcome measures to make accurate conclusions, and ultimately, randomized studies to prove superiority. The ability to deliver ablative doses in the spine also challenges traditional viewpoints on the role of surgery for spinal metastases, and will reshape not only how we select patients for surgery, but what surgery should be performed. It is an exciting time for research and development in the treatment of spinal metastases, and spine SBRT will undoubtedly be a standard therapeutic option for patients in the years to come.

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Arjun Sahgal, M.D., F.R.C.P.C.

Dr. Sahgal is a leader in the field of high precision stereotactic radiation to the brain and spine. His main focus is on developing spine stereotactic body radiotherapy (SBRT) as an effective therapy for patients with spinal tumors. Research achievements include publishing spinal cord tolerance guidelines for spine SBRT as part of an international multi-institutional effort. This work allowed for safe dose limits for the spinal cord specific to spine SBRT and the first of their kind. Currently, he has developed the spine SBRT program for the University of Toronto and initiating the first Phase 2 clinical study on spine SBRT for metastases in Canada.

Michael G. Fehlings, M.D., Ph.D., F.R.C.S.C., F.A.C.S.

Dr. Fehlings is the Medical Director of the Krembil Neuroscience Center and heads the Spinal Program at the Toronto Western Hospital. Dr. Fehlings is a Professor of Neurosurgery at the University of Toronto, holds the Krembil Chair in Neural Repair and Regeneration, a Scientist at the McEwen Centre for Regenerative Medicine and a McLaughlin Scholar in Molecular Medicine. Dr. Fehlings leads a multi-disciplinary team of researchers which is examining the application of stem cells, nanotechnology and tissue engineering for spinal cord repair and regeneration. Dr. Fehlings is a principal investigator in the Christopher and Dana Reeve Foundation North American Clinical Trials Network, is co-chair of the internationally renowned Spine Trauma Study Group and leads several international clinical research efforts through AOSpine.

Clinical Trials Improving Lives—One Day at a Time

Research Notes

Karen Busse, M.S.

At any one time, there are over 112,000 clinical trials, with locations in over 175 countries.[1] Of these trials, approximately four percent are spine-related. The number of ongoing studies, which varies daily, is significant. More impressive is the impact that spinal research has on the lives of those individuals participating in clinical trials.

Mike Rudicel did not realize that a childhood injury would come back to haunt him in his adult years. When Mike was 17 years old, he had a water skiing accident resulting in a partially herniated cervical disc. He recovered rather quickly from this injury, and in three to four months was back to normal activities. It wasn't until Mike was in his 30s that he started having pain in his neck. While golfing one day, he experienced sharp neck pain. Over the next twelve years, his pain increased and negatively affected his daily life. After years of medical management, which included physical therapy, chiropractic care, and medications, he could no longer get relief from his pain. During his physician visits, he was diagnosed with degenerative disc disease as a result of his accident and it was recommended that he have a spinal fusion. A lover of sports, especially golf and water skiing, Mike was not ready for this option which could limit his neck mobility. He decided to wait in the hope that there would be new technology on the horizon.

Figure 1. Bryan Cervical Disc System incorporates technology developed by Gary K. Michelson, M.D. Image provided by Medtronic Sofamor Danek USA, Inc.

Soon, Mike was experiencing debilitating pain that not only affected his normal daily activities, but also resulted in loss of mobility and numbness in his fingers. "I was running out of options; all of the medical management treatments were now ineffective. I knew something had to be done." At this point, Mike turned to the Internet. In his professional career he was a technology expert. An internet search helped Mike discover what he needed . A few search phrases that he remembers using were 'spinal procedures', 'spine breakthroughs', and 'spine surgery'. During his search, he found information about clinical trials being conducted in Europe on a new procedure, the Bryan® Cervical Disc. Soon after that, a friend sent him a newspaper article about the first cervical disc surgery that was performed in North America in May 2002. To Mike's surprise and relief, this procedure was performed just minutes from his home in Indianapolis by spine surgeon Rick Sasso, M.D., a principal investigator in this clinical trial. After an appointment with Dr. Sasso, surgery was recommended. Mike met the guidelines for the clinical trial, and it was now a matter of waiting to see if he would be selected. Meanwhile, Mike discussed the research protocol with his primary care physician and one of the physicians at his place of employment. He was randomized into the trial and had surgery in November 2002. Once Mike woke up from the anesthesia, he immediately knew the surgery was a success. He was able to feel his fingers and had no pain. The day following surgery, he walked out of the hospital. He started walking on the treadmill the next day and

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began working out as soon as he was medically released, just two weeks later.

"I didn't realize how much pain affects your daily life. I couldn't lift my kids when they were little, and I couldn't even carry luggage when we traveled," Mike says. Mike reports that nine years since participating in the clinical trial, he is pain-free and has no limitations. "The coolest part is I can now play 18-holes of golf, walk the course, and carry my golf clubs," Mike adds.

Participating in the same Bryan® Cervical Disc clinical trial as Mike Rudicel, Nazli Kahn had a similar experience. It has been nine years since her surgery and Nazli also reports that she is pain-free, and there is nothing that she cannot do. Nazli still vividly remembers the pain she suffered prior to the surgery. Suffering from severe neck pain for over five years, she found little relief. None of the doctors she visited could find anything wrong with her, and only prescribed medications. Eventually, these became ineffective and she could barely function at home or work. One evening, a friend, who happened to be a physician, was visiting. He was aware of the research and expertise of Dr. Sasso and recommended that she see him. After one appointment and diagnostic x-rays, it was concluded Nazli was developing arthritis in her neck. Surgery was recommended. It was also determined that Nazli met the research criteria for the Bryan® Cervical Disc protocol.

Never having had surgery before, Nazli was somewhat hesitant to participate in the study and sought advice from her brother who was a physician. Her brother reassured her that clinical trials are not done on patients until they are determined safe. He also pointed out that with this study, she had access to the latest technology available and she should take advantage of this opportunity. In November 2002, Nazli underwent surgery. Two days later, she was up and about and soon returned to work. Nazli states that this procedure gave her a new lease on life, and that she is back to normal.

Today, Angela Allsup is planning her wedding. In 2004, she was planning how to manage her classes while suffering from debilitating back pain. Angela suffered from degenerative disc disease as a result of a high school basketball injury. While a college student, this debilitating pain severely limited her physical activities, and even attending class was painful. When the school year concluded, Angela knew she needed to do something and could not continue to function with her pain. She visited Rick Sasso, M.D., and was informed surgery was her best option. At this time, Dr. Sasso was participating in a clinical trial for a lumbar disc replacement (Figure 2) for which Angela met the patient criteria. When asked about her thoughts on participating in a clinical trial, Angela indicated that she was a little scared, but was desperate to try anything that would work and was open to this option. Since the surgery, Angela has finished pharmacy school and is now a clinical pharmacist at a hospital. She reports that she is doing great. "I am leading a normal life and have no pain!"

Figure 2. Nazli Kahn after her surgery.

Spinal research has not only improved the lives of the individuals highlighted in this article, but continues to daily improve the lives of those affected by spinal disorders and abnormalities. It has been concluded that medical research is considered vital to the health and wealth of societies.[2] Rick Sasso, M.D., a spine surgeon with Indiana Spine Group, has been doing spinal research for approximately 20 years and has participated in over 30 trials. The goal of spinal research is for the patient to have a high quality life and to return to their normal activities as soon as possible. As a result of research, patients benefit from shorter hospital stays, less invasive surgical techniques, shorter recovery periods, less blood loss during surgery, and a greater likelihood of maintaining normal spinal movement and mobility. Additionally, with newer surgical devices and techniques, patients have more options for surgical procedures.

The physicians that participate in research are committed to the goal of improving the quality of life of their patients. A single research project can take over ten years to complete. For example, the Bryan® Cervical Disc was conceptualized in 1993. Pre-clinical testing did not begin until 1998, and the first device was implanted in Belgium in January 2000[3] and in North America in May 2002 by Dr. Sasso. As a part of the clinical trials, ongoing patient monitoring at scheduled intervals is required. This is followed by Food and Drug Administration (FDA) preliminary hearings, more research and outcome studies, and then finally the FDA decision. Dr. Rick Sasso and Mike Rudicle testified at the FDA hearings for the Bryan® Cervical Disc in 2007. In 2009, sixteen years after this device was conceived, the Bryan® Cervical Disc received final FDA approval.

Individuals can find out about clinical trials at the web site sponsored by the National Institutes of Health (www.clinicaltrials.gov). This web site provides a database of federally and privately supported clinical trials that are conducted worldwide. Additionally, for each study, this site provides the purpose of the study, participant criteria, and contact information.[1] Physicians involved in spinal research continue to develop newer technologies, improved devices and surgical techniques. These research efforts will continue to revolutionize spinal surgery. This is a win-win situation for both physicians and patients. Physicians will have many more viable spinal treatment options for their patients and patients will continue to see their quality of life improve.

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Karen Busse, M.S.

Karen Busse is a marketing consultant with Indiana Spine Group. She received her master of science in Health Care Administration and has over 25 years of health care marketing experience. Working extensively in physician and hospital marketing, Karen has worked with Indiana Spine Group for close to ten years.

Unilateral Cervical Facet Fracture: A Case Report and Review of the Literature

Paul J. Slosar, M.D.
Luis G. Marrero, M.D.

Introduction

Facet fractures are common cervical spine injuries. Unilateral fractures are usually associated with less offset or anterolisthesis, compared to bilateral fractures, and can often be treated successfully in a rigid cervical orthosis. This is a case of a patient with a unilateral cervical facet fracture who presented approximately one year after the injury with persistent pain and neurological symptoms. She was treated with anterior cervical decompression and fusion with an excellent clinical result. A review of the pertinent literature regarding cervical facet fractures will be presented.

Case Report

A 48 year old female was involved in an accident in July 2009. The patient was standing in her boat when a 250 lb. intoxicated man jumped off an adjacent houseboat, landing on her neck. The patient had acute forward flexion of her neck with immediate pain and left arm numbness. She was taken to the emergency room the same day. The patient was diagnosed as having a left-sided C6 lamina fracture with extension into her left inferior C6 facet with 25% of anterolisthesis of C6 on C7. The patient was in the hospital for approximately five days and placed in a Miami J collar. She wore the collar for 5 months until December 2009. Before our evaluation, she had received physical therapy and epidural injections, which provided her with temporary relief of her neck and arm pain.

The patient presented to our institution almost a year later with complaints of disabling neck pain and arm numbness. On examination, she had reduced sensation in the C7 dermatomal distribution and an absent triceps (C7) reflex. Motor function was abnormal with 4/5 the left triceps muscle (C7), with decreased sensation to light touch in the left C7 dermatome distribution.

Surgery

The patient failed several non-surgical managements and continued experiencing progressive worsening of the symptoms one year after injury. We therefore recommended surgical stabilization. An anterior cervical discectomy, decompression of the neural canal, and interbody fusion was performed with a dual acid etched titanium cage (Titan Spine) packed with Vitoss (Stryker/ OrthoVita). An anterior plate (Alphatec) was used for stable fixation of the spine.

Results

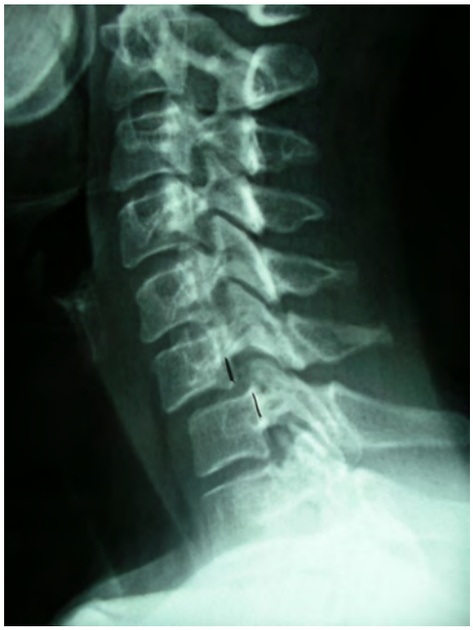
The patient was in the hospital for twenty-three hour observation and went home with immediate relief of her neurological symptoms in the arm. The neck pain resolved approximately four weeks after the surgery with evidence of solid fusion by three months. The patient was able to return to work after four weeks and now she is fully functional in athletics and her social life. She stopped using all pain medication within four weeks of surgery.

Discussion

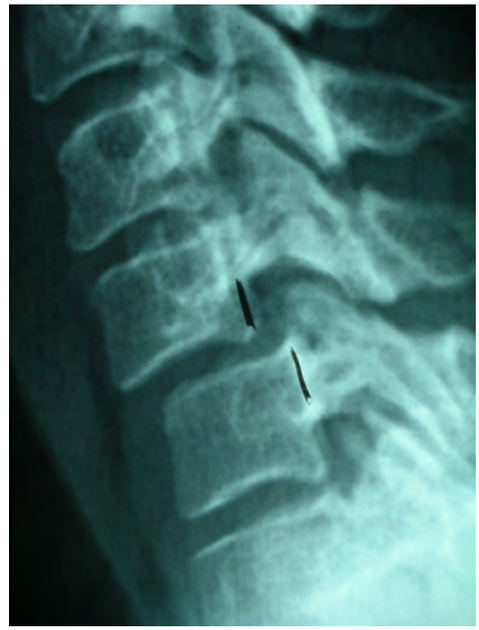
Cervical spine unilateral facet joint injuries are not common and represent around 6% of all cervical spine injuries.[1,2] The spectrum of injuries could go from undisplaced fractures or subluxation (associated or not with fractures) to complete dislocations.[3] Undisplaced cervical facet fracture is one of the most common injuries among this spectrum as reported in the series of Dvorak et al.[4] These injuries have been attributed to a flexion-rotation injury.[5–7] Nonetheless, Crawford et al.[8] identified, in a recent study, the importance of hyper-rotation over the hyperflexion to produce the facet dislocation.

Sometimes, it can be difficult to diagnose unilateral facet joint injuries with plain x-rays. A series of twenty-four patients by Halliday et al.[9] reported that pathological images could only be identified in six of the twenty-four patients with plain radiographs, even in the swimmer position. The study also found that a

CASE REPORT



Lateral X-Ray Cervical spine showing C6-7 anterolisthesis.



Lateral X-Ray: C6-7 20% offset.

CT-scan is helpful in diagnosing the fracture, but not in predicting the instability. The dislocations might not be identified even in the reconstruction studies carried out by CT-scan.

MRI has become more sensitive in identifying ligamentous injuries (such as anterior longitudinal ligament injuries) and identifying annulus tears.[10–13] Vaccaro et al.[14] and other authors have discussed the use of MRI in the acute trauma period in their series. They reported that early use of MRI in trauma is sensitive for diagnosing the ligamentous injury and predicting instability. The relationship of the pathological segment with the spinal column can also be evaluated utilizing flexion-extension dynamic MRI as described in the literature.[9,10,14]

The objectives of treatment of unilateral facet fracture and fracture-dislocations, as described by Beyer et al.,[15] are primarily preservation of the functional and anatomical continuity of the spinal cord and nerve roots, restoration of spinal canal alignment to relieve neural compression, establishment of spinal stability to provide freedom from post-injury pain or delayed neurological problems, and finally, quick restoration of the highest functional level consistent with the patient's neurologic complication. However, the treatment for these injuries remains controversial, especially when the patient requires surgical stabilization.

Surgical options, including anterior and posterior approaches, have been proposed and tested with different results.[10,16–21] An open reduction is considered when closed reduction proves to be insufficient and when early decompression is required due to neurological deterioration.

On the other hand, the non-operative treatment of unilateral facet fractures without subluxation is immobilization with a halo-vest or hard-collar. Several series of cervical facet fractures with subluxation immobilized in a halo vest have documented a high failure rate of healing. One problem with halo immobilization is the movement of the cervical spine. A snake-like movement of the middle and lower cervical vertebrae occurs even with a properly placed halo-vest.[9–11,22] In his series of twenty-six patients, Rorabeck et al.[23] documented that the spontaneous fusion rate of the unilateral facet fractures following non-operative treatment was only 20% and they stated that chronic cervical pain might occur because of late dislocations. Also, Lifeso et al.[10]

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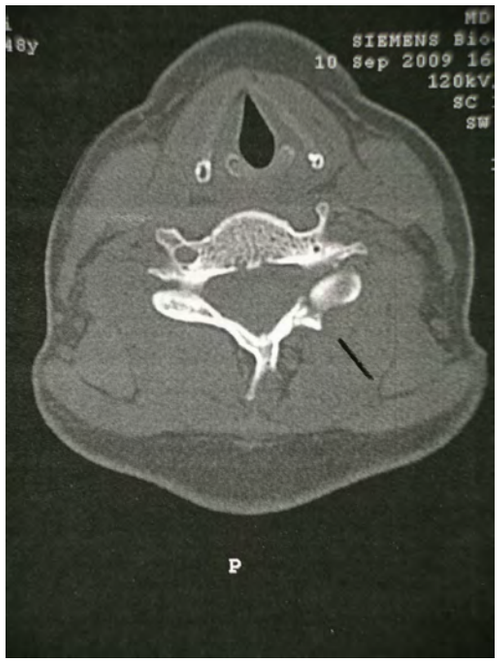
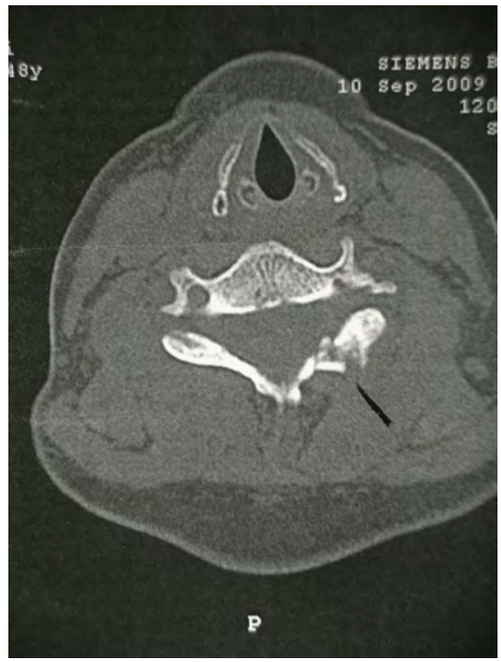


CT scan demonstrating left C6 lamina fracture



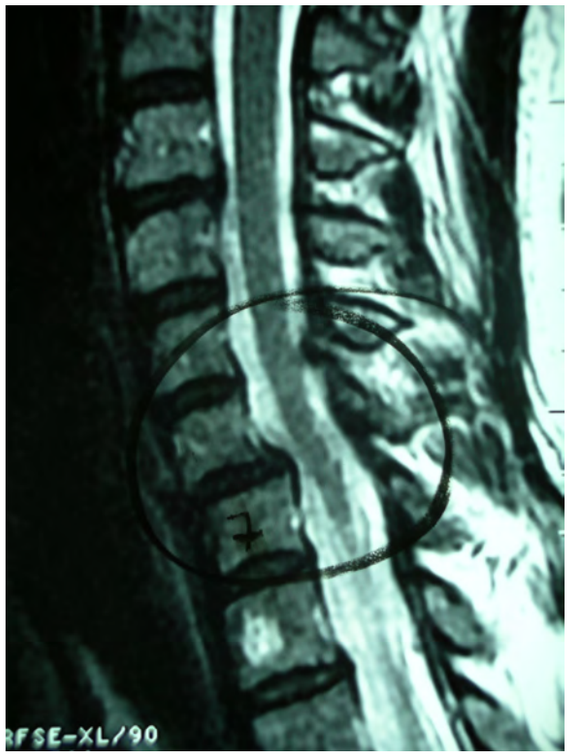
CT scan demonstrating left C6 lamina fracture extending into the facet joint

described that none of the six patients treated by halo-vest or the 12 patients treated with hard-collar had success in his series.

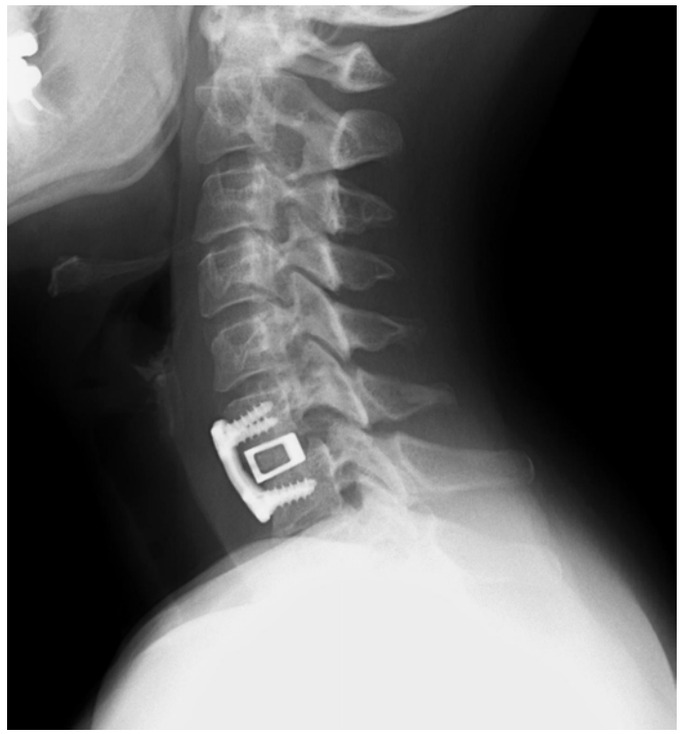
Halliday et al.[9] evaluated the anterior longitudinal ligament, the posterior longitudinal ligament, interspinous ligaments, and facet capsules with MRI during the acute period of injury. He recommended early surgical treatment in patients with injury in at least three of these structures. He stated that outcomes of surgery in the early period for these patients prevents the chronic cervical pain or radicular pain that might develop via complications such as kyphosis, rotation, and subluxation.[9,23] MRI studies are useful for the selection of the surgical procedure approach, anterior or posterior, based on the location of injured structures.[9,10,24,25]

Surgical options include posterior and anterior approaches with different techniques. Surgical treatment with the anterior approach includes a discectomy and stabilization with an anterior cervical plate. The rationale is that the facet fracture is the result of a hyperextension injury, with anterior soft tissue rupture. The application of the anterior plate in this region can achieve a good stabilization. This method has been reported to provide adequate long-term clinical stability without significant complications.[10,20,30] However, some authors have suggested that anterior stabilization techniques are biomechanically inferior to posterior stabilization techniques, specifically in the treatment of distractive flexion-type injuries.[26,29] Others, like Garvey et al.,[30] demonstrated lower complication rate with the anterior approach than with the posterior approach and, similarly, a lower cord injury rate with the anterior approach than the posterior approach. Also, Lifeso et al.,[10] in the prospective part of his series, treated 18 patients with anterior cervical decompression at a single space, fusion with autogenous tricortical iliac crest graft, and stabilization with anterior cervical plate. In the follow-up of these cases (for at least 2 years), there was no evidence of inadequate fusion or nonunion, and none of the patients needed further surgery. Disc collapse to the operation field or neighboring spaces, or signs of instability, was not observed in these cases.

Wiring or stabilization and fixation with plate and screw systems have been used in the surgical



MRI scan: C6-7 anterolisthesis with spinal canal narrowing.



3 month post-operative X-ray demonstrating anterior fusion utilizing a titanium interbody fusion cage.

treatment of unilateral facet fractures by the posterior approach.[1,9–10,15] Coe et al.,[26] in his cadaver study, compared posterior stabilization techniques (Rogers wiring, sublaminar wiring, Bohlman wiring, Roy–Camille posterior plate fixation, oblique posterior hook plate fixation) and any significant biomechanical difference was not found between them. Unfortunately, the fixation with posterior wiring could be limited in the treatment of these injuries due to the associated injuries like laminar and lateral mass fractures. Additionally, posterior approaches to the cervical spine may damage the posterior muscle and facet complexes and cause late deformity at adjacent levels.[15] Posterior plating techniques are biomechanically more effective in controlling rotational instability; however, because of the weakness of the posterior structures, collapse of the disc space and late kyphosis may develop.[10,27,28]

Lifeso et al.[10] have reported that posterior fusion procedures led to failed results in five of the 11 patients (45%). This was primarily related either to late kyphosis or rotational instability. The authors also performed a retrospective review at 2-year follow-up of 29 patients who were treated with either halo-vest, hard-collar or posterior surgical approach. A total of 19 patients had persistent displacement at the fracture or fusion site, 14 had late anterior disc space collapse, 10 had persistent neurological deficit, and one patient at 5-year follow-up had significant cord myelopathy. Adequate results were found in only 6 (21%) patients. They concluded that in unstable unilateral facet fractures, non-operative treatments and posterior surgical approaches have a high failure rate.

Conclusion

Patients presenting with persistent symptoms attributable to a unilateral cervical facet fracture, and 0–25% anterolisthesis, are candidates for surgical stabilization. The anterior discectomy with interbody fusion is an accepted option which provides biomechanical stability and predictable clinical outcomes.

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CASE REPORT

Radiation-Induced Sarcoma

Brian R. Subach, M.D., F.A.C.S.

A 35-year old woman came to our office in December 2010 with complaints of pain in the right leg and low back. She had been diagnosed with Hodgkin's lymphoma in 2005 and treated with both radiation therapy and chemotherapy. After treatment, she had been free of the cancer for the 5 years prior to seeing me. She suffered from severe back and leg pain for 6 to 12 months prior to coming to the office; the pain began acutely and gradually increased to a disabling level. She recalled having injured her back while riding on a motorcycle in January 2004. She re-injured her back "pushing and pulling" at work in July 2007. She stopped working at the end of November 2010 due to the severity of her pain. There was no memorable injury this time.

An MRI of the lumbar spine and a nuclear medicine bone scan were performed in December 2010. The sagittal (side-view) MRI showed an obvious burst fracture of the L3 vertebral body (Figure 1). The axial (cross-section) MRI showed bone and tumor compressing the spinal canal and the sciatic nerve endings (Figure 2). Given her young age and history of minimal trauma, the obvious concern was that cancer or infection had weakened the L3 bone causing it to fracture. A needle biopsy was performed of the L3 vertebral body to confirm the cause of her fracture. The results of the biopsy indicated a high grade sarcoma (cancer), called a spindle cell tumor invading the L3 bone of her lumbar spine.

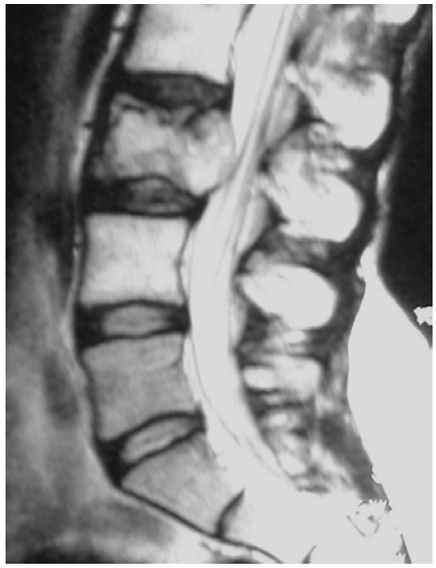

Figure 1. Sagittal MRI showing L3 burst fracture.

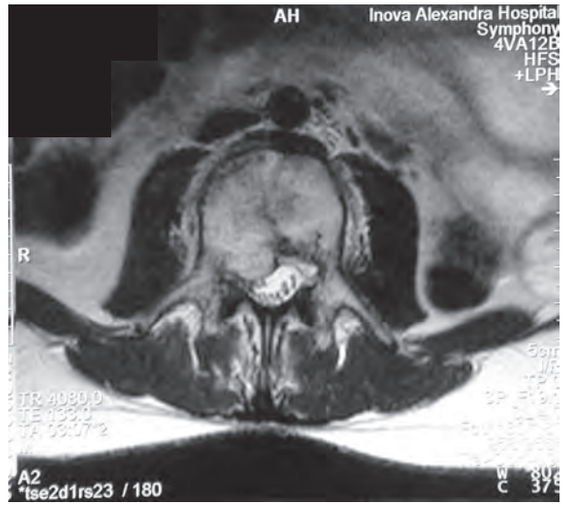

Figure 2. Axial MRI showing compression of the spinal canal by the tumor.

The patient's leg and back pain escalated to the point where she was essentially bedridden by February 2011. Surgery was scheduled to stabilize her spine and free the sciatic nerve branches which were compressed by the fractured bone. When the bone fracture is due to tumor infiltration, it is known as a pathologic fracture. The surgery could stabilize her spine and improve her pain, but could not cure her cancer alone. It was not possible to remove the entire tumor. She would require additional chemotherapy and radiation after her spinal surgery.

Surgical Procedure

The patient was placed in the side-lying position with the left side of the torso between the ribcage and the hip exposed. The area was prepped and draped in the usual sterile fashion. A curved incision was made along this area, paralleling the ribcage. The transversus abdominis musculature was divided, the rectus muscle was identified, and the retroperitoneal space entered. Dissection in this area identified the lateral aspect of the spine as well as the disc spaces and vertebral bodies. The appropriate L3 vertebral body was

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identified using fluoroscopic guidance and marked with the placement of a marking pin into the disc space adjacent to the diseased vertebral body (Figure 3). The discs above and below the L3 vertebra were aggressively removed, then the tumor was removed in small pieces. There was significant bleeding noted. After excision of the spinal segment, the thecal sac (which is the spinal fluid sac containing the sciatic nerve branches) and the exiting nerve roots at the L3 level were visible (Figure 4).

The appropriate implant to reconstruct the spine was designed using a cylindrical titanium cage filled with cancellous cadaver (donor) bone (Figure 5). The space between the adjacent vertebral bodies was distracted and the titanium cage was impacted into the spine to take the place of the fractured vertebral body. Screws and rods were used to stabilize the spine (Figure 6). The patient was taken to recovery in stable condition.

Postoperative Course

An x-ray was obtained to check the placement of the titanium cage and the screws (Figure 7). Imaging studies demonstrated realignment of the spine. There was excellent vertebral body reconstruction with the titanium cage, stabilized with a paired rod and screw system. The patient had excellent relief of her pain involving both the back and leg and began ambulating almost immediately with a brace. She ultimately did require additional chemotherapy for treatment of the spindle cell sarcoma.

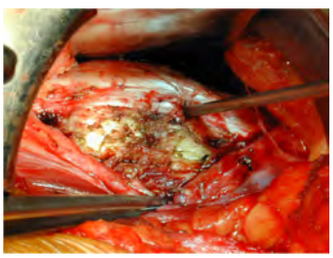


Figure 3. L3 vertebral body.

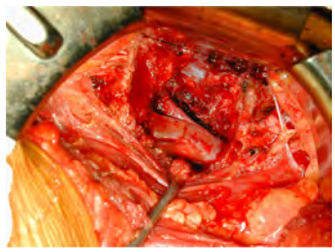


Figure 4. Thecal sac and exiting nerve roots.

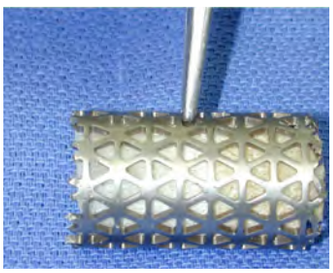


Figure 5. Titanium cage.

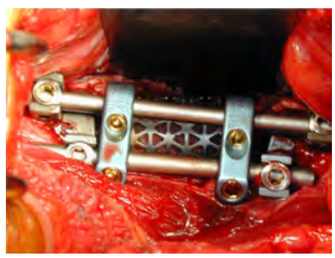


Figure 6. Implanted titanium cage and instrumentation.

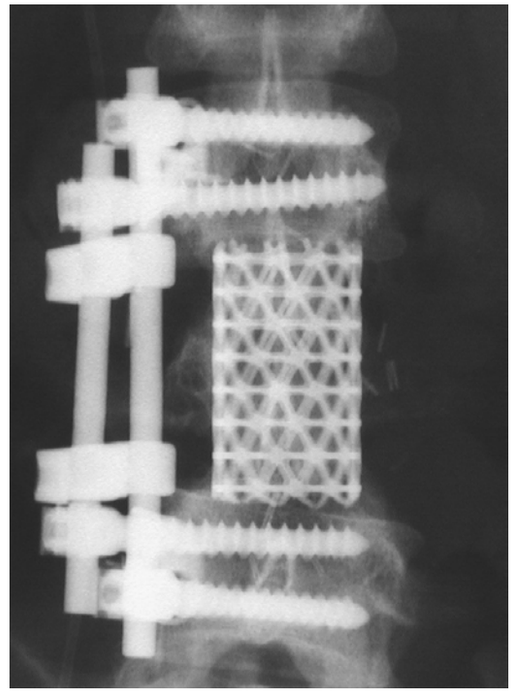
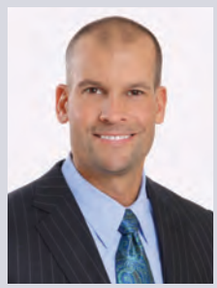


Figure 7. Post-surgery x-ray.



Brian R. Subach, M.D., F.A.C.S.

Dr. Subach is a spine surgeon and the Director of Research at the Virginia Spine Institute. He is a nationally recognized expert in the treatment of spinal disorders and an active member of the American Association of Neurological Surgery, the Congress of Neurological Surgeons, and the North American Spine Society. He is an invited member of the international Lumbar Spine Study Group and a Fellow in the American College of Surgeons. He lectures extensively regarding the management of complex spinal disorders in both national and international forums. He is the Director of Research and Board Member for the non-profit Spinal Research Foundation (SRF) and Editor-in-Chief of the Journal of the Spinal Research Foundation (JSRF). He has written 15 book chapters and more than 50 published articles regarding treatment of the spine.

CASE REPORT

Spine Tumor: Multiple Myeloma

Christopher R. Good, M.D., F.A.C.S.

I have the pleasure of introducing you to Christopher Dann who is the focus of the spine tumor case study in this issue of Spinal Research Foundation. Mr. Dann is a forty-six year old healthy active man who first noticed pain in his back after sledding in December 2009.

As time passed, his low back pain worsened and he was seen by his chiropractor. With exercises, his back pain somewhat improved and Mr. Dann continued to work and stay active. However, the pain worsened again over the next four months. This prompted Mr. Dann's chiropractor to order x-rays in May 2010. On the x-rays, an unusual appearance of one of the bones in the spine was noted with a small amount of compression (a change in the shape of the bone). Because of the appearance on the x-rays, Mr. Dann's medical doctor ordered an MRI scan. The MRI scan showed an unusual appearance of the bone at the T12 level with compression fracture of the bone in that area. Ultimately, his chiropractor suggested that he see the physicians at Virginia Spine Institute for further evaluation.

When Mr. Dann was seen, he had severe back pain with loss of flexibility and pain with even small amounts of movement of the low back. Because of the severity of his pain and concern about the appearance of the x-rays and MRI scan, a full medical evaluation was initiated (Figure 1). Mr. Dann had a whole body bone scan which is an x-ray taken of the entire body, looking for abnormal areas of bone activity. This bone scan confirmed an irregular appearance at the T12 vertebral body consistent with fracture and possibly tumor. Also noted was an area of unusual activity in the rib which had not previously been identified. Brace treatment started during this time. Ultimately, the doctors recommended to Mr. Dann that a needle be inserted into the bone at T12 for a biopsy to determine the cause for the broken bone in that area. Mr. Dann underwent the biopsy, but unfortunately, the tissue that was examined under the microscope did not give a specific answer to the question.

Mr. Dann continued to have worsening pain in his back. New x-rays and a MRI scan showed the deteriorating of the broken bone at T12 with tumor growing in the bone. The doctors explained to Mr. Dann and his wife that a cancer growing inside the bone had weakened the structure of the bone, causing the fracture. At that point, the doctors elected to bring the patient into the hospital for a rapid evaluation.

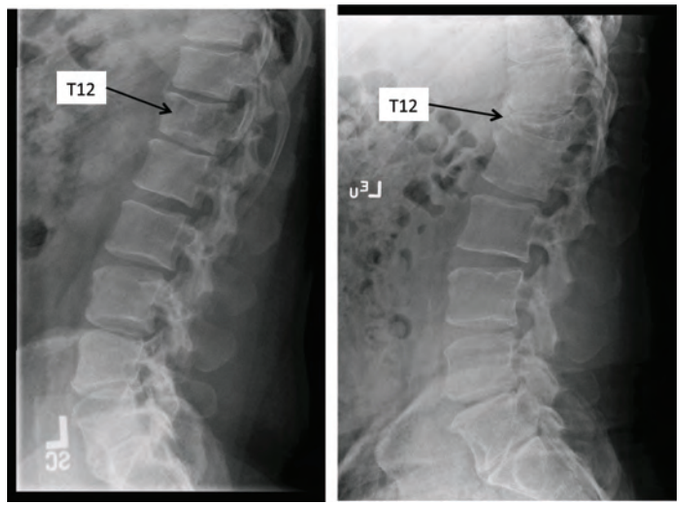


Figure 1. X-rays taken of the thoracolumbar spine from the side. The first x-ray (left) shows a small amount of compression in the T12 vertebra. The x-ray on the right shows worsening of the compression at T12.

In the hospital, he had x-rays of his entire body, as well as a CT scan to look for a potential source of tumor in his spine bones and look for tumors in other areas. The doctors were assisted by doctors specializing in medicine, radiology, and oncology. The thorough work-up revealed that tumors were present in multiple areas of his body including the spine, hip, and pelvis as well as the ribs. As the tumor in the T12 vertebra had increased in size, some of the tumor had begun to push against the front of the spinal cord (Figures 2 and 3). Because the situation was worsening, the decision was made that surgery would be necessary to prevent compression or damage to the spinal cord as well as stabilize the area of the spine that had been eroded away by the tumor.

First, the doctors performed surgery through a small incision made just underneath the ribcage to remove the broken bone and tumor at the T12 level. A titanium cage was used to replace the T12 vertebra in order to realign the spine in the area that had been

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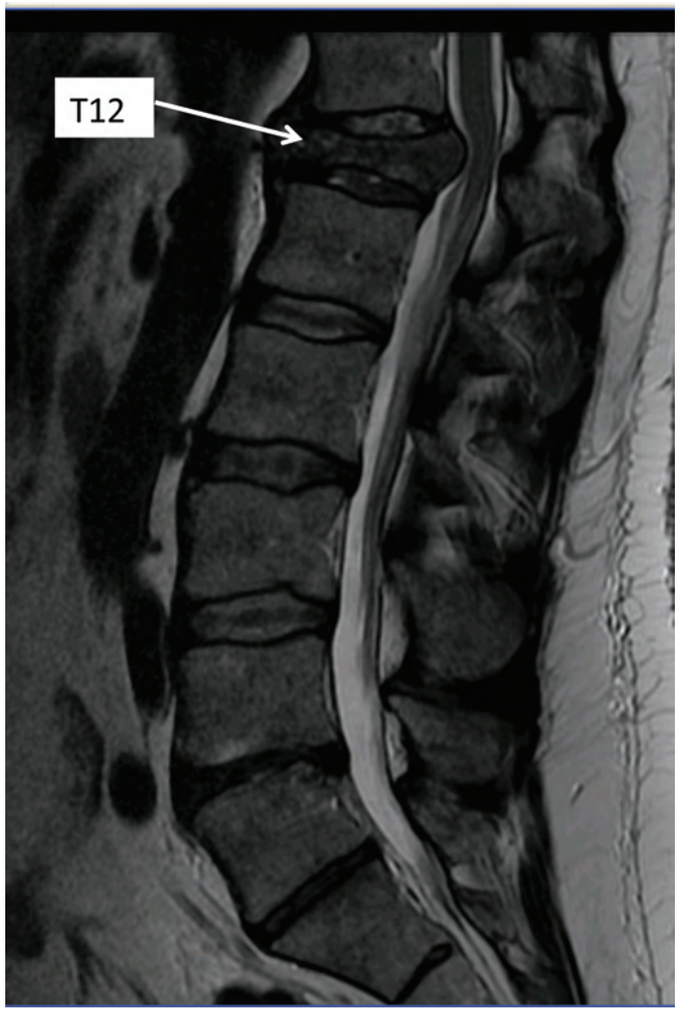


Figure 2. MRI image of the spine showing tumor in the bone at T12 (arrow) with compression of the spinal cord behind T12.

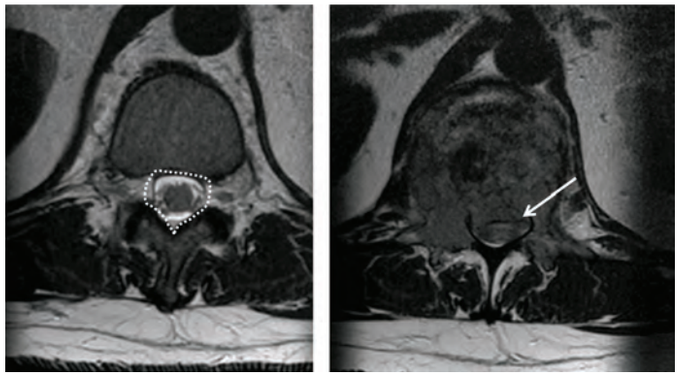


Figure 3. Cross-sectional MRI scan showing a normal amount of space around the spinal cord (left picture, white dotted line). On the right, tumor has invaded the space around the spinal cord causing compression (arrow).

destroyed by tumor. Once that part was completed, the doctors performed surgery through the back of the spine, placing titanium screws and rods to stabilize and fuse the spine, restoring normal spinal alignment. Also, additional bone and tumor were removed to take all pressure off the spinal cord (Figures 4 and 5).

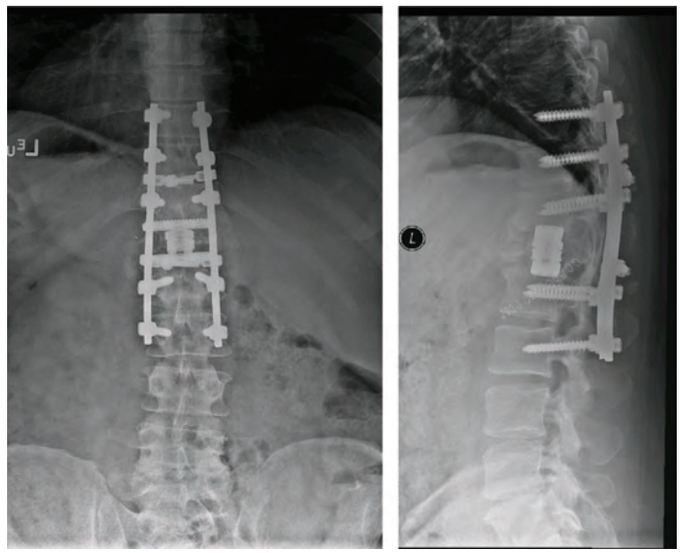


Figure 4. X-rays after surgery taken from the back and the side showing removal of the T12 vertebra with titanium cage placement and titanium instrumentation holding the spine in proper alignment.

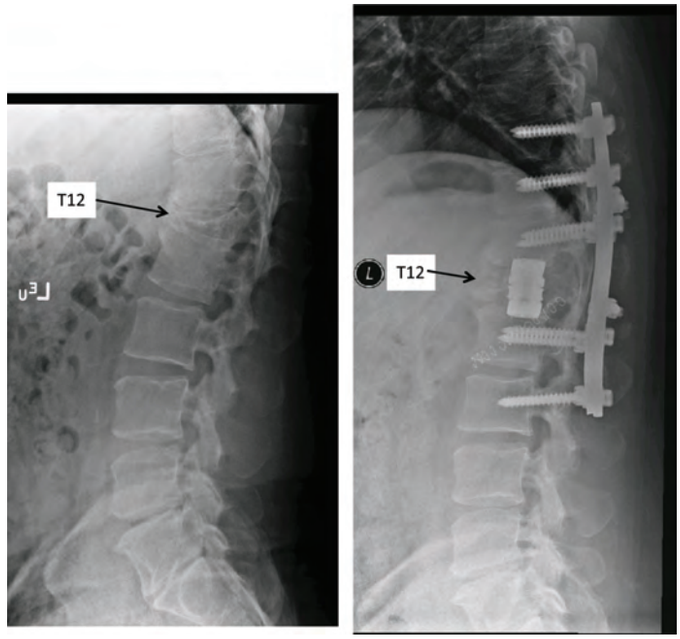


Figure 5. X-rays of the spine taken from the side before and after surgery show restoration of spinal alignment.

After the surgery, Mr. Dann did well in the hospital. He worked with physical therapy and began to walk. Pain medications were needed to help control the pain from his surgery as well as for the pain from tumors in other bones.

During the surgery, the doctors had removed the tumor at T12 so that it could be examined under a microscope. After a thorough pathology evaluation, Mr. Dann finally had the answer to what was causing his problem. He had a disease called multiple myeloma and tumors had formed in his bones in various locations. A tumor had led to destruction of the bone in the spine causing his pain and change in spinal alignment.

As Mr. Dann recovered from surgery, full medical evaluation of his myeloma was performed. One of the tumors in the pelvis was large enough that there was concern that a fracture of the pelvic bone may occur. For a period of time, he was placed in a wheelchair to avoid placing weight on his pelvis.

Mr. Dann and his family worked with the oncology team regarding his options. He chose to be very aggressive, moving forward with treatment for his disease. Mr. Dann ultimately chose to enroll in a study protocol and he underwent treatment with double autologous stem cell transplantation as well as an aggressive chemotherapy regimen with multiple medications. After completing the second transplant, he was declared to be in near-complete remission from his disease.

At this point, Mr. Dann is on a maintenance dose of chemotherapy medication in an effort to prevent any recurrence of his tumors. Mr. Dann has returned to walking and full activities without any limitations and reports complete improvement of his back pain (Figure 6). Mr. Dann and his family are enjoying their time together and he is happy to be able to return to more normal activities. He and his family will continue with his treatment, working to fight the potential return of his multiple myeloma in the future.

Mr. Dann's story serves as an inspiration to all patients and families who are fighting against cancer. With the use of revolutionary surgical techniques and medication treatment including autologous stem cell transplantation, Mr. Dann is now in complete remission.

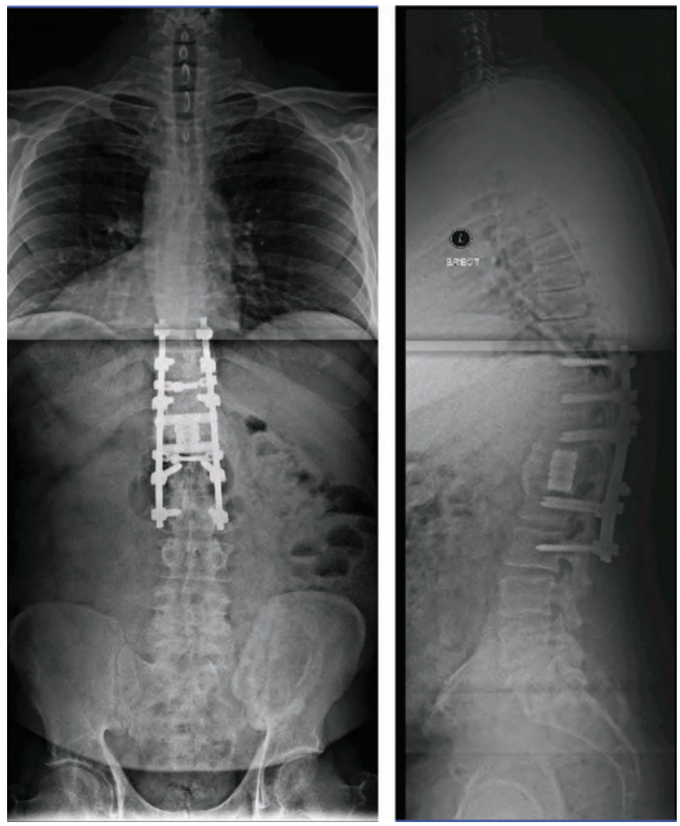
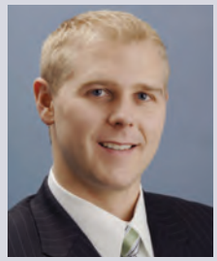


Figure 6. X-rays of the entire spine at the last visit show healing of the bones and excellent spinal alignment.



Christopher R. Good, M.D., F.A.C.S.

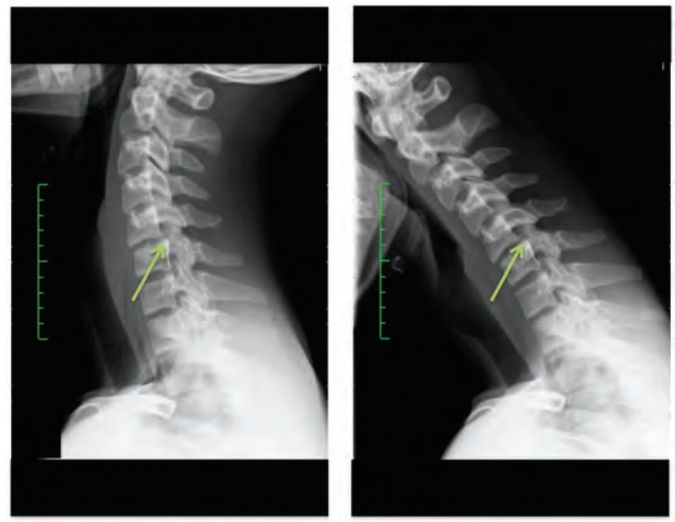
Dr. Good is a spine surgeon at the Virginia Spine Institute. He has extensive training and experience in the treatment of complex spinal disorders with special expertise in non-operative and operative treatment of adult and pediatric spinal deformities including scoliosis, kyphosis, flatback, and spondylolisthesis. Dr. Good has co-authored numerous articles and has been invited to lecture nationally and internationally at the Scoliosis Research Society, the International Meeting on Advanced Spinal Techniques, the American Academy of Orthopaedic Surgeons, and the North American Spine Society.

Spine Trauma: C5-C6 Anterolisthesis with Perched Facets

Najeeb M. Thomas, M.D.

James Little, Jr. was a high school junior and wide receiver on his school football team in Louisiana. On March 20, 2009, this 17 year old male was involved in a motor vehicle accident. He was attempting to pass someone when he had a blowout of the right-front tire. James was headed toward a pole, so he cut back sharply in the opposite direction and rolled his SUV six times. No airbags deployed in the crash. James did not have any neck pain at the time of the accident and was moving his head around without any problems. He was immediately taken to a local university hospital where he was told he had a fracture at C5 per CT scan. He was placed in a hard collar and told that, in 2 months, it would be removed and he would be released to resume regular activity.

James' mother was still concerned and wanted a second opinion, so she contacted a neurosurgeon, Dr. Najeeb M. Thomas. Dr. Thomas saw James on March 23, 2009 and immediately ordered cervical A/P, lateral, flexion, and extension x-rays. James denied numbness, tingling, manual dexterity problems, and difficulty unbuttoning clothes. He did not have radicular symptoms, but had some neck pain which he attributed to the collar. James was not on any medications. After Dr. Thomas reviewed the CT scan and the new x-rays, he found a small misalignment at the C5-6 level that was about 3mm and persisted on the flexion and extension x-rays. An MRI was ordered to make sure there was no ligamentous instability, given the fact that James was having a lot of muscle spasm.



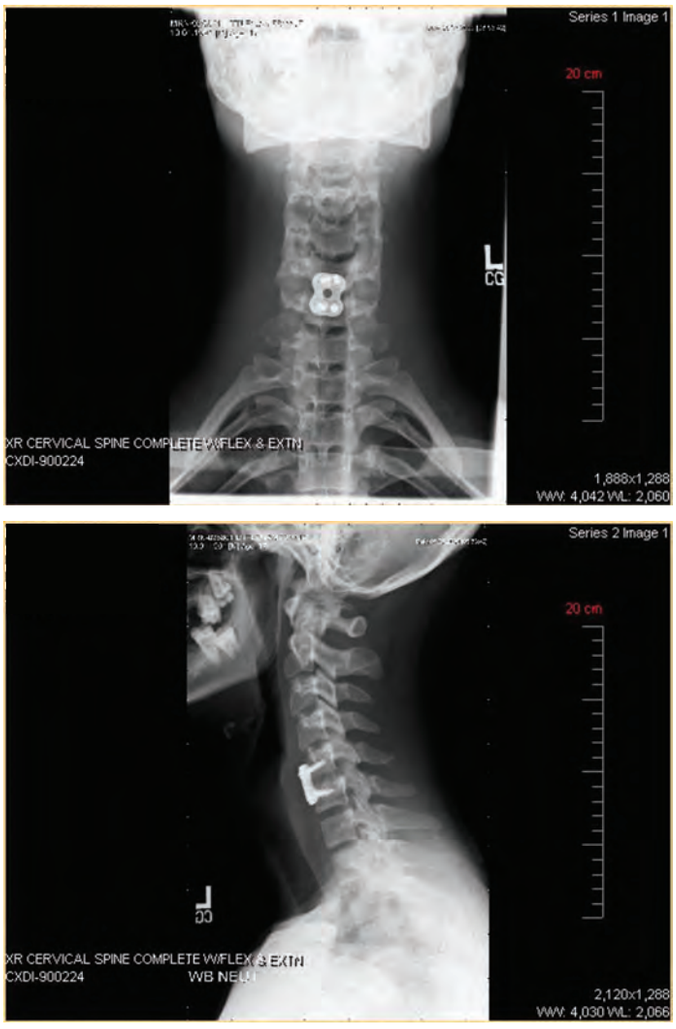
March 23, 2009 Pre Operative X Rays showing C5-6 Anterolisthesis

When Dr. Thomas reviewed the MRI, it showed internal disruption of the disc and anterolisthesis at C5-6 with a perched facet and segmental kyphosis. James clearly had ligmentous instability at the C5-6 level and was now having pain at that level. Given the fact that James had a perched facet, focal segmental kyphosis, and evidence of ligamentous instability, he was offered an anterior cervical discectomy and fusion to stabilize this level and restore cervical lordosis. James was strongly advised to avoid contact sports.

James was taken to surgery seven days after the accident to have an anterior cervical discectomy and fusion at C5-6 with interbody arthrodesis using left-

CASE REPORT

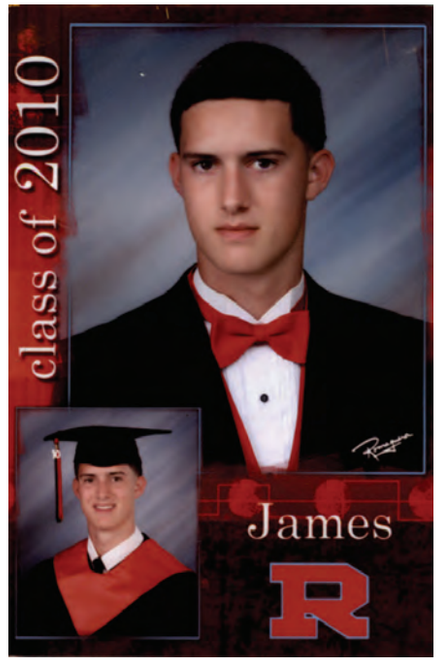
sided iliac crest autograft, a 19 mm Medtronic Atlantis locking plate, 13 mm fixed screws inferiorly, and 14 mm screws superiorly. He stayed in the hospital overnight with no significant pain issues. James was able to ambulate, void, and tolerate food without difficulty swallowing and he was discharged in a cervical collar.



Post operative Radiographs

At James' two week post-operative visit, he stated that he had no pain whatsoever. He had not taken any pain medications. His hip was bothering him a little, but not enough to warrant pain medication. He had no neck pain, numbness, tingling, or any signs of myelopathy. His motor strength was a five out of five. James was instructed to wear his cervical collar at all times, except when showering or sleeping. At James' six week post-operative visit, he stated he continued to be pain free. He was still wearing his collar and his cervical films showed the beginnings of solid arthrodesis at the C5-6 level. He had good alignment and his cervical plate was in good position.

By August 2009, four and a half months after his injury, James was cleared at the beginning of football season to resume training and workouts. He played wide receiver his senior year in high school without restrictions. Dr. Thomas' goal is to restore patients to the normal, active life they had before an injury. With James Little, Jr., he was able to accomplish that, returning him to playing football his senior year with a pain free life.



Najeeb M. Thomas, M.D.

Dr. Thomas is a neurological surgeon at Southern Brain & Spine in New Orleans. He specializes in minimally invasive surgical techniques for the spine. He has lectured about spinal procedures on four continents and had interactions with hundreds of surgeons around the world. He is recognized as an innovator, continues to be active in the latest development of minimally invasive spine procedures so that his patients may receive the most advanced spinal care in the world.

Metastatic Spinal Disease

Brian R. Subach, M.D., F.A.C.S.

Metastatic spinal disease, or the spread of cancer from its original location to the spine, is extremely common. Metastatic disease means that the cancer cells from the primary site actually spread via the bloodstream or the lymphatic system to a remote site, such as the spine. The spine is actually the third most common site for cancer cells to metastasize, with both the lung and the liver being the more likely sites for tumor cells to grow.

Nearly sixty to seventy percent of patients with cancer will have spinal metastases. Of the patients afflicted with metastatic cancer, only one in ten is actually symptomatic. Most patients with spinal metastatic cancer will present to the physician's office with either involvement of the spinal cord and nerve endings (epidural), or the vertebral column (bones) itself.

The most common causes of metastatic spinal disease are generally primary tumors arising from the lung (31%) and breast (24%). These are the most likely to metastasize to the skeleton.

Case History

BK is a fifty-two year old woman with a history of breast cancer. She underwent a lumpectomy from the left breast, resecting a tumor approximately the size of a quarter. She underwent additional chemotherapy and radiation, since some of the lymph nodes in the armpit area had cancer cells present (lymphatic spread). She underwent the surgery and chemotherapy approximately three years prior to coming to the office.

She arrived in the office complaining of an insidious onset of neck pain, which had become quite severe recently. There was no obvious injury to blame for the progressive neck pain, but she felt that any posture other than lying flat in bed caused her significant discomfort. She also noticed the gradual, but progressive, loss of function in her arms and legs. She felt that her balance and dexterity were both deteriorating. She initially was told that she had arthritis by her primary care physician, but then saw a chiropractor. The chiropractor noted brisk reflexes on her neurologic examination and ordered an MRI scan. The MRI scan demonstrated a large tumor of the cervical spine, involving the C4, C5, and C6 vertebral bodies (Figure 1). There was significant compression of the spinal cord and, clearly, the structure of the spine had been destroyed by the tumor.

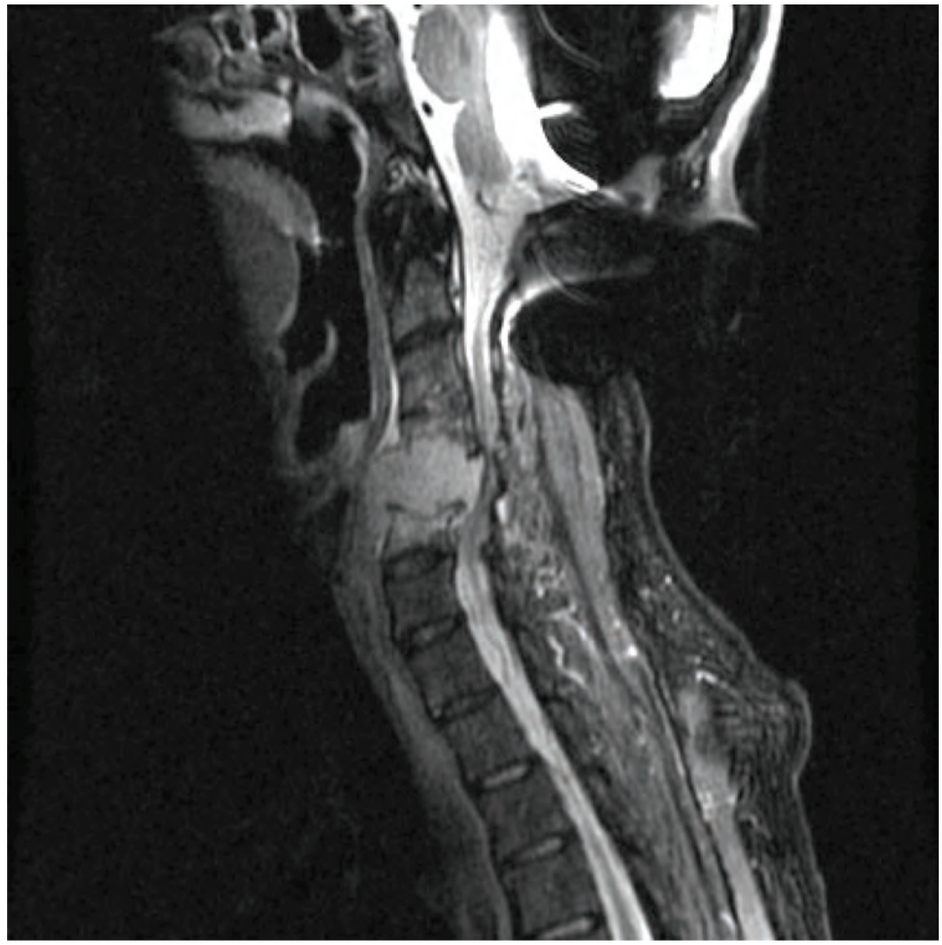


Figure 1 Preoperative cervical imaging.

CASE REPORT

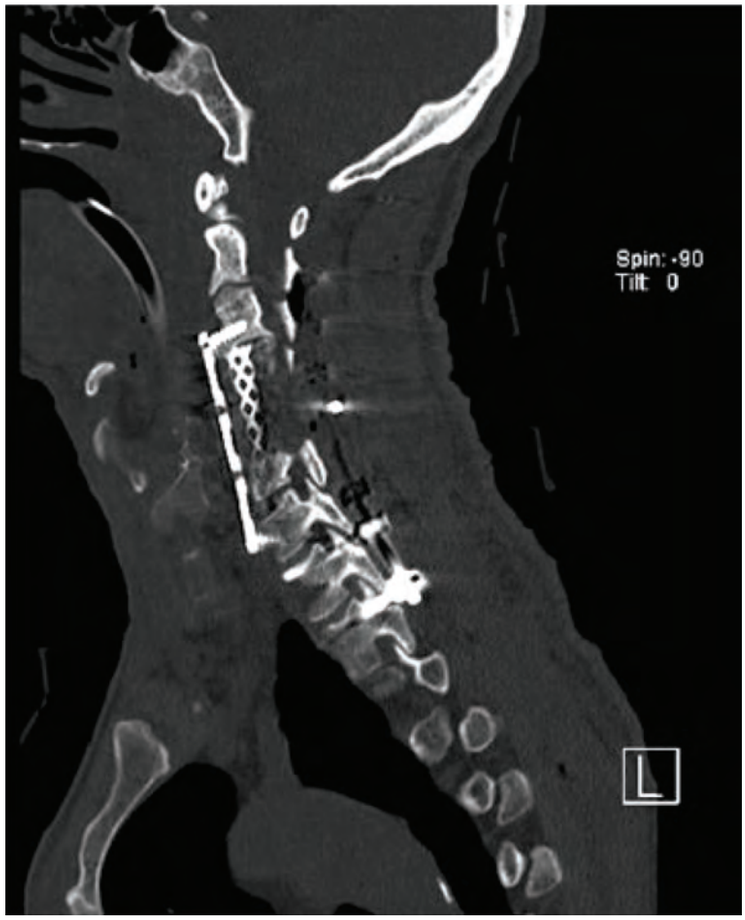
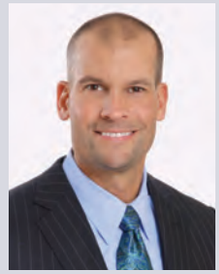


Figure 2 Postoperative cervical imaging.

Surgical Summary

Given the severity of her neck pain, as well as the progressive loss of function, she was taken to surgery. Specimens sent from the involved vertebral bodies demonstrated obvious breast cancer tumor cells. The bones of C4, C5, and C6 were removed from the front of the neck, leaving only a shell of bone protecting the nerve endings and important blood vessels. Her operation was completed from both the front and the back of the neck, with a spinal reconstruction using titanium cages, plates, and screws (Figure 2). Her spinal cord was completely decompressed and her spine stabilized in its normal posture. BK's neck pain was brought under control by the surgery and she regained her motor function. The surgery did not eradicate the cancer and cancer treatment (additional chemotherapy and radiation) was provided by BK's oncologist.



Brian R. Subach, M.D., F.A.C.S.

Dr. Subach is a spine surgeon and the Director of Research at the Virginia Spine Institute. He is a nationally recognized expert in the treatment of spinal disorders and an active member of the American Association of Neurological Surgery, the Congress of Neurological Surgeons, and the North American Spine Society. He is an invited member of the international Lumbar Spine Study Group and a Fellow in the American College of Surgeons. He lectures extensively regarding the management of complex spinal disorders in both national and international forums.

Spinal Research Foundation Regional Research Partners

The Spinal Research Foundation has named 23 Regional Partners across the country that share one core mission: improving spinal health care for the future. These centers offer the best quality spinal health care while focusing on research programs designed to advance spinal treatments and techniques.

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MUSC Darby Children's Research Institute
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Neck and Back Pain Affects Millions

The Spinal Research Foundation has made remarkable progress in scientific research associated with neck and back pain. Located in Reston, Virginia, the Foundation collects data relative to patients' treatments and outcomes and has embarked on projects designed to better understand the biochemistry of neuropathic pain and develop new drug and surgical regimens to address it. The Foundation continues to expand its research efforts, partnering with other research institutions to further the advancement of spine related research. The Spinal Research Foundation has been involved in numerous studies:

- ***The use of novel perioperative drug therapy to improve surgical outcomes.***
- ***The evaluation of medical devices for the relief of back pain.***
- ***The evaluation of analgesic drug regimens.***
- ***The development of non-operative techniques to resolve disabling neck and back pain.***
- ***Investigating the use of BMP (Bone Morphogenetic Protein) in minimally invasive spinal surgery to minimize post-operative pain and dysfunction.***
- ***The development of cervical and lumbar disc replacement technologies.***
- ***The development of disc regeneration technology through the use of stem cells derived from the bone marrow.***
- ***The investigation of lactic acid polymers to prevent fibroblast in-growth in surgical wounds.***
- ***A nation-wide multi-center prospective spine treatment outcomes study.***

The Spinal Research Foundation is a non-profit organization dedicated to improving spinal health care through research, education, and patient advocacy. The Foundation collaborates with spinal research partners across the country to prove the success of traditional approaches, as well as develop new techniques and technologies. These results are shared with both the medical profession and the general public to improve the overall quality and understanding of optimal spinal health care.

More than 85% of the population will suffer from severe neck and/or low back pain during their lifetime. Eight percent of these people develop chronic pain, which means that at any given time, around 25 million people in the United States are directly affected by this condition and many more indirectly. Techniques to cure, manage, and prevent this limiting and disabling condition need to be developed. Educating the public, health care providers, and insurance providers is the first step in advancing spinal health care.

You can help!

The Spinal Research Foundation is America's leading non-profit health organization dedicated to spinal health. Friends like you have made it possible for us to make huge strides and groundbreaking research discoveries. Join us in our mission to improve spinal health care. Support cutting edge research by making a donation to the Spinal Research Foundation.

Support Cutting Edge Reseach

- Visit www.SpineRF.org to make a secure online donation.
- Call (703) 766-5404 to make a donation over the phone.
- The Spinal Research Foundation is a non-profit 501(c)(3) organization. Donations are tax deductible.

Stay Informed

- Visit our website often to keep up-to-date on the Foundation's activities and research breakthroughs.

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