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Journal of the Spinal Research Foundation

Spines in Motion: Biomechanics of the Spine

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

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From the Editor

Brian R. Subach, MD, FACS

Welcome to the fall 2012 issue of the *Journal of the Spinal Research Foundation*. This journal is specifically dedicated to the science of biomechanics. For those of you who are unfamiliar with the term, biomechanics is the study of movement of the human body. I prefer to divide the concept further into two areas: structure and function. Obviously the spine provides structural support for the torso, head, arms, and legs, but the intrinsic motion of the components of the spine (discs, joints, ligaments, etc.) allow for its function. Whether one considers the flexibility of an Olympic gymnast, the raw strength of a power lifter, or the torque generated by a scratch golfer, the spine is truly the basis for all such activities.

Our society is certainly an active one. For example, our children play soccer, swim, wrestle, play tennis, and skate. Young adults row, ride, and run, while as adults, we struggle with the conflict between an active mind and a less than cooperative aging body. The degenerative or arthritic process, which affects us all, is directly opposed to the concept of normal motion, meaning that aging weakens the structure of the spine and clearly slows its function.

For this issue, we have brought together a number of experts in the field of biomechanics that present both review articles and their original research in this area. Our "Spine Tales" are stories of patients whose impaired spinal biomechanics have made it impossible for them to perform in their respective competitive or recreational sports. Having overcome their spinal diseases through expert diagnoses and interventions, these spinal champions are both back at a level of functioning which would have seemed unobtainable only a few years ago.

Spinal biomechanics, which seems to be a dauntingly complex topic to researchers, coaches, and physicians alike, is truly the study of movement. Whether in a young athlete or an elderly woman, spinal disease clearly affects us all. Hopefully, this issue will give you some insight into the structure and function of the spine, as well as the diseases leading to its impairment and the interventions available.

From the President

Thomas C. Schuler, MD, FACS

The Fiscal Crisis is on a Collision Course with America's Health Care

Our growing national debt is the single greatest threat to our national security and our way of life. The debt continues to grow because of the ongoing annual deficit spending produced by our elected officials. In reviewing the 2012 data from the Office of Management and Budget, it reveals that Washington will spend 3.8 trillion dollars in 2012. Taxes produce 2.5 trillion dollars and deficit spending, projected to be 1.3 trillion dollars, funds the remainder.

OFFICE OF BUDGET AND MANAGEMENT PROPOSED 2012 BUDGET
2012 OUTLAYS (In Billions of Dollars)

Appropriated ("discretionary") programs	
Security	868
Non-security	450
Subtotal Appropriated Programs	1,319
Mandatory Programs	
Social Security	773
Medicare	478
Medicaid	255
Troubled Asset Relief Program (TARP)	35
Other mandatory programs	711
Subtotal mandatory programs	2,252
Interest	225
TOTAL OUTLAYS	**3,796**

To understand why we continue to run a deficit, we need to define where the government spends its money. The government spends its money in three categories: first, the appropriated programs (discretionary), second, the mandatory programs, which are known as entitlements, and third, interest. Discretionary spending under appropriated programs is broken into two subcategories: security (the military, FBI, CIA, etc.) and non-security (education, energy, etc.). Mandatory programs, or entitlements, consist mainly of Social Security, Medicare, Medicaid, and pensions. The third category is interest on the debt.

Approximately 1.3 trillion dollars in 2012 will be spent on the discretionary programs. Two and a half trillion is spent on the mandatory programs, or entitlements, and interest. Approximately 1.5 trillion of that amount is for Social Security, Medicare, and Medicaid. Even if 100% of the discretionary programs were eliminated, Washington does not have enough money to pay the entitlements as they are currently obligated, and this is with interest rates at a historic low. If interest rates rise, then the fiscal crisis only worsens.

To summarize this, the main contributors to our debt are government funded health care (Medicare and Medicaid) and government funded retirement (Social Security and pensions), totaling 2.3 trillion dollars in 2012. We all know that a family or business cannot continue to spend more money than they make without insolvency being the end result.

There is no question that the U.S. Government subsidized health care is an enormous part of the problem. This is where health care collides with fiscal reality. Currently, the United States has the best quality health care in the world, but the government is looking for ways to limit expenditures. They are trying to implement rationing of care to cut expenses. Instead of them directly approving or disapproving procedures, they are pushing the burden onto physicians and hospitals. Medicare has issued many edicts designed to decrease utilization of services. The most recent edict tells spinal specialists that for both the physician and the hospital to be paid, they must document in the hospital record that the patient has failed non-operative treatments for greater than six months (only three months for some spine diagnoses), the patient's compliance with weight loss, smoking cessation, and much more. If this is carefully documented in the doctor's office notes, but not in the hospital record, then no payment will be made to either the doctor or the hospital. This is just another attempt to drive a wedge between the doctor and his or her patient. The elderly are the most complicated patients to manage because of the number of medical conditions affecting them and the increased fragility of their health. Research has proven that medical complications postoperatively are higher in patients over the age of seventy versus younger patients. Medicare has previously told hospitals and physicians that it will not pay for the cost of treating medical complications that occur during hospitalization, even though we know that the elderly patients will develop more complications.

The bottom line is simple: the government does not want to pay for treating the elderly and is creating a system which is rapidly and progressively de-incentivizing physicians to provide care for our seniors.

There is a better way to solve the debt crisis, reform entitlements, and still provide care for our seniors. Raising the age for initiation of entitlements, both Medicare and Social Security, will solve the main driver of deficit spending. Due to our excellent health care system, life expectancies have increased. It is unreasonable to tie the age of initiation of benefits to an outdated model when people died at younger ages. It does not make intellectual or economic sense. The increase in age of access to entitlements should be implemented in a graduated fashion so as not to hurt those on a near timetable for retirement. Also, elimination of waste in discretionary programs, as well as in entitlement programs, is essential in the taming of the deficit and eliminating the debt.

The essential message is that access to spinal health care (and medical care in general) is dependent on the United States improving its financial health and then making smart choices so that all Americans, and especially our seniors, will continue to have access to the best health care in the world.

Issue Overview

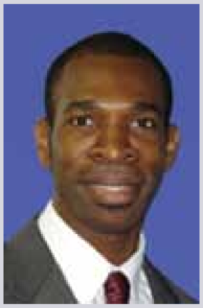
Marcus M. Martin, PhD and Anne G. Copay, PhD

Even in our sedentary society, life demands movement. Those who have suffered from back pain know how restricted life can be when they are not able to move freely. Movement of the spine, which may appear simple and easy, relies on the intricate collaboration and coordination of multiple elements. This issue of the *Journal of the Spinal Research Foundation* explores the complexity of spinal movement from the perspectives of physical therapists, chiropractors, spinal surgeons, and, most importantly, through the eyes of those afflicted with spinal disease. We have included the stories of two athletes, a Division I collegiate swimmer and a 1st Degree Jiu-Jitsu Black Belt. Both were struck by spinal disease and unable to participate in their athletic endeavors. After proper treatment and recovery, they are successfully competing again.

Dr. Banton, a highly skilled physical therapist at the Virginia Therapy & Fitness Center, is the author of the main review for this issue of the *Journal of the Spinal Research Foundation*. He provides a comprehensive introduction to spine biomechanics and draws a picture of the spine as a dynamic unit composed of multiple joints, each contributing to its alignment and function. Dr. Daddio from Purcellville Family Doctors provides an expert chiropractor's view on the biomechanics of the golf swing, the mechanisms of golf injuries, and their avoidance. He explores how the manipulation of spinal segments can accomplish the goal of improving the structural integrity and stability of the spine, facilitating proper biomechanics.

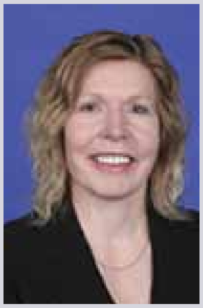
Dr. Orndorff, a distinguished orthopedic surgeon with Spine Colorado, describes the types of forces applied to the spine and the structures affected by those forces. A healthy spine should be able to withstand a variety of forces but may be tested beyond its limits if proper technique and proper posture are ignored. Dr. Girasole, who practices at The Orthopaedic & Sports Medicine Center, provides excerpts from his book, *The 7-Minute Back Pain Solution*, and gives us the spine surgeon's perspective and techniques to maintain a healthy spine. Dr. Goel, a world-renowned scientist at the University of Toledo, and his skilled research team provide an in-depth review of the effect of aging on the biomechanics of the spine.

Overall, this issue of the journal will help our readers understand the complexities and motions of the spine. Our readers will gain not only knowledge, but also renewed respect for their spines.



Marcus M. Martin, PhD

Dr. Martin's research interests include neuroimmunology, virology, and immunology. He is engaged in collaborative research through the Spinal Research Foundation 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. Dr. Martin's current research collaborations include research initiatives to apply stem cell therapy for tissue preservation, the development of regenerative therapies for intervertebral discs, and the development of novel methods of enhancing bone fusion.



Anne G. Copay, PhD

Dr. Copay has conducted research and authored several articles in the areas of organizational structure, work site health promotion, the effect of physical activity on energy expenditure and body weight, and the outcomes of spine fusion surgeries. Dr. Copay has ongoing research projects concerning the effectiveness of new spine technologies and the long-term outcomes of surgical and non-surgical treatments.

"We've Got Your Back" Race for Spinal Health Reston, Virginia

Laura A. Bologna, Spinal Research Foundation National Program Coordinator

The Spinal Research Foundation's fifth annual "We've Got Your Back" Race for Spinal Health was hosted by the Virginia Spine Institute on May 12th, in Reston, Virginia. It attracted more than 800 participants, more than 100 volunteers, and raised over $100,000 in support of the foundation's mission to improve spinal health care through research, education, and patient advocacy.

"We want to empower spinal patients with knowledge and hope, and today celebrated that," said Thomas C. Schuler, MD, president of SRF. "We have had people with major spinal issues who were worried that their lives were over, that they couldn't do things they love, or carry out their careers. But through modern spinal care– both operative and non-operative– we've gotten people back to unbelievable levels of activity, even returning people to careers in the military and the National Football League."

Washington Redskins players Rocky McIntosh, Reed Doughty, and Josh Wilson– who have all undergone spinal treatment and returned to the NFL– gave powerful testaments to the value of effective spinal treatment and are considered Spinal Champions.

Spinal Champions were celebrated on race day with commemorative race shirts and a special tent where they could share their stories of success. A Spinal Champion is defined as someone who has suffered from back or neck pain, has overcome it through either non-operative or surgical treatments, and regained his or her life.

Dr. Schuler noted that more than nine out of ten people will suffer from severe neck and/or low back pain during their lifetimes. Approximately ten percent of these people develop chronic pain, which means that at any given time, 35 million people in the United States are directly affected by disabling pain and many more indirectly. Techniques to cure, manage, and prevent these conditions need to be developed, implemented, and proven.

The event also included a Spinal Health Fair that focused on nutrition, exercise, and prevention of spinal problems. The Spinal Health Fair provided educational

materials about the spine, a calcium campaign including a photo booth with milk mustaches, a massage station, and kids' activities. The race festivities also included live entertainment, refreshments, and free giveaways.

"SRF 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 our Regional Research Partners to host 5K events in their cities 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 have the only run/walk event in the country designed to celebrate the accomplishments of Spinal Champions as they continue to research new techniques to improve spinal health care for future generations. To learn more about the Spinal Research Foundation's "We've Got Your Back" Race for Spinal Health and other host sites, visit www.spinerf.org/race.

Spine Tale
Bill Scott, Mixed Martial Arts Fighter

Mark R. McLaughlin, MD, FACS

Bill Scott, a Mixed Martial Arts Fighter and 1st Degree Brazilian Jiu-Jitsu Black Belt.

When mixed martial arts fighter Bill Scott felt severe pain in his lower back and numbness in his entire right leg in 2003, he thought it was the after-effect of a head-on car crash two years earlier. But a prominent neurosurgeon who examined Scott found a serious spinal problem that was unrelated to the accident.

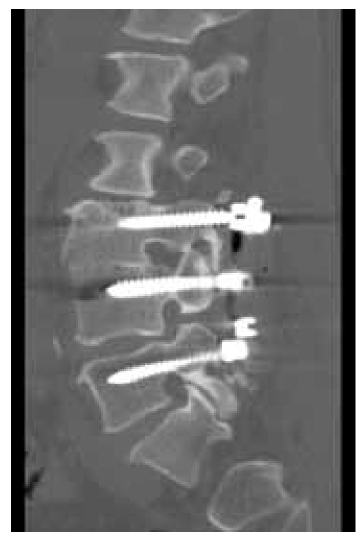
During the consultation with Mark McLaughlin, MD, medical director of Princeton Brain & Spine Care, an MRI revealed that several of Scott's lumbar vertebrae had collapsed, shifted to the right side of his body, and fused together. Although Scott had received a surgery to fuse the 3rd and 4th lumbar vertebrae many years ago, he was unaware of any problems until the fused bones began pressing on his spinal nerves and causing pain. When Dr. McLaughlin told Scott that a second spinal fusion procedure was necessary, he responded with a question:

"I asked him, 'When will I be able to fight again?'," said Scott, 47. "He said I shouldn't, but as far as I was concerned, there wasn't any question that I would, it was just a matter of when."

The primary goal of the five-hour surgery, performed by Dr. McLaughlin through a small incision in the low back, was to realign and fuse the 4th and 5th lumbar vertebrae to eliminate abnormal motion in the spine. The results would expectantly remove pressure from the spinal nerves in order to relieve pain. Spinal disks, which consist of cartilage, were removed from between the vertebrae; bone tissue taken from Scott's hip was inserted to replace them. The implanted bone tissue, in conjunction with the body's natural bone-growth processes, created the fusion of the vertebrae.

Dr. McLaughlin inserted titanium rods and screws at the site of the surgery. The screws, inserted in three consecutive vertebrae, served as anchor points for the connecting rods. The rods and screws kept the lumbar region stable and prevented motion that hinders the proper fusion of the vertebrae.

Lateral view CAT/Myelogram of previous spinal fusion surgery at L3-L4. The arrow indicates spondylolysthesis at L4-L5.



Lateral view CAT/Myelogram of Dr. McLaughlin's fusion extension surgery to fuse L4-L5.

After the surgery, Dr. McLaughin explained to Scott that it would take three months for the vertebrae to fuse properly and wearing a back brace the entire time was necessary for the best outcome.

Scott followed his instructions to the letter and the procedure was successful. However, Dr. McLaughlin was skeptical about his patient's chances of returning to his sport.

"After the healing was completed, the area where we performed the surgery was solid as cement, and it still

Bill Scott during a professional Mixed Martial Arts fight. *Photo courtesy of Keith D. Mills.*

is," says Dr. McLaughlin. "I had some concerns about the levels of the spine above and below the surgery. In 2008 we inserted more screws to give more stability to the lower vertebra, but all these years later, everything is holding up very well."

At the end of the recovery period, Dr. McLaughlin reviewed an X-ray of Scott's spine and gave him the OK to start exercising again. But he didn't approve a return to fighting. "Dr. McLaughlin is a former champion wrestler himself," says Scott, "and as much as I respect his medical opinion, I had other plans."

Scott, a 1st Degree Brazilian Jiu-Jitsu Black Belt and a former All-American wrestler at Middlesex College, didn't follow a formal rehab program. After spinal fusion, patients are advised to stay active with brief, gentle exercise and stretching which promotes blood flow and healing. But when Scott returned to his martial arts training center (Bill Scott BJJ- Brazilian Jiu-Jitsu Shore Academy) in his hometown of Point Pleasant, NJ, he picked up right where he left off.

"For my rehab, I just returned to my usual training for Brazilian Jiu-Jitsu and instructing martial arts students. I wanted to get right back in the swing of things, and I went at full speed right away. I believe that a person's mind-set is extremely important in this type of situation. I've seen people who have had this type of injury become depressed and feel sorry for themselves, and I could have easily gone that route. But I didn't allow myself to think that way. I worked hard, and I was determined not to let the situation damage my life. I wanted to get back to being active and doing what I love to do."

These days, in addition to a rigorous schedule of teaching martial arts, including self-defense training for local and state police officers in New Jersey, Scott competes in and has won several mixed martial arts bouts. He is currently training for the 2012 Pan Jiu-Jitsu No Gi Championship which takes place this fall.

"I'm a fighter; it's what I do for a living, and it's also my attitude," says Scott. "When you participate in my sport, you're going to have injuries now and then. When one happens, I get fixed up, move on, and keep fighting."

Working with the unstoppable Scott taught Dr. McLaughlin a great lesson: "I learned that you have to listen to your patient very closely, not only to understand how they feel physically, but also where they are emotionally. When I did Bill's surgery and told him he really shouldn't fight anymore, that was like telling him not to breathe. Instructing and competing in martial arts are in his DNA, and it was absolutely impossible for him to give it up. When working with an elite athlete like Bill, a spine surgeon's job is to provide the stability he needs to compete again the best he can. Scott returned to fighting and won matches, which is remarkable considering the major surgery he had. His energy, enthusiasm, and positive attitude helped him pull through and inspire me."

Bill Scott, Spinal Champion!

Mark R. McLaughlin, MD, FACS

Dr. McLaughlin practices neurological surgery with a focus on spine disorders and specific cranial conditions at Princeton Brain and Spine Care in Princeton, NJ. He served as the President of the Young Neurosurgeons' Committee, a national section of the American Association of Neurological Surgeons. He is the Scientific Program Chairman of the AANS/CNS Joint Spine Section, and also an editor of Spineuniverse.com, a website dedicated to patient and physician education of spinal disorders. He has published more than 65 articles on neurosurgery and spine surgery, and has authored two textbooks about spine surgery. He has been an invited speaker, presenter, and course director at numerous scientific meetings, and teaches complex spine surgery nationally and internationally. Dr. McLaughlin was recently elected Member-at-Large of the Joint Spine Section of the Congress of Neurosurgeons.

Spine Tale
Emily Ferguson, Division I Collegiate Swimmer

Emily Ferguson, Thao Nguyen, PA-C, MPAS, and Thomas C. Schuler, MD, FACS

As a collegiate swimmer at Virginia Tech, my physical health was crucial to my success in the pool as well as in the classroom. During the fall of my junior year, I began noticing low back pain as a result of prolonged sitting through classes. I had to constantly readjust my posture while sitting because of the discomfort I was experiencing. As my back pain became increasingly unbearable, my performance at practices was also affected. I had a demanding weekly training schedule of nine swimming practices, two dryland workouts, and three lifting sessions; after two months of pain, I knew I had to get my back evaluated.

The first step I took in November of 2011 was to visit the doctors within our athletic department. My team physician ordered some x-rays and sent me to a spine specialist in Blacksburg, VA. I had an MRI of my lumbar spine completed just before winter break. The results came after I had already traveled back home for Christmas; I had two herniated discs. The doctors suggested I head back to Blacksburg to receive an injection before our swimming team's annual training trip. December is a crucial training period for swimmers and I hoped to receive some relief from the pain to participate in the team trip. However, the injections were ineffective, and I was unable to work out during the entire trip.

After I got back home, there was about a week before spring semester classes began. In the meantime, my neighborhood friend had referred my parents to Dr. Schuler. I immediately made an appointment at the Virginia Spine Institute before heading back to school. Once I stepped into VSI I knew I was going to be taken care of and in good hands.

"Emily came into our office as a 20 year-old collegiate swimmer from Virginia Tech who had been suffering from back pain for months. Especially for our young athletes, we like to approach spine care with non-operative measures first and foremost," noted Thao Nguyen, PA-C at the Virginia Spine Institute after her first visit with Emily in January, 2012. "Our primary objective with Emily was to treat her symptoms so she could return to competitive swimming. It is standard to have athletes suspend participation in their sports to reduce symptoms; so unfortunately, Emily was advised to discontinue swimming and focus on physical therapy and the foundation of spinal health– core stabilization, strengthening, and aerobic conditioning. Dr. Schuler and I discussed with Emily and her family that we always exhaust all non-operative treatment before surgery is considered. After rounds of physical therapy and medications, Emily was not having the symptom relief we all hoped for; we added injections next."

Figure 1. The pre-op MRI with two disc herniations.

After these interventions, I returned to school, but I was unable to redshirt, which meant I could not suspend my status as a collegiate athlete in order to elongate my competitive eligibility. I adjusted my goals to be able to compete se-

Figure 2. An x-ray after the anterior lumbar fusion surgery at L4-L5.

nior year. I came home in May and was frustrated that I was still in pain, so I scheduled another appointment with Dr. Schuler.

"Emily did not respond to the therapy and injections, so she underwent a procedure called a discography" Dr. Schuler recalls. "This test helps us receive information on whether her discs are the cause of her pain and helps us determine if she is a candidate for surgery. Our decision making reviewed Emily's ongoing history, a physical examination, diagnostic imaging, her response to previous treatments, and the results of the discography. We recommended an anterior lumbar fusion surgery, which is a minimally invasive technique that would optimize her recovery with the goal to return her to swimming."

After discussing surgery with my parents and doing some personal research on the surgical procedure, I decided to give it a go.

"Emily did extremely well after surgery and had a great support group– her family. She started physical therapy the day after surgery by walking the halls of the hospital, and she went home the next day after that," Thao commented.

After surgery I was able to swim competitively for all of my senior year at Virginia Tech. Prolonged sitting no longer caused pain.

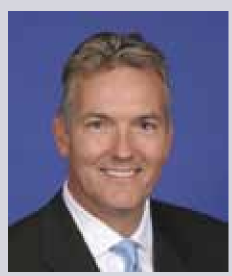
It has been a little more than one year after surgery and I am able to run, bike, and do any other activities pain-free. My advice to anyone suffering from back or neck pain is to seek treatment immediately. Your neck and back health are crucial for your entire lifetime.

VSI is uniquely exceptional because of its comprehensive care. The clinic, the pain management center, and the Virginia Therapy and Fitness Center are all under one roof. Overall, I had an amazing experience with VSI! I was so impressed with the quality of service and care I received as a patient, that I applied for a job as a medical assistant with VSI. Today, I am a VSI employee and am able to help people who are going through the same type of pain I went through.

Dr. Schuler and Thao were inspired by Emily's story. "Emily went on to compete in the swimming pre-Olympic trials after her lumbar fusion surgery, making her a primary example of a true spinal champion! We are proud to share her exceptional story of success through determination and devotion to her passion of swimming."

Thao Nguyen, PA-C, M.P.A.S.

Thao is a highly skilled Physician Assistant at The Virginia Spine Institute (VSI). She received her Master of Physician Assistant Studies degree from Shenandoah University, VA and a Bachelor of Science in the College of Humanities and Science from Virginia Commonwealth University. She completed her residency in medical and surgical management of spinal disorders and is licensed by the Virginia Board of Medicine.



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

Dr. Schuler is a distinguished spine surgeon and founder and CEO of the Virginia Spine Institute (VSI). His knowledge, drive, and innovative techniques have revolutionized spinal healthcare in the Washington D.C. metropolitan area. Dr. Schuler is double board certified in spine surgery and orthopaedic surgery. He is nationally recognized as a leader in the treatment of cervical and lumbar spine disorders and was named among the **100 Best Spine Surgeons and Specialists in America**. Additionally, *U.S.News & World Report* has recently named him among the top 1% of physicians in his specialty nationwide. As the spine consultant to the Washington Redskins since 1993, he returns elite athletes to the playing field safely and quickly using non-operative and operative techniques. Dr. Schuler also serves as the President of the Spinal Research Foundation (SRF).

Ask the Expert

James P. Burke, MD, PhD

What are the benefits of an active lifestyle for the spine?

An active lifestyle is of great importance to the health of the spine. The following are specific benefits: 1) *Postural muscle strength*. The spine is supported by muscles, tendons, and ligaments. Exercise that strengthens the postural muscles contributes to the maintenance of good spine posture. 2) *Bone strength*. The spine is vulnerable to osteoporosis and vertebral fractures. Weight-bearing exercise helps maintain or increase bone mineral density and prevent osteoporosis. 3) *Body weight*. Excess body weight, particularly increased abdominal girth, places extra stress on the spine. As everyone knows, exercise helps maintain a healthy body weight. 4) *Health of intervertebral discs*. The intervertebral discs do not have their own blood supply; they receive nutrients through diffusion from the vertebral bodies. Movement will help "flush" the discs and increase diffusion.

What is the best activity/sport for the spine?

Activity in general is beneficial to the spine. Some particular exercises are designed to strengthen the muscles that support the spine. For instance, plank exercises (exercises based on a push-up position) strengthen your core muscles, including the transverse abdominis, rectus abdominis, and the erector spinae, all of which support your lumbar spine. Stability and balancing exercises, such as balancing on one foot or on unsteady surfaces like a BOSU ball, balance board, or gymnastics mat, also develop proprioception, core stability, and strength.

Can some activities be hurtful to the spine?

People who suffer from back pain or degenerative disc disease may need to avoid *high impact* activities, such as running. The pounding created every time a runner's feet hit the ground may cause repeated trauma to the disc space. Aquatic exercises are a great alternative to reduce stress on the spine while still benefiting from physical activity. Axial bearing exercise is another type of exercise that puts the spine at risk. *Axial bearing* exercises are movements where the weight compresses your spinal column from above. Military presses and squats, in which the weight is held over head or supported by the shoulders, are examples of axial bearing exercises. Performing those exercises with the spine incorrectly aligned may cause injury. Finally, *start-and-stop* sports with rapid changes in direction are very demanding on the spine. Such sports are basketball, football, and racquet sports.

If I have spine fusion, will I be able to participate in strenuous sports/activities?

After spinal fusion surgery, it is critical to follow a rehabilitation program centered on stretching, strengthening, and aerobic conditioning. At the early stage, exercise helps fuse the vertebrae, but may hurt the fusion if it is too strenuous. After fusion is achieved, you will be able to carefully resume your habitual activities. However, the more vigorous the activities, the longer it may take before you can resume them.

James P. Burke, M.D., Ph.D.

Dr. Burke is a neurosurgeon with Allegheny Brain and Spine Surgeons in Altoona, Pennsylvania. He is certified by the American Board of Neurological Surgeons. His professional associations include American Academy of Neurological Surgeons, Congress of Neurological Surgeons, North American Spine Society, and the Alpha Omega Alpha National Honor Medical Society. Dr. Burke's specializations include brain tumors, concussions, trauma, degenerative spine, spinal stenosis, spinal tumors, and other spinal deformities.

Biomechanics of The Spine

Richard A. Banton, DPT, OCS, CMPT, ATC

Movement in the human body occurs at joint surfaces; movement occurs with bones; movement of muscles moves the bones; coordinated movements of limbs create strong purposeful movements in a pain-free person. Notice that the list begins with movement at a joint. It is at this anatomical level that the central nervous system interprets and coordinates a neuro-musculoskeletal response into a functional movement. Therefore, logic would tell us that to improve function, one must ensure that articular motion is functionally optimal.

"If there is a single word that encapsulates all that physical therapy stands for, it is movement." [1]

In physical therapy school, it is tradition to study anatomy and biomechanics in a regional manner. For example, the lumbar spine is studied separate from the sacrum which is, in turn, studied separate from the hip. While it is important to understand regionally specific anatomy, successful outcomes in physical therapy are only achieved by understanding how the regions of the body work together. This article summarizes a few biomechanical principles of the spine as viewed from the perspective of manual physical therapists.

Movements and Motions of the Spine

Rotational movements are movements of the vertebra around an axis. All rotations produce a change in the orientation of the vertebra.[2]

Translational movements are movements of the whole vertebra by the same amount in a given direction. There is no change in the orientation of the vertebra. Translation is the "gliding" of the vertebra; it rarely occurs by itself, but often accompanies other movements.

The movements of each spinal segment are limited by anatomical structures such as ligaments, intervertebral discs, and facets. Specifically, anatomical structures

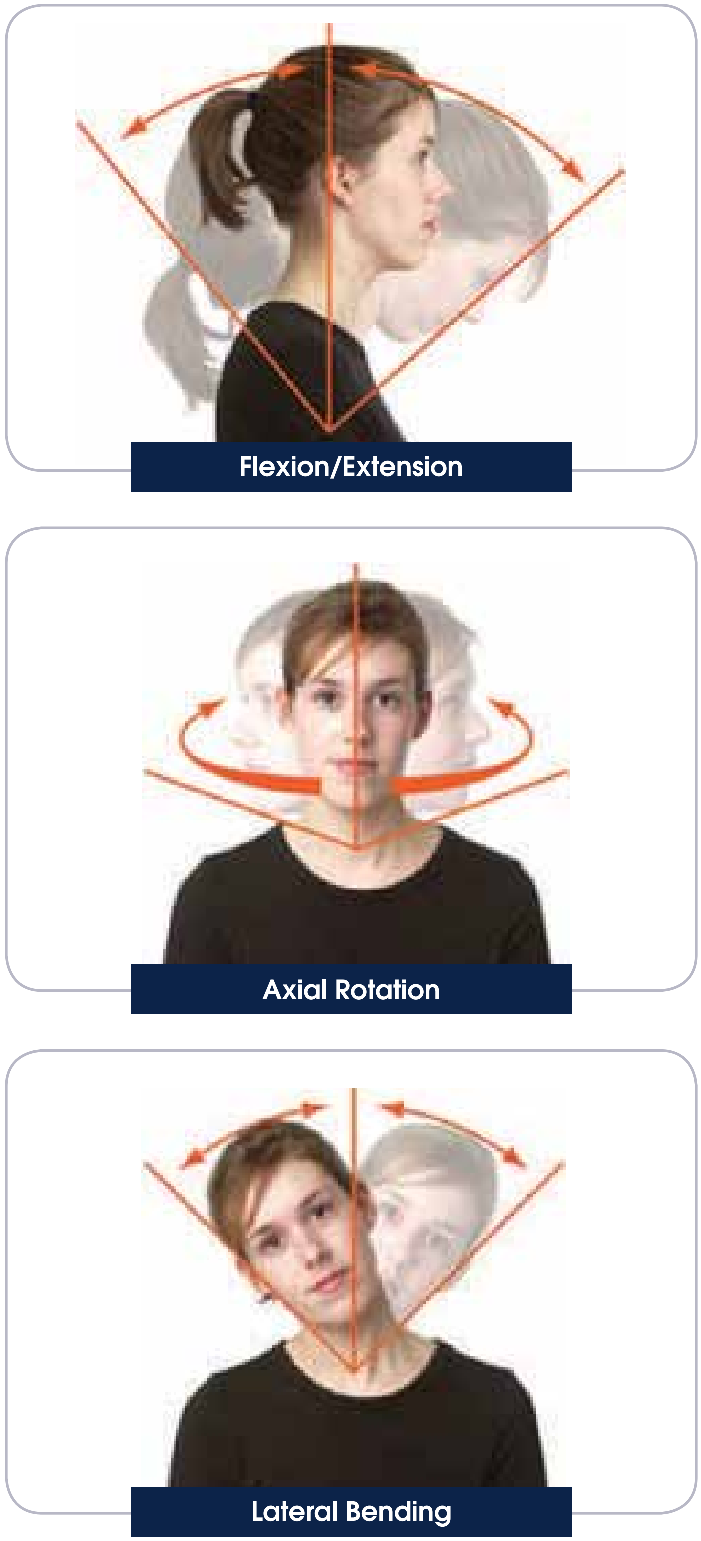


Figure 1. Flexion/Extension (bending), axial rotation(torsion), and lateral bending (side bending). *Picture courtesy of Medtronic, Inc.*

R. Banton/The Journal of the Spinal Research Foundation 7(2012) 12–20

cause the *coupling of motions* of the spine, that is, movements occur simultaneously. Flexion, extension, translation, axial rotation, and lateral bending are physiologically coupled. The exact pattern of coupling depends on the regional variations of anatomical structures.

In the cervical and upper thoracic spine, side bending is coupled with axial rotation in the same direction. In the lumbar spine, lateral bending is coupled with axial rotation in the opposite direction. In the middle and lower thoracic spine, the coupling pattern is inconsistent.[1] However, the pattern of coupling will change depending on which movement is initiated first. In the lumbar spine, lateral bending will be coupled with axial rotation in the same direction if lateral bending is the first movement. Conversely, if axial rotation is the first movement, it will be coupled with lateral bending in the opposite direction. The terms *latexion* and *rotexion* have been applied to these coupling patterns (Figure 3 and 4).

There has been relatively more interest in latexion and rotexion recently, largely because abnormal coupling patterns have been linked to instabilities. Changes in coupling patterns have also been observed adjacent to spinal fusions. Finally, these particular coupling patterns may have relevance in the basic biomechanics of the different regions of the spine and understanding them may lead to new discoveries in the evaluation and treatment of scoliosis.

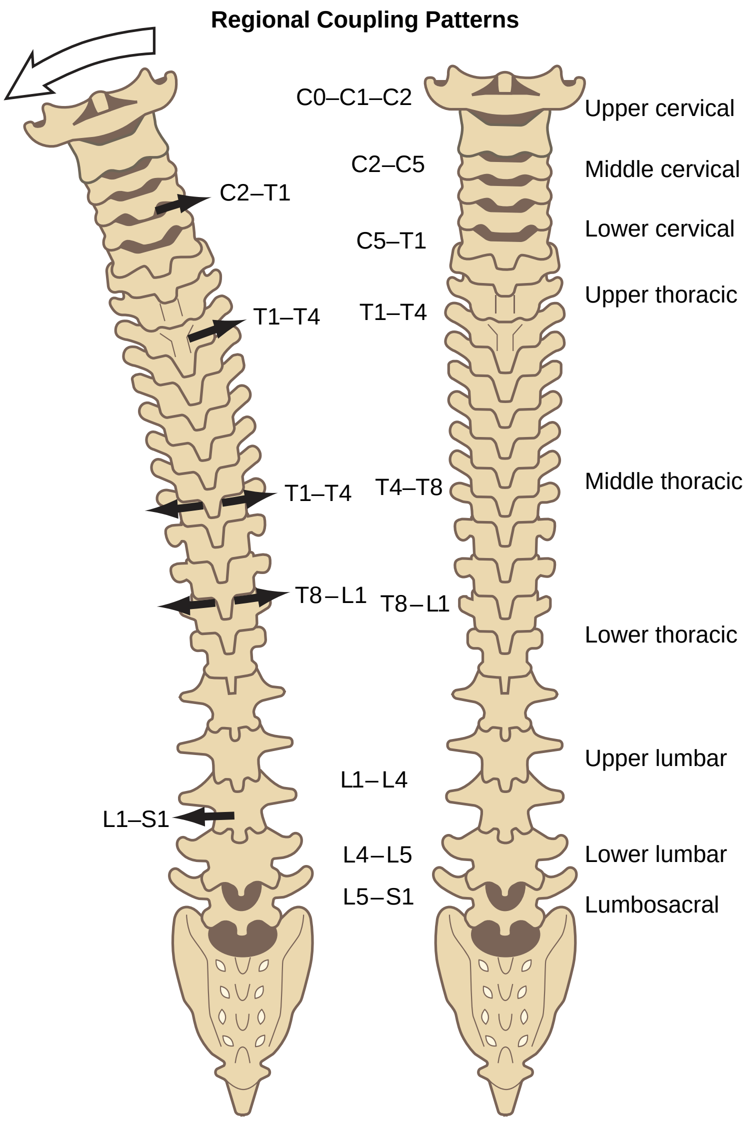


Figure 2. Regional coupling patterns of lateral bending and axial rotation. *Image modified and adapted from White, A.A. and M.M. Panjabi (1990). Clinical Biomechanics of the Spine. Philadelphia, PA, Lippincott.*

The Cervical Spine

Because of kinematic and clinical uniqueness, the cervical spine is divided up into the occipital-atlanto-axial complex (C0-C1-C2), the middle cervical spine (C2-C5), and the lower cervical spine (C5-T1).[3]

The occipital atlanto-axial region is so unique and complex that controversy exists regarding the exact biomechanics of the region. About 60% of the entire cervical spine axial rotation occurs from C0-C2 and about 40% occurs from below.[1] The uniqueness of this region is primarily related to the articular surfaces of the first two cervical vertebrae. They are unlike any other vertebrae in the human body because they are both convex articulating surfaces. This unique geometric shape facilitates significant motion of the human head.[1] While other vertebral segments acquire their stability from vertebral discs, the C1-C2 complex achieves stability through dense ligamentous structures (i.e., alar ligaments and transverse ligaments.)

The Occipital-Atlanto-Axial Complex (Upper Cervical Spine)

Most controversy regarding movement of the spine exists in the upper cervical spine. The unique convex on convex orientation of the C1-C2 complex

Figure 3. Rotexion: rotation to the right coupled with lateral bending to the right. *Image courtesy of the Virginia Therapy and Fitness Center.*

Figure 4. Latexion: lateral bending to the right coupled with rotation to the left. *Image courtesy of the Virginia Therapy and Fitness Center.*

has created debate among researchers for decades. The accepted coupling pattern of this region is that rotation and sidebend of the head occurs in opposite directions. For example, when the head rotates right, C1 sidebends left. This movement pattern is made possible because of the shape of the articular condyles of C1 and C2. They are both convex in nature; however, the incline of the posterior condyle of C2 is twice as steep as the anterior surface of the condyle. Therefore, when the head rotates to the right, the right C1 condyle has farther to glide down the posterior surface of C2 than the left C1 condyle has to glide on the anterior surface of the left C2. One can easily understand how controversy exists when you consider the complex anatomy of each segment. Figure 5 demonstrates the anatomical uniqueness of the C1-C2 complex.

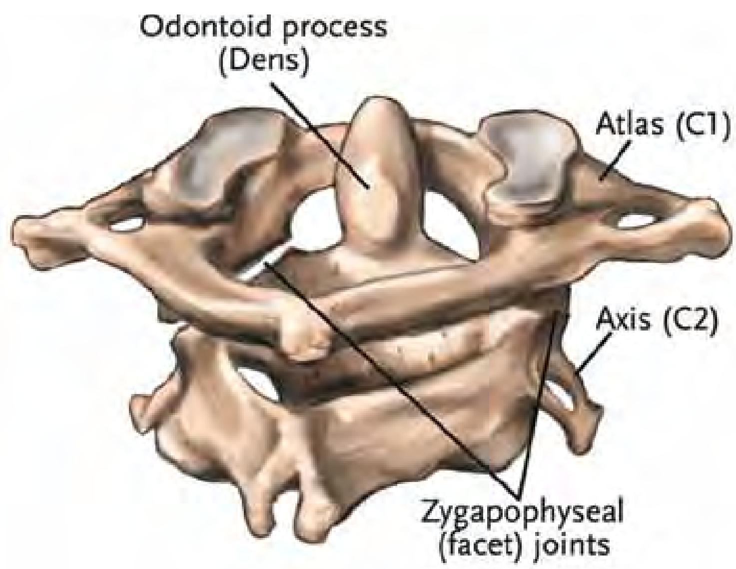


Figure 5. Posterosuperior view of the upper cervical vertebrae. *Image courtesy of Medtronic, Inc.*

The importance of coupling in the human spine is that it allows for increased mobility without sacrificing stability. When treating movement pattern restrictions of the spine, it is critical for the manual therapist to understand the unique coupling patterns of each region so that maximum mobility and stability can be achieved.

The C5-C6 interspace is generally considered to have the largest range of motion in the cervical spine,

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hence the potential reason for the high incidence of cervical spondylosis (arthritis) at this segment.[1] As discussed earlier, the cervical spine tries to achieve maximum mobility without sacrificing stability; the uncinate processes are the structures conferring stability with mobility in the cervical spine (Figure 6). The uncinate processes become fully developed at age 18 but do not begin to develop until ages 6 to 9 years old. Considering that they help guide flexion and extension of the neck, limit lateral bending, and prevent posterior translation, one has to question the reasoning behind allowing adolescents to play tackle football or any collision sport before their necks are fully developed. Injury to the middle cervical region during adolescent years could lead to lifelong complications.[1]

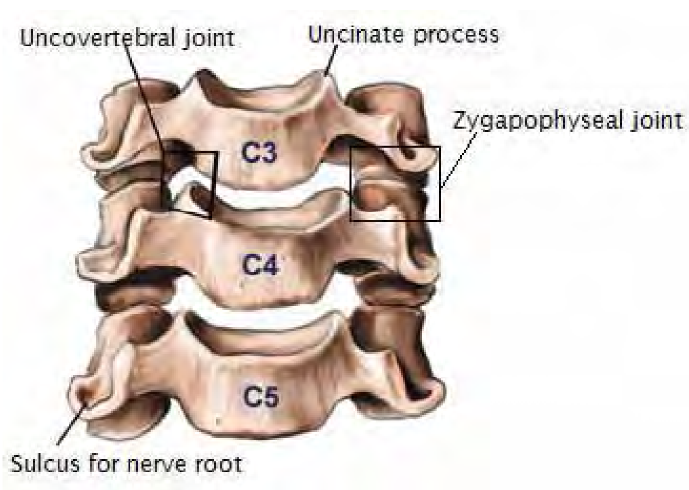

Figure 6. The vertebral bodies of the subaxial cervical spine have upward projections on the lateral margins called uncinate processes. These processes articulate with the level above to form the uncovertebral joints. The zygapophyseal joints are also known as the facet joints that are comprised of the superior articular process of one vertebral body and the inferior articular process of the adjacent vertebra. *Image courtesy of Medtronic.*

Movement of the cervical spine involves a combination of uncovertebral and zygapophyseal motion (Figure 6). During neck flexion, the zygapophyseal and uncovertebral joints glide in a combined superior, lateral, and anterior direction. Reciprocally, during neck extension, the joints glide in a combined inferior, medial, and posterior direction.

The Thoracic Spine

While hypermobility of the cervical spine has been associated with whiplash injuries, hypomoblity of the thoracic spine has been associated with abnormal mechanical influences on both the cervical and lumbar spine.[1]

The unique feature of the thoracic spine is the coordinated movement of the ribcage with the vertebral segments. The addition of the ribcage increases the required compressive load necessary to cause buckling of the spine.[4] There is considerable motion of the spine and sternum independent of one another, allowing for motion of the spine without movement of the ribcage. During flexion of a thoracic spinal segment, there is anterior translation. This anterior translation facilitates anterior rotation of the adjacent rib. A similar motion occurs in the middle thoracic spine (T4-T7), but because of the anatomical shape of the transverse processes and the heads of the ribs, there is anterior roll of the ribs associated with a superior glide.[2] These minor variations in biomechanics of the thoracic spine and ribcage are critical for manual therapists to understand and analyze if their goals are to be successful in treating and restoring mobility to the thoracic spine and ribs.

The pattern of coupling in the thoracic spine is similar to the cervical spine. Lateral bending is coupled with axial rotation in the opposite direction when lateral bending occurs as the first movement (latexion). Likewise, thoracic rotation is coupled with lateral sidebending in the same direction when rotation occurs as the first movement (rotexion). In the thoracic spine, the ribs are oriented so that they approximate when the spine sidebends. However, as further sidebending occurs, the ipsilateral ribs glides anteriorly and inferiorly along the plane of the costotransverse joint, while the contralateral rib moves superiorly and posteriorly creating rotation in the opposite direction of the sidebend (Figure 7). Conversely, rotation in the thoracic spine is accompanied by sidebending in the same direction, not because of facet orientation, but because of the ligamentous attachment of the ribs to the thoracic vertebrae (Figure 8).

Understanding the biomechanics of the thoracic spine and ribcage is important when addressing breathing and respiratory issues, chronic pain, facilitated

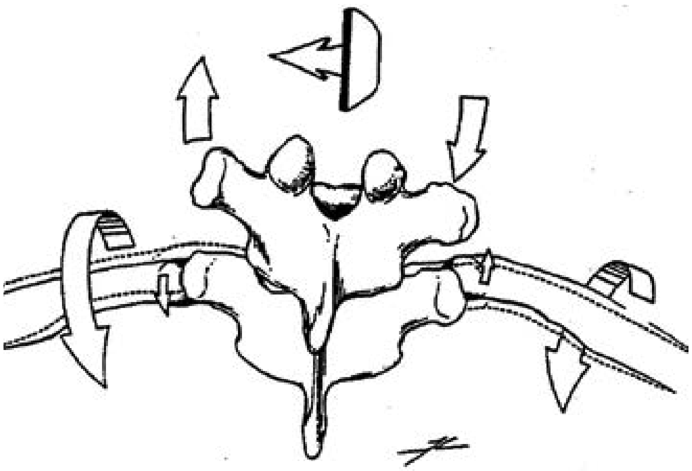

Figure 7. Bilateral coastal rotation in opposing directions drives the superior vertebra into left rotation.[4] *Image courtesy of Lee, D. (1993). "Biomechanics of the thorax: A clinical model of in vivo function." Journal of Manual and Manipulate Therapy 1(1): 13-21*

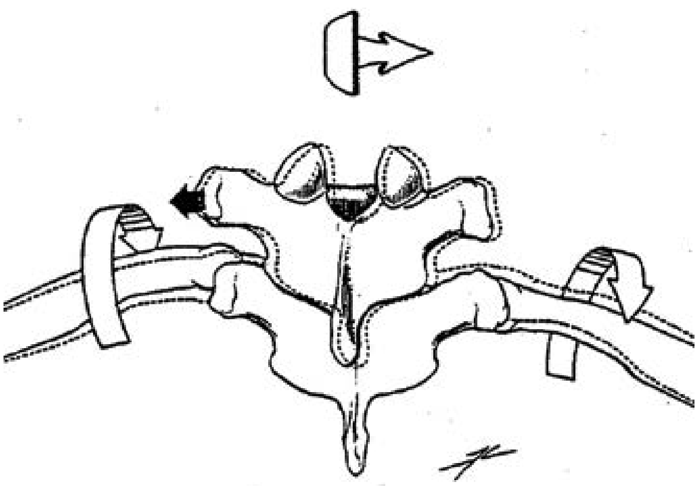

Figure 8. As the superior thoracic vertebra rotates to the right, it translates to the left. The right rib rotates posteriorly and the left rib rotates anteriorly as a consequence of the vertebral rotation.[4] *Image courtesy of Lee, D. (1993). "Biomechanics of the thorax: A clinical model of in vivo function." Journal of Manual and Manipulate Therapy 1(1): 13-21.*

segments (hypersensitive spine segments), and spinal instability. A restriction (or other dysfunction) in the spine is associated with illness of the organ(s) related to the vertebral segment (viscerosomatic reflex). Previous studies have shown that an increase in somatic dysfunction in the thoracic spine may be linked to viscerosomatic reflex phenomena. For example, Beal demonstrated that somatic dysfunction of T1-T5 was linked to cardiovascular disease.[5] Similarly, T6 is associated with the stomach.

During respiration, the ribs move upwards, sideways ('bucket handle") and forward ("pump handle").[3] This is important to understand when treating rib hypomobilities because the therapist must not only improve the ability of the rib to elevate and depress, but must also make sure the ribs can move medially and laterally.

The Lumbar Spine

The facet orientation of the lumbar spine facilitates more flexion and extension than rotation (Figure 9).

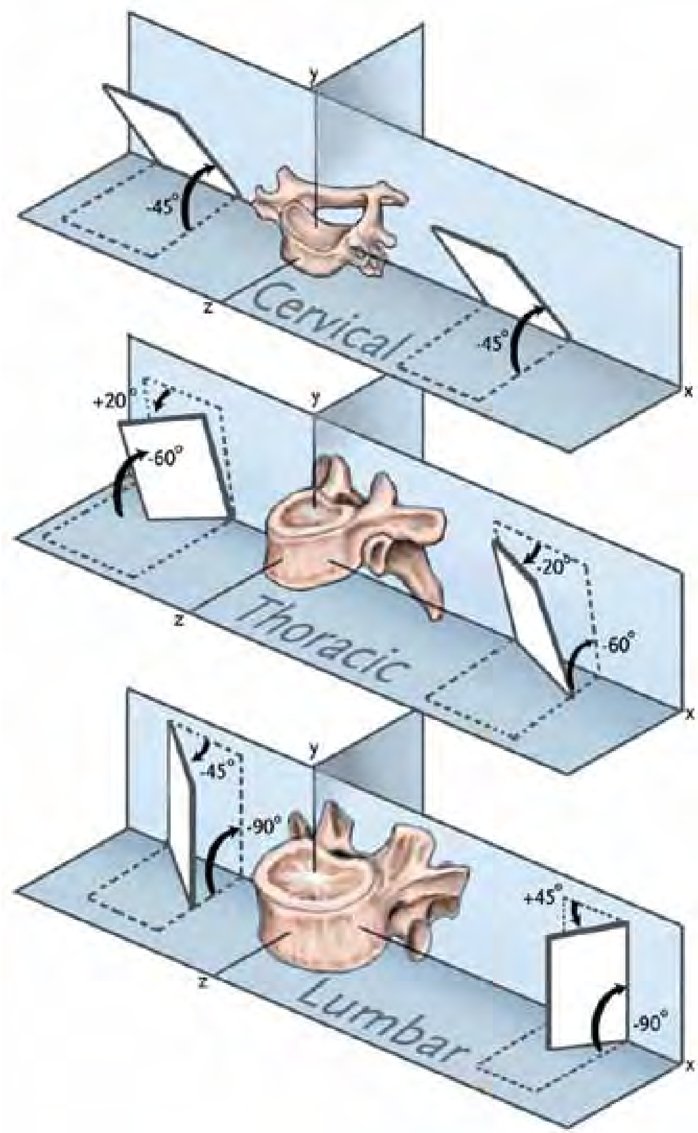

Figure 9. Facet joint orientation in the cervical, thoracic, and lumbar spine. *Image courtesy of Medtronic, Inc.*

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In the lumbar spine, flexion and extension motions increase in range from the top to the bottom with exception of the lumbosacral joint (L5-S1). The lumbosacral joint offers more flexion/extension motion than any other lumbar segments.[1] With regards to lateral bending in the lumbar spine, each lumbar segment presents with approximately the same amount of movement. Likewise, axial rotation in the lumbar spine is very limited and nearly equal among each segment.

The most important aspect of lumbar biomechanics is the translation that occurs with flexion and extension.[1] The measure of translation in the lumbar spine is the determining factor in the diagnosis of spinal instability. Although much research is required in this region to determine more accurate measures of true spinal instability, current literature suggests that 2 mm of translation is normal for the lumbar spine.[1] Translation beyond 4 mm should be evaluated for clinical instability.

The unique coupling patterns associated with the lumbar spine, along with minimal mobility in the transverse plane, may directly or indirectly contribute to the higher incidence of clinical instability at the L4-L5 segment. Panjabi and colleagues have confirmed previous lumbar kinematic investigations that showed the upper lumbar segments L1-L2, L2-L3, and L3-L4 share a coupling pattern different from that of L4-L5 and L5-S1.[1] In the upper lumbar spine, sidebend and rotation occurs in opposite directions, while in the lower lumbar segments, sidebend and rotation occur in the same direction. In addition, Panjabi and associates discovered an interesting effect of posture on coupling patterns. In extension, the coupling motion was a flexion movement; in flexion, the coupling movement was an extension movement.[1] In other words, the lumbar spine always shows a tendency to straighten from either flexion or extension. The clinical significance of this finding is not yet known, but it does provide reason to further investigate the biomechanics and kinetics of the lumbar spine.

The Sacroiliac Joint

Although mobility of the sacroiliac joint has been debated since the early 17th century, it is now accepted among all medical professionals that there is movement available in this joint.[6] Motion at the sacroiliac joint occurs during movement of the trunk and lower extremities. Flexion of the sacrum is called *nutation* while extension of the sacrum is termed *counternutation*. When the sacrum nutates, the sacral promontory moves anterior into the pelvis. When the sacrum counternutates, the sacral promontory moves backward (Figure 10).

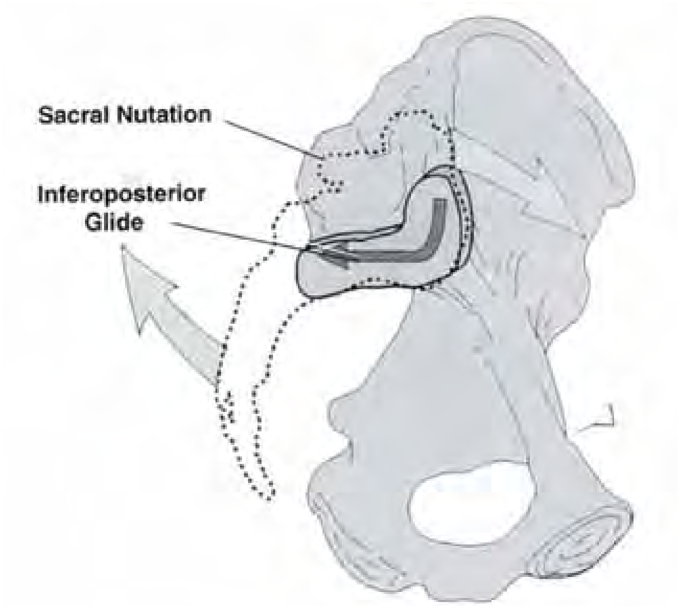

Figure 10a. When the sacrum nutates, its articular surface glides inferoposteriorly relative to the innominate.

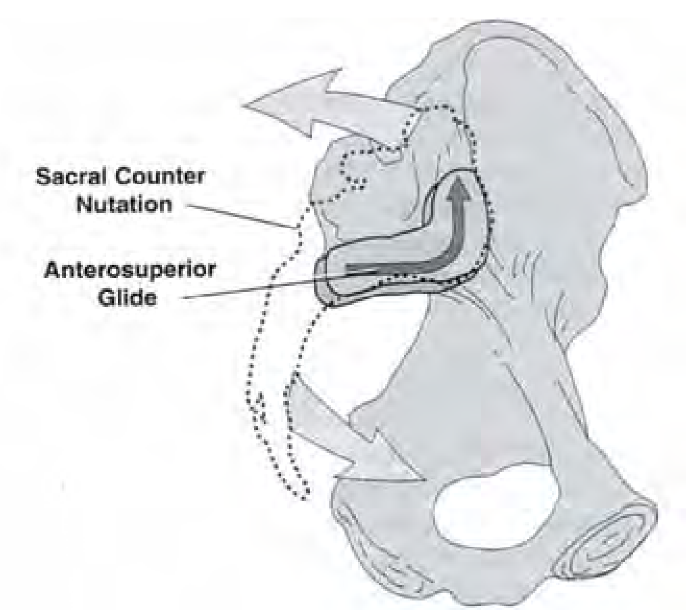

Figure 10b. When the sacrum counternutates, its articular surface glides anterosuperiorly relative to the innominate. *Images courtesy of Lee, D. (1999). The Pelvic Girdle. Edinburgh, UK, Churchill Livingstone.*

The sacroiliac joint is shaped like an "L" that has fallen backwards on its long arm. When the sacrum nutates , the sacrum glides inferiorly down the short arm of the "L" and posteriorly down the long arm of the "L" resulting in a relative anterior rotation of the pelvis. Conversely, counternutation involves the sacrum gliding anteriorly along the long arm and superiorly along the short arm.

During leg flexion, it is expected that the sacrum will nutate on the side of the flexed leg. Conversely, during leg extension, the sacrum counternutates on the side of the extended leg. Physical therapists often ask patients to flex and extend their legs during evaluation so that they can assess the mobility of the sacroiliac joint. They assess the osteokinematic of the bone or, in other words, how the bone moves in relation to another bone. When the sacrum nutates relative to the pelvis, a translation motion, or arthrokinematic occurs. Arthrokinematic refers to motion within the joint regardless of the motion of the bones.

When these movements do not occur naturally, the sacroiliac joint is diagnosed as restricted or jammed. Conversely, if these translatory motions are deemed to be excessive in nature, the sacroiliac joint is diagnosed as hypermobile. Successful results in physical therapy are achieved if the therapist and physician can concur on the state of the sacroiliac joint and appropriate treatment. Locked or jammed sacroiliac joints respond well to appropriate manipulation and mobilization, while hypermobile sacroiliac joints respond well to prolotherapy, belting, and stabilization.[6]

Biomechanics and Sitting

Biomechanics during sitting is of particular interest to ergonomics and the millions of people who perform their occupation while sitting. Research currently suggests that lumbar support has the greatest influence on lumbar lordosis and the inclination of the backrest had the most influence in reducing pressure within the lumbar disc.[3] As the inclination of the lumbar support increases, more weight is distributed on the backrest and less muscle activation is required from the erector spinae muscles of the spine (Figure 11). When the erector spinae muscles are resting there is considerably less load placed upon the vertebral discs as opposed to when they are contracted.

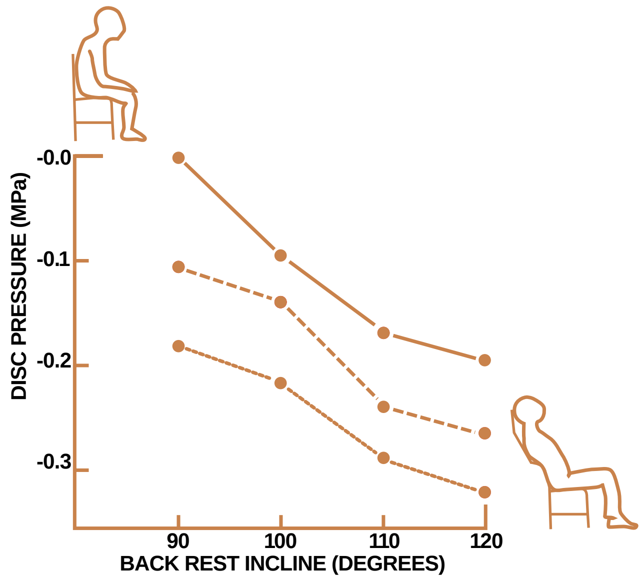

Figure 11. Decrease in the intradiscal pressure with greater backrest. *Image modified and adapted from White, A.A. and M.M. Panjabi (1990). Clinical Biomechanics of the Spine. Philadelphia, PA, Lippincott.*

In addition to using a lumbar support, it is also recommend that using an arm rest to support the trunk can further decrease the amount of load placed upon the vertebral discs during sitting.[3]

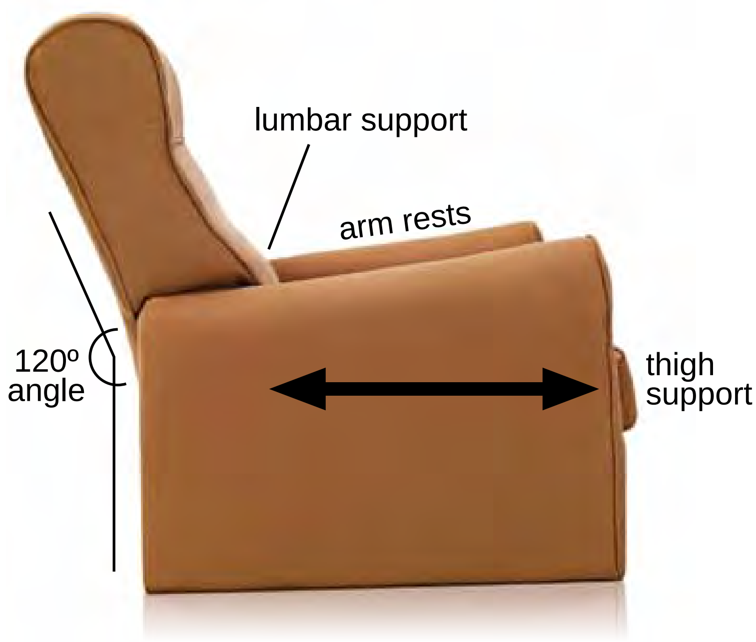

Figure 12. Example of good seat design. *Image modified and adapted from White, A.A. and M.M. Panjabi (1990). Clinical Biomechanics of the Spine. Philadelphia, PA, Lippincott.*

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Biomechanics and Lifting

Intradiscal pressures vary with position and activities[7] (Figure 13).

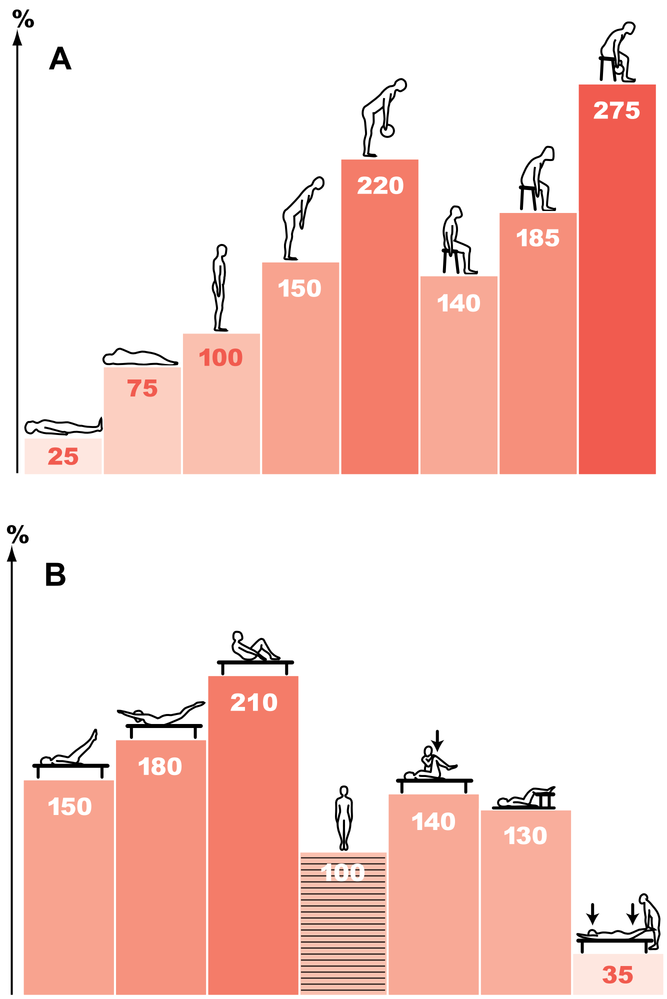

Figure 13. (A&B) Comparison of disc pressures in different positions and during various activities. *Image modified and adapted from White, A.A. and M.M. Panjabi (1990). Clinical Biomechanics of the Spine. Philadelphia, PA, Lippincott.*

It has been demonstrated that intradiscal pressures increase when heavy weights are lifted. The heavier the weight, the larger the increase in intradiscal pressures.[3] Proper lifting techniques reduce the disc load (Figure 14).

Interestingly, a protruding abdomen acts as a weight carried further away from the body (Figure 15).

To avoid injury to a vertebral disc during lifting, the intradiscal pressure must be countered. Normal biomechanics and normal discs are necessary to achieve counter pressure. In a normal disc, the annular

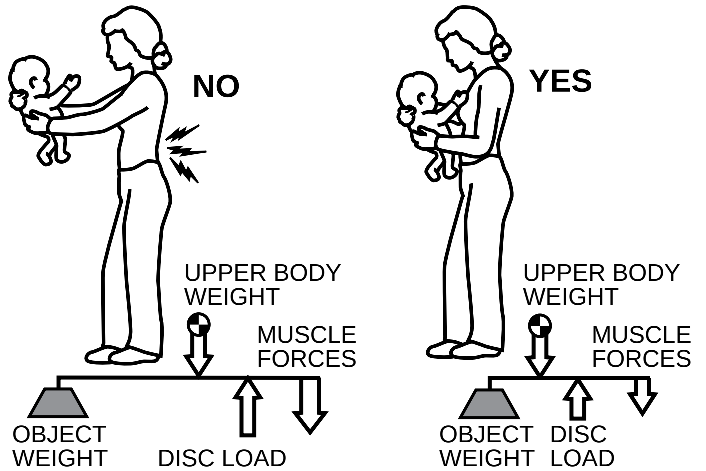

Figure 14. Disc pressure is a combined result of the object weight, the upper body weight, the back muscles forces, and their respective lever arms to the disc centers. On the left, the object is farther away from the disc centers and creates greater muscle forces and disc pressures than on the right. *Image modified and adapted from White, A.A. and M.M. Panjabi (1990). Clinical Biomechanics of the Spine. Philadelphia, PA, Lippincott.*

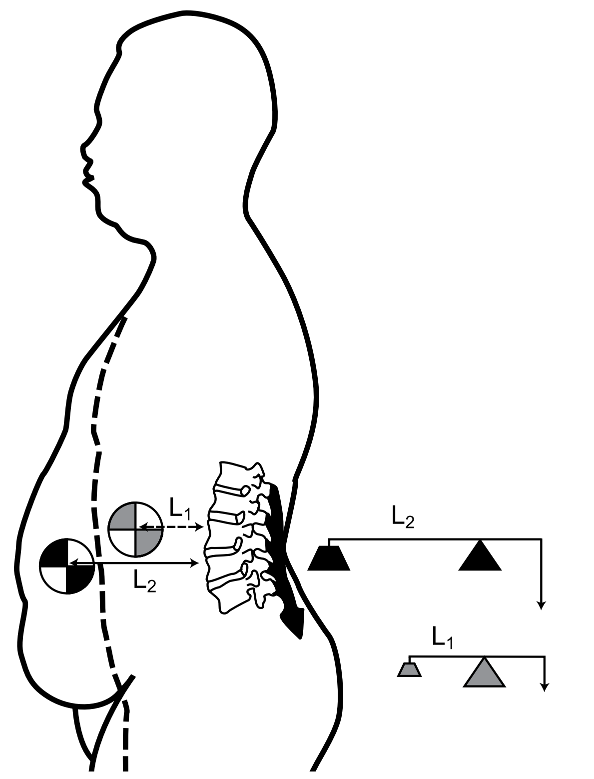

Figure 15. The weight here is the adipose tissue rather than an external object. The further the abdomen protrudes, the longer the lever arm to the disc centers and the greater the disc pressures. *Image modified and adapted from White, A.A. and M.M. Panjabi (1990). Clinical Biomechanics of the Spine. Philadelphia, PA, Lippincott.*

fibers will be tensed by increased intra-discal pressure from the trunk flexing forward. “Normal” being the key word here, as the annular fiber orientation in a normal disc is 60 degrees from vertical as compared to a degenerative disc, whose annular fibers become more horizontal. For that reason, degenerated discs are unable to resist shear forces and therefore are more likely to be injured during lifting.

The lumbar spine achieves stability and balance during lifting because as the spine flexes forward, the accompanying counternutation of the sacrum increases tension in the thoraco-lumbar fascia. Forward flexion of the lumbar spine also triggers contraction of the pelvic floor and transversus abdominus muscles, which biomechanically tightens the thoraco-lumbar fascia. This combined action on the posterior ligamentous system acts as an anti-shearing force on the lumbar spine. If the erector spinae muscles are contracted in a flexed lumbar spine, the effect is an increased compression on the zygapophyseal joints. This would facilitate transference of load through the cortical bone of the neural arches, decreasing compression on the lumbar vertebrae, and thereby countering the intra-discal pressure.

In summary, normal biomechanical flexion is the position of power for the lumbar spine. In the absence of adequate flexion of the lumbar vertebra or in the absence of adequate ligamentous and muscular support, lifting could be hazardous to the spine.

Conclusion

One of the primary reasons for studying spine biomechanics is to accurately identify and analyze changes that occur with pathology. For example, Panjabi and co-workers found an increase in lumbar spine translation movement in the presence of lumbar disc degeneration.[3] Increased translation in the lumbar spine has been linked to lower back pain.[3] Conversely, research has observed that up to 43% of people with low back pain have decreased or absent motion at L4-L5 and L5-S1 levels.[3] Some hypotheses suggest an increase in lumbar motion, while others propose a decrease in lumbar motion as a cause of low back pain. The answer is likely both. Additional research is required to learn more regarding the effects of faulty biomechanics on the spine. Recent research has added clarity to the biomechanical model of the spine, allowing manual therapists to evaluate and treat with techniques that are more specific, thereby improving outcomes.[5] Further research will always be necessary to establish reliability and validity of treatment techniques and their effects on the biomechanics of the spine.

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Sporting Activities and the Lumbar Spine

Excerpts and Summaries from *The 7-Minute Back Pain Solution*
by Gerard J. Girasole, MD and Cara Hartman, CPT

Sports are great fun and wonderful activities that keep our cardiovascular system functioning well and our muscles and bones strong and supple. But due to the many kinds of motions needed to play sports, athletes and those who work out have a greater risk of sustaining a lower back injury. With sports such as skiing, basketball, football, dance, ice-skating, soccer, running, golf and tennis, the spine endures a significant amount of stress and absorption of pressure, twisting, turning and even bodily impact during play.

An estimated 5 to 10 percent of athletic injuries involve the lower lumbar spine area, and most are simple strains. They're usually caused by a specific event or trauma, like overreaching for a backhand volley on the tennis court or getting tackled on the football field, though some are due to repetitive minor injuries that result in micro-trauma.

The reason why lower back injuries are so prevalent in sports-related injuries is directly related to the intricate anatomy of the lumbar spine. Five vertebrae compose the lumbar segment of the spine; each of the five levels consists of a functional component known as the motion segment. The combination of two vertebral bodies, an intervertebral disc between the adjacent vertebral body, and two facet joints form the motion segment. The facet joints are classified as synovial joints and allow for mobility of the lower back. However, although these joints provide articulation of the vertebrae and flexibility of the lumbar spine, the joints are susceptible to injury in instances of hyperextension or using incorrect form during other physical activities.

The most common form of lower back pain is when a motion segment is injured, in turn activating the supporting paraspinal muscles to protect the spine. These muscles then become inflamed due to the increase in stress, and the result is debilitating pain. However, the inflammation in the paraspinal muscles is not identical to inflammation found in joints. Joint inflammation due to a trauma is an initial reaction that signals a cascade of biological responses to increase blood cells, immune cells, and other cells to rush to the site of injury and begin the healing process.

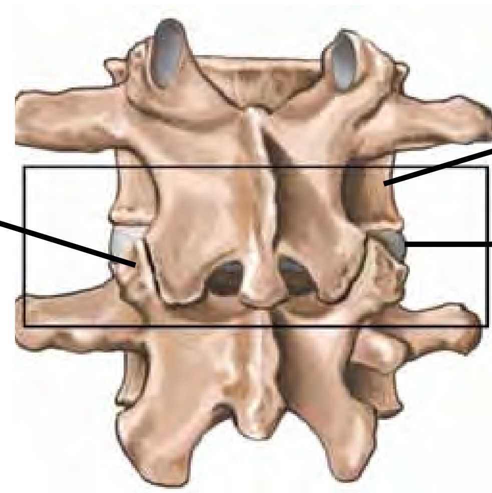

Figure 1. The motion segment (outlined by black box) of the lumbar spine. *Image provided by Medtronic, Inc.*

Lower back pain or muscle strain happens when your muscle fibers are abnormally stretched or torn. Lumbar strain also happens when the ligaments, the tough bands of tissues that hold the bones together, are torn from their attachment. (Differentiating a strain from a sprain can be difficult as these injuries show similar symptoms.)

To reiterate, inflammation in a muscle is not the same as inflammation in a joint. If you have lower back pain or strain from an injury, there is a slight disruption of the muscle fibers, which triggers an inflammatory response in the muscle, inducing even more muscle soreness. Much of this soreness is due to a buildup of by-products that are formed from the initial injury, predominately lactic acid, which is highly caustic. These by-products prevent the muscles from working properly and act as noxious stimuli. The by-products irritate the muscles and impede the normal flow of nicely oxygenated red blood cells to the area, which are needed to clear out the substances that have built up.The uniqueness of spinal anatomy and the increased stress that sporting activities or exercise place on the spine increases vulnerability to injury. The vulnerability is specific to the type of exercise occurring-either open chain or closed chain exercise.

During an open chain exercise, such as running or tennis, your feet constantly leave the ground, and then when they make contact with the ground again, force is delivered to the lower lumbar spine, where the motion segments are. During closed chain exercises, such as riding a stationary bike or using a StairMaster, a stairstepper, or an elliptical machine, your feet never leave the ground and there is no direct force delivered to the lower lumbar spine.

Due to the pounding nature of open-chain activity, there can be repetitive trauma to the disc spaces. In those who have weak muscles (especially in their core) or any form of degenerative disc problem, the chances increase that they will develop chronic lower back pain if they engage in open-chain exercise.

Running and Your Lower Back

Running is a very common and enjoyable sport for millions of people. Not only can it be stress relieving to go for a contemplative jog or a longer run before or after a tough day at work, but running provides an excellent cardiovascular workout, which is good for heart and lung health as well as weight loss. But because running is an open-chain exercise, it is very demanding on your lower lumbar spine. Your core must be strong for you to be able to balance yourself for an extended period of time when you run. Any muscle imbalances you have place stress on your spine when you run. In addition, running or jogging is an extension activity, meaning that your spine and pelvis are tilted backward, which puts significant pressure on the entire spine. Most runners or joggers run in this extended position, which puts repetitive compressive loads onto their spine's motion segments every time their feet leave and then hit the ground. Run like this for several miles at a time, multiple times a week, and eventually your back might start screaming in protest.

To avoid this, you want to run using perfect form. This means you should seek out your ideal neutral spine position, one in which your muscles all counterbalance each other so that you maintain a perfect alignment. If you hyperextend (your spine moves backward) or flex (your spine moves forward) due to fatigued muscles, this will cause even more stress to be placed on the lumbar spine, and not dispersed throughout your core muscles. Tired muscles also provide less support, as well as placing more pressure on the spine, which can also lead to damage to not only the discs themselves but also to the facet joints. When that happens, you are at increased risk for developing low back pain.

Racquet Sports and Your Lower Back

Tennis is a popular sport for all ages. The specific repetitive movements when serving and when hitting tennis balls are what make it so much fun, but this also means that tennis is notorious for causing lower back pain in recreational players as well as professionals.

More specifically, a tennis player goes through countless trunk rotations and twisting motions while performing forehand and backhand shots. While doing the normal routine of a forehand or a backhand shot, there is a change from extension to flexion, often while running and turning at the same time, and this creates a constant load on your spine's discs and facet-joint complexes. Not only that, but these shots are done with rapid start-and-stop motions, making tennis an open chain exercise that places significant stress on the lumbar spine, especially as all these motions are absorbed by your lower back and pelvis.

The back muscles must endure repeated sudden forward and lateral movements and the start/stop movements. It is almost impossible to think about Back Mindfulness in the less than split second it takes to go after a ball. Back Mindfulness is a new mind-set for thinking about, using, and strengthening your back.

And then there's the overhead serve. This is done in a static position, but when throwing up the ball and then bringing your racquet down to hit it, it is necessary to hyperextend your lower back, which compresses the

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Figure 2. The spine is hyperextended in the initiation phase of the tennis serve.

Figure 3. As the tennis player follows through with the serve, the back transitions from extension to flexion.

lumbar discs and the joints, which rely on the muscles around them to stabilize them (Figure 1 and 2.) People who have weak core muscles will not be able to withstand this repetitive hyperextension. Eventually, they will develop lower back pain, and if it is not rectified, chronic lower back problems can result.

Golf and Your Lower Back

Golf grows more and more popular every day. It's a wonderful sport that anyone, from kids to seniors, can enjoy– but it's also a sport that compromises the lower back like no other. It is widely believed that at least 80 percent of all amateurs play with lower back pain or get injured at some point in their playing days. This is especially true for older golfers. I've found that many of my patients are incredibly depressed about having to give up their cherished golf games because their back hurts too much during and after play. It has also been estimated that a whopping 90 percent of professional golfers suffer from lower back pain, and back pain is one of the leading disabilities on the PGA Tour.

In nearly all cases, golf-related lower back pain stems from improper postural alignment and muscle imbalance, either during play or from everyday life. The reason for all this pain is that the golf swing is a very traumatic motion for the entire body, but especially the lower back. There is significant torque involved in the proper mechanics of the swing. In order to hit a golf ball correctly and accurately, you must undertake an extremely complicated set of motions relying on many different muscle groups and then pivot through the lower back and the hips.

A golfer needs to know about his or her "spine angle," which is the angle formed during a proper swing so you can hit the ball correctly. If you flex too far forward or extend too far back, it is almost impossible to hit the ball correctly. The only way that you can achieve the correct spine angle and maintain it through the rigors of a golf swing is to have a strong core. Your spine and its motion segments rely on the muscles surrounding them, as well as those in the pelvis, to stabilize them and disperse the forces and loads that occur during the intricate golf swing.

Owing to the fact that the swing is so complicated and the spine angle is so important, an experienced professional golfer who has excellent swing mechanics and is physically fit can still have lower back pain.

Not surprisingly, amateur golfers and weekend warriors are more likely to have poor swing mechan-

Figure 4. Spine angle is the optimum spine posture throughout the entire golf swing. A spine angle of 30° should be maintained from beginning to follow-through of the swing to produce the most accurate results.

ics, lack fitness, and avoid proper warm-ups and stretches, resulting in injury and chronic, nagging lower back pain.

The lumbar spine is designed to endure stresses that come with everyday motions, such as bending, flexing and rotation. When these stresses are magnified by certain activities, such as a golf swing or a tennis shot, especially when combined with poor technique and poor muscle strength, you overload your spine.

Stretching

What is the one thing the most competent and high-performing professional athletes– from ballet dancers to football players to golfers– have in common? They stretch every day.

Stretching is an activity that must be done properly and consistently in order to be beneficial. It should never be considered a full workout, but rather a supplement to your regular fitness routine. Daily stretching is the best protection against intervention; instead of implementing a stretching routine as a reaction to acute pain, you should develop a consistent and regular stretching schedule to prevent lower back injury. Then future bouts of pain can be minimized and current pain can be alleviated. Here's what stretching does:

- It maintains, improves, and increases flexibility. Muscle flexibility allows your joints to move through their normal ranges of motion. A tight muscle can prevent your normal range of motion– which in turn can lead to an injury and pain.
- It lengthens the muscles and tendons, aiding in the prevention of injuries. By increasing the length and flexibility of your muscles through these stretches, less force is placed on the spine, and this, believe it or not, reduces the incidence of lower back pain.
- It aids in the repair of muscles and tendons, preventing soreness after exercise or sports.
- It increases the blood flow to the muscles, bringing them the nourishment they need while helping to remove waste and by-products. The better your blood flow to your muscles, the better your chances of a normal recovery from muscle and joint injury.
- It may slow the degeneration of muscles and joints. It often triggers the release of endorphins, those feel-good neurotransmitters in your brain that are a wonderful stress reliever and your body's very own pain relief system.
- It helps you get a good night's sleep, as stretching before bed is not only relaxing but lengthens your muscles and helps with stiffness the next morning. This is especially important for those who find that spending many hours lying in bed makes their back pain worse. And, of course, a good night's rest is so important to your overall health and well-being.
- It improves your postural alignment. Tight muscles contribute to poor posture, while stretching makes muscles more flexible and less tight. With better posture when standing and sitting, you automatically reduce the pressure on your discs– causing you to hurt a lot

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less or not at all– and you stand taller and look leaner.

- It helps with balance and coordination, and thus has a positive impact on how you perform your regular daily activities.

Professional athletes are not the only people who suffer from lower back pain. As you can imagine, it is also very common in the weekend warrior or sporadic exerciser and in regular exercisers, doing their best to stay healthy. Of course, it is always great to work out whenever possible, but you need to apply Back Mindfulness to any physical activity, including sports.

Gerard J. Girasole, MD

Dr. Girasole is a board certified orthopaedic surgeon at The Orthopaedic & Sports Medicine Center. He has extensive experience in the treatment of lumbar disc disease, neck pain, scoliosis, herniated discs, and spinal stenosis using both operative and non-operative techniques. Dr. Girasole is on the forefront of minimally invasive surgical techniques for patients with low back pain and he is very active in the training of other surgeons in the various techniques. He has recently completed a FDA trial study for the treatment of patients with back pain with a Total Disc Replacement procedure. He is very active in the Academic Society for the Spine and teaches yearly at several accredited spinal courses.

Cara Hartman, CPT

Cara Hartman is a back-pain survivor who lived through years of suffering until she transformed her life by becoming a personal trainer certified with the National Exercise Trainers Association (NETA). She also has a sports injury specialist certification with the National Exercise & Sports Trainers Association (NESTA). Cara's specialties are core and flexibility training as well as back pain prevention, and she developed the exercises in the book and fine-tuned them with Dr. Girasole's expert advice. She carefully instructs her clients with back pain during exercise how to heal their backs and strengthen their core muscles while providing prevention tips for daily life.

Spinal Biomechanics of the Golf Swing: Chiropractic Perspective

Peter M. Daddio, DC, CCSP

The biomechanics of the lumbar spine during the golf swing and its relationship to low back pain has become a major concern among both professional and amateur golfers. Golfers desire to hit the ball further and straighter while preventing low back pain. These concerns have led to an increase in the number of studies related to the biomechanics of the lumbar spine and its relationship to the improvement of the golf swing. Sports medicine professionals have to deal with this issue in their offices more often due to the increase in the number of amateur golfers. In addition, most golfers do not engage in crucial off-season exercise and preparation for the beginning of the season. This contributes to the high incidence of injuries early in the season. A good off-season workout is extremely important.

As a chiropractor, I do not only examine the actions of the muscular, neurological, and ligamentous structures of the lumbar spine, but I also evaluate the relationship of the lower extremities to the biomechanical function of the lumbar spine. When we look at what has to occur in the lumbar spine to initiate a proper golf swing, we see that the multifidus muscles are extremely important. Numerous studies show that the stability of the spinal segments during motion is essential to minimize the torque on the joints. The deep muscles of the spine, particularly the transverse abdominus and the multifidi, are more effective and anatomically suited for specific spine stabilization and are activated first. Subsequently, the superficial muscles of the spine facilitate proper rotation of each individual spinal segment.[1,2] Ligamentous stability ensures balance surrounding the joint. The neurological innervations of these soft tissues must be efficient to allow the necessary actions to take place. There must not be any interference with the nerve function.

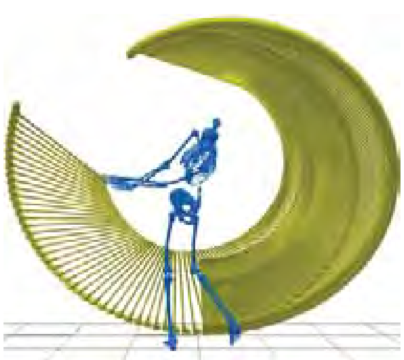

Figure 1. *Image courtesy of Sean Horan.*

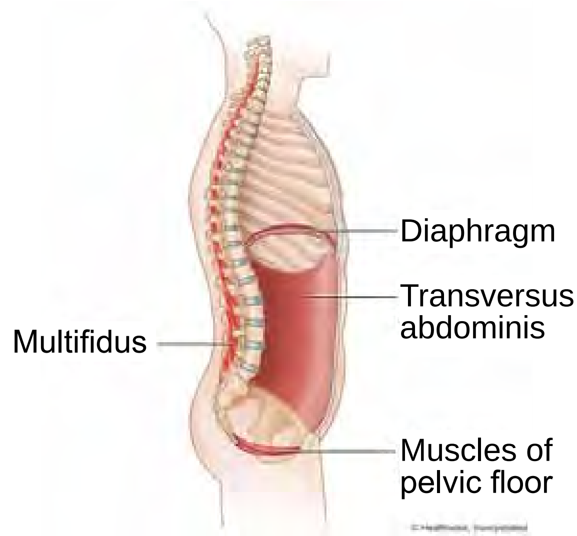

Figure 2. Inner core muscles including the multifidi and transverse abdominus muscles that support the spine. *Image courtesy of emedicinehealth.com.*

Panjabi has stated that clinical spinal instability is an important cause of low back pain.[3] He describes the stabilizing system of the spine as being divided into three subsystems: the spinal column, the spinal muscles, and the neural control unit. There are also studies that indicate a strong relationship between the neuromuscular control system and spinal stability. Any decrease in the efficiency of the neuromuscular system will decrease spinal stability. Therefore it is essential to evaluate the golfers both at the driving range during their swings and at their office visits.

Professional golfers, as opposed to amateur golfers, tend to possess a better combination of strength and flexibility in their torsos, shoulders, and hips. They also tend to have greater single leg balance.[4] Another advantage of professional golfers is their superior club head speed, which is related to the amount of spinal rotation and shoulder girdle protraction at the top of the backswing.[5] The amount of spinal segmental rotation is directly related to the proper function of the three subsystems Panjabi described.[3]

Evaluation

Evaluation of proper technique when performing any activity is important in order to produce a

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neuromuscular advantage.[7] For instance, if during the evaluation it is determined that the erector spinae and the external oblique muscles are firing as the primary spinal stabilizers instead of the stronger, deeper transverse abdominus and multifidi muscles, then the patient may be compensating for low back pain.[6] Consequently, this causes the patient to develop overuse injuries due to poor biomechanics during the golf swing.

Figure 3. Bone spurring (osteophyte formation) in the lumbar spine. *Image courtesy of Dr. Shane Mangrum.*

The use of lumbar spine radiographs is important to determine the presence of any disc degeneration, joint subluxation (dislocation or displacement between articulating bones), or osteophyte formation (Figure 3). These factors can change the biomechanical stress on the joints, as well the range of motion at the different levels. Specifically, the decreased motion in the lower levels of the lumbar spine can have a much greater negative effect on the stability of the spine during the golf swing. It is very common to see degenerative disc disease present at the L5 level in many of my patients who present with vague low back pain after playing a round of golf.

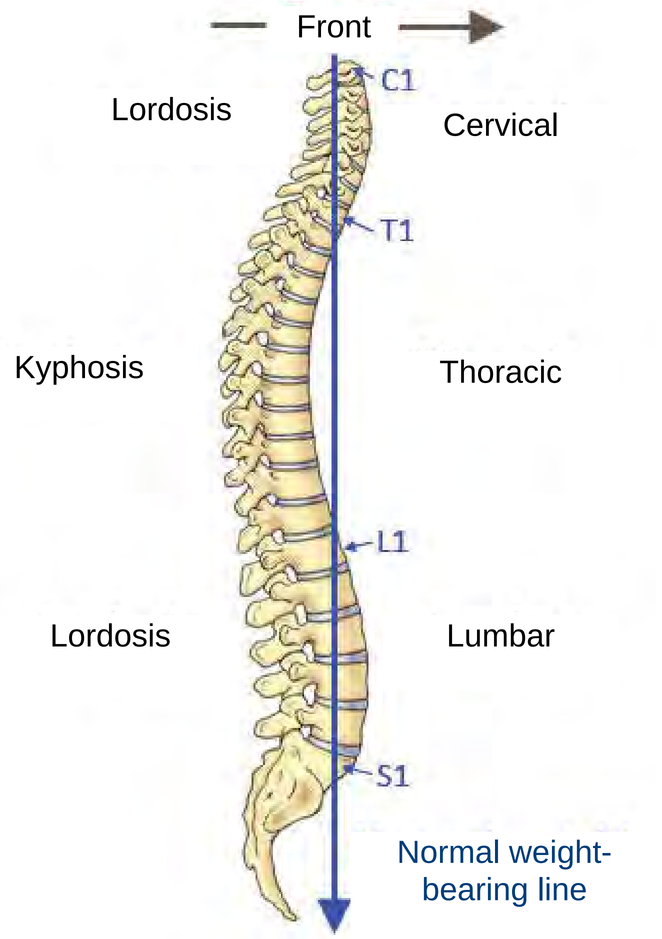

Figure 4. Curvatures of the Spine. *Image courtesy of srs.org.*

The films will also help to evaluate the lordotic curve of the lumbar spine (Figure 4). An increased lordotic curve causes stress on the posterior segments, particularly during the backswing, and also reduces the range of motion in this area. This reduction limits the backswing and directly affects the power generated to hit the ball farther. Similarly, a decreased lumbar lordotic curve will also decrease the segmental range of motion in the lower spine. Its effect on the backswing will be similar, however the approach to improve proper biomechanics in the region will be significantly different.[8] Another factor to consider is the sacral base angle. An increased sacral base angle will cause a decreased range of motion in the L5-S1 level.

Sacroiliac joint dysfunction is commonly seen with cases of lumbar instability and low back pain. Since the sacroiliac joint must compensate for decreased flexibility in the lower lumbar segments, it is subjected to overuse injuries. The exact location of subluxations must be determined prior to treatment because the sacroiliac joint is comprised of two separate joints, an upper and a lower one. Also, there is the potential for neurological dysfunction, trigger points, and muscle spasm in the gluteal muscles, particularly the gluteus medius. These factors will create an area that blocks the range of motion of the lumbar spine on the backswing.

A sacroiliac joint subluxation can also affect the hip on the side of the subluxation. As previously stated, the hips are very important in creating the torque during the backswing, which is necessary to produce the overall strength of the swing. As a habit, I always check the iliotibial band on the side of the hip fixation to rule out trigger points, which may inhibit the flexibility needed throughout the swing. There is always the potential for trigger points (commonly known as muscle knots) to develop, especially with chronic structural instability, which would consequently change the postural biomechanics during the follow through and acceleration of the swing.

The next step of evaluation is of the lower extremities and their effects on the postural biomechanics of the lumbosacral region. The lower extremities play an important role in the outcome of the golf swing, particularly the mechanics of the foot and ankle joint. First, it is extremely important to rule out any structural defects in the foot and ankle that may interfere with the normal segmental movements of the spine. For instance, a very common abnormal finding is the presence of pronation (Figure 6). This translates into muscular imbalances and spinal joint dysfunction.[8] If the pronation is ignored, the stability of the spinal segments is compromised. Since there will always be some biomechanical stress put on the spine and sacroiliac joints during the swing, it is very important to have balance and stability in your foundation, particularly on your backswing. The transfer of force from the back foot on the backswing, to the front foot on the downswing and acceleration, will determine the distance of the ball.

The importance of posture and proper spinal biomechanics during the golf swing is essential to preventing injuries in the low back and maximizing the distance and accuracy of golf shots. The lumbar spine must be in a stable position during the stance phase; the lower spinal segments to approximately L3-L4 are locked in flexion and the upper lumbar vertebrae are in extension. The transitional level where there is a slight shift from flexion to extension becomes a stress point for the lumbar spine. It is necessary for there to be normal neuromuscular function in this phase. When evaluating a patient's stance phase, I have found that if there is interference

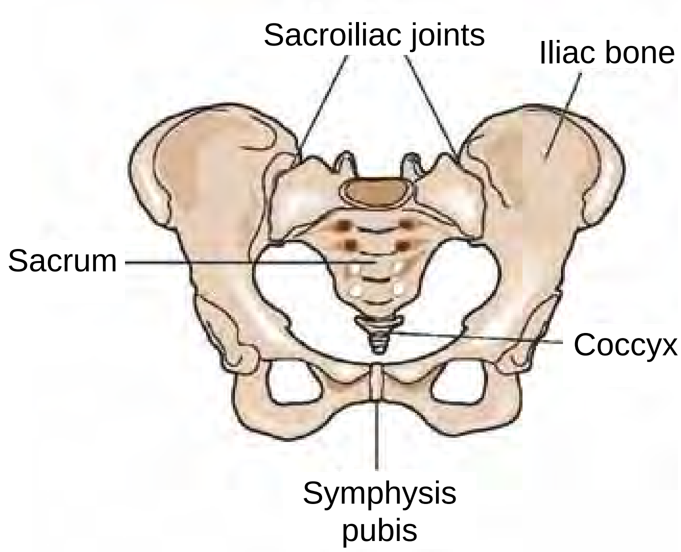

Figure 5. The two sacroiliac joints are seen at the articulation of the sacrum and the ilium. *Image courtesy of spine-health.com.*

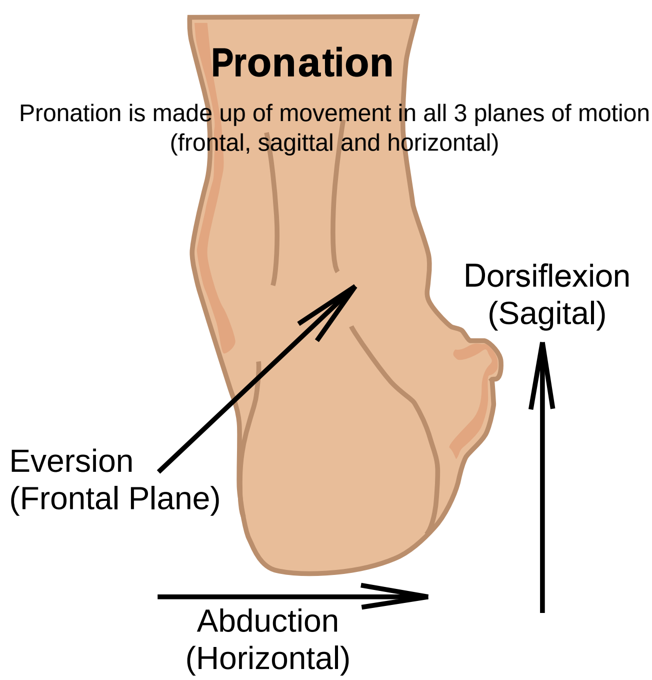

Figure 6. Pronation of the right foot. *Image courtesy of docpods.com.*

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Figure 7. Frontal and sagittal plane views of a swing sequence for an elite male golfer. *Image courtesy of Sean Horan at golfmedicine.com.*

with the neuromuscular innervations, the deep muscles, particularly the multifidi, the erector spinae, and external oblique muscles are activated too soon.

Clinical Approach

Spinal manipulation is a hands-on therapeutic approach necessary to treat the lumbar instability present with improper biomechanics. It has been shown in numerous studies that the high velocity, low amplitude thrust of spinal manipulation actually increases the function of the multifidus muscle by activating the ligament stretch receptors. In turn, the multifidus muscle contracts and decreases the load stress on the joint.[9] By alleviating the tension on the spinal segments, the manipulation can improve the structural integrity and stability of the joints to allow for proper biomechanics. The manipulation treatment also includes the use of a technique called Cox flexion/distraction. This technique requires a flexion/ distraction table that allows the practitioner to flex the lumbar spine and apply manual traction to the spinous processes of each individual segment of the lumbar spine. Both the erector spinae and the deep muscles of the spine can be affected by the dynamic motion traction. Along with the manipulation, the use of electrical muscle stimulation is very effective in reducing spasms and muscular imbalances.

Once the proper spinal positioning is achieved, spinal strengthening exercises are recommended to provide additional stability. If necessary, orthotics may be recommended to stabilize any pronation or other foot issues and to maintain spinal stability.

The knowledge of sports biomechanics can definitely improve performance and reduce the risk of injuries. Proper training methods prior to beginning the activity should include both strengthening as well as stretching programs.

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Dr. Daddio is a Certified Chiropractic Sports Physician. He is a 1985 graduate of New York Chiropractic College. He has lectured to numerous groups on the topic of sports medicine. From 1996-1999, he was the Team Chiropractor for the NFL Washington Redskins. He served as Medical director and Team Physician for the Italian National Lacrosse Team at the 2006 World Lacrosse Championships as well as International Tournament in Amsterdam. He has been in private practice specializing in spinal sports injuries.

Force Transfer in the Spine

Douglas G. Orndorff, MD, Morgan A. Scott, Katie A. Patty, MS

In comparison to the rest of the body, the motion and segments that make up the spine are the most dynamic and poorly understood of all. The spine is a mechanical system that supports the torso against loads and allows motion, within limits. The spine is organized into three regions: cervical, thoracic and lumbar. All sections total 33 vertebrae separated by 23 intervertebral discs. Each segment of the spine (vertebrae, discs, ligaments, and muscles) interacts and articulates in a controlled manner by mimicking a complex system of levers, pivots, and passive restraints. Knowledge of biomechanics and how the forces and alignment affect the individual components of the spine is essential to understanding all aspects of clinical analysis and management of spinal problems.

Compressive Forces

Forces that act along the axis of the spine, or downward onto the spine or disc, are referred to as compressive forces. These forces act to flatten the spine and associated components, such as discs and vertebral bodies. Compressive forces are caused by multiple internal and external forces that create a transfer of force. Common external forces include gravity, and external contact forces, such as a weight being lifted. Internal forces include contracting musculature or passive actions of ligaments or tissues. An example of the spine under a compressive load is a person beginning to jump; the acceleration upward applies the compressive force onto the spine.

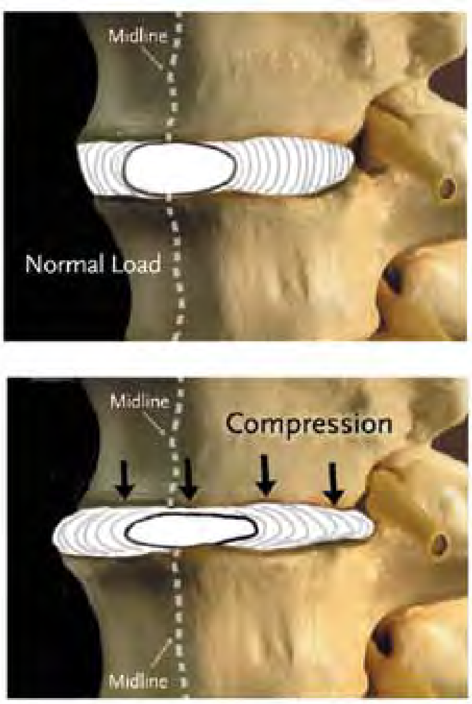

Figure 1. Compressive forces action on the intervertebral disc. *Image provided by Medtronic, Inc.*

The effects of a compressive load are shared among the anatomical features of the spine, including the vertebral bodies, the facet joints, spinal ligaments, and the intervertebral discs. An intervertebral disc consists of multiple components. The annulus fibrosus is the outer edge of the disc and is composed of type-1 collagen; it completely encircles the more hydrated center, the nucleus pulposus.[1] Each section of the disc reacts differently to varying forces. In association with the facet joints and vertebral bodies, the discs are subjected to the all of the compressive loads.[2] The intervertebral discs act as shock absorbers. As the compressive force is applied to the vertebral body, the hydrated disc obtains enough fluid pressure to resist the force and pushes the surrounding structures in all directions away from the nucleus center. The disc will slightly compress, decreasing in size during the physiological action. This action prevents the vertebral bodies from coming in close contact with each other and maintains the integrity of the associated nerves and spinal structure. However, in a degenerative disc, the nucleus pulposus loses the water content, thus decreasing the hydrostatic pressure inside the disc space (Figure 2). The internal pressure required to resist compression is decreased, and as a result, the endplates are subjected to less pressure at the center. This decreased pressure causes the loads to be distributed more around the periphery (Figure 3).

High compressive loads applied to discs cause permanent deformation; however, Virgin (1951) found no herniation of the nucleus pulposus.[3] This work and additional studies by Hirsch et al. suggest that disc herniation is not caused solely by excessive

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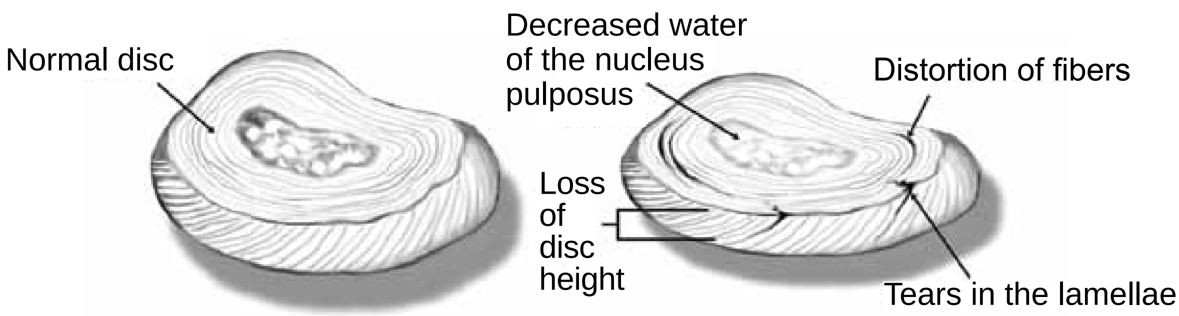

Figure 2. Loss of water content from the nucleus pulposus when comparing a normal lumbar disc to a degenerative lumbar disc. *Image provided by Medtronic, Inc.*

compressive loading.[4] Markoff et al. conducted a study analyzing the effects of axial loading in association with repetitive flexion on the disc herniation mechanism.[1] He found that axial twist and repetitive flexion increased delamination of the annulus (separation of the fibers of the annulus). Axial twisting alone did not affect the integrity of the annulus, implying that the tendency for the disc to herniate to the side and towards the back of the spine, as seen in the clinical situation, is not inherent in the structure of the disc. The herniation must depend on certain loading situations more than the compression.[1]

Tension Forces

A tension force in the spine acts to elongate the discs and vertebral body. An example of a tensile force on the spine is when a person hangs freely from a bar, allowing the spine to elongate due to the gravitational forces. The vertebral discs again transfer many of the tensile forces in the spine through the outer portion of the disc (the annulus fibrosus) which is basically a system of collagen strings; as the strings are pulled in opposite directions, tensile force is applied onto the disc.[1] These tensile stresses occur during the physiologic motions of flexion, extension and lateral bending. During bending loads, the intervertebral disc experiences equal forces in both tension and compression. Bending and torsional loads are more damaging to the spine than compressive loads.[1] Due to the unique structure of the intervertebral disc, general motion may increase or decrease the stiffness of the disc. Studies on tension and compression on the intervertebral disc demonstrate that the stiffness of the intervertebral disc decreases during tension and increases during compression.[1] The increased stiffness during compression is a direct result of the fluid pressure of the nucleus pulposus. Clinically, the spine is never loaded purely in tension; other forces act with tension and are applied to parts of the vertebral disc during physical motions.

Intradiscal Pressure and Posture

Intradiscal pressure is the hydrostatic pressure measured in the nucleus pulposus of a healthy intervertebral disc. Pressure is applied to the intervertebral discs during all daily activities including walking, sitting and lying down. Each position carries with it a

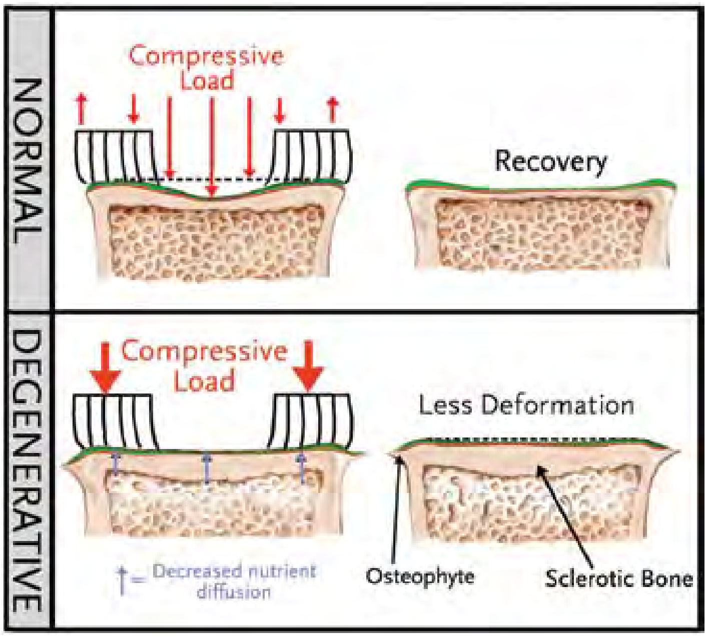

Figure 3. Illustration of the changes that occur in the vertebral end plate due to degeneration. *Image provided by Medtronic, Inc.*

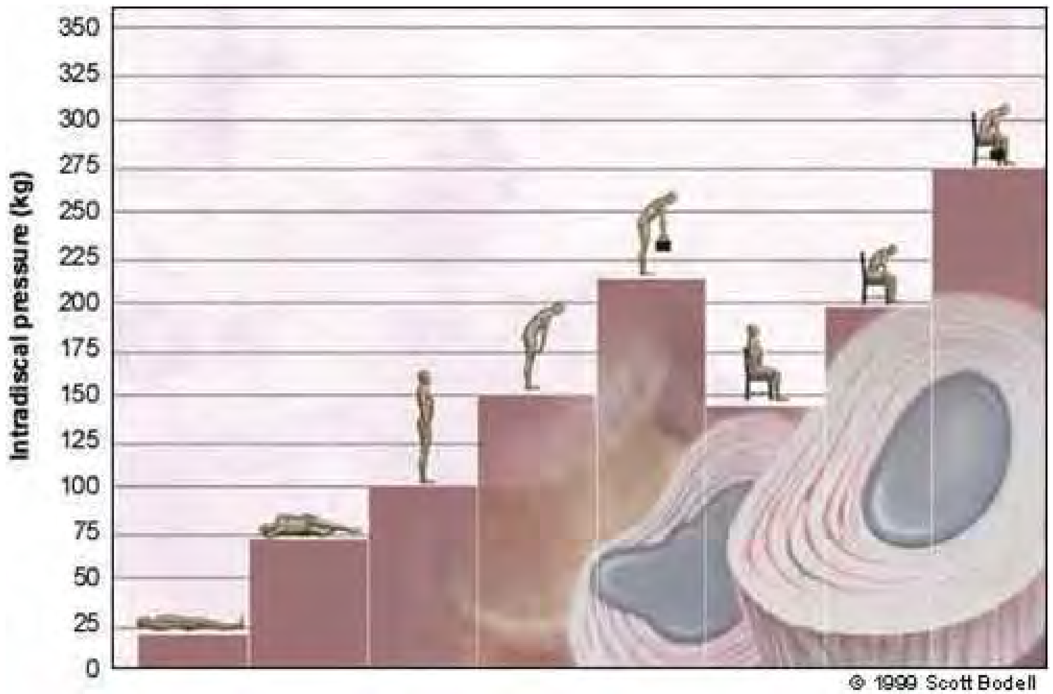

Figure 4. Intradiscal pressure measurements at various positions.

different level of force exerted onto the spine and associated discs.

Several studies measure the intradiscal pressure of a person during varying tasks. In the original studies, a pressure transducer (or gauge that reads the internal pressure of the disc) was placed into the L3-L4 disc. The results indicated that 60% of an individual's body weight affects the intradiscal pressure at L3-L4.[5] This pressure increased to 200% of the individual's body weight during sitting, standing with 20 degrees of flexion, or forward bending. The pressure increased to 300% of the individual's body weight when the person was asked to hold a 20 kg weight while remaining in a flexed position.

Another study was conducted to expand on the previously measured pressures associated with various positions or postures.[6] The intradiscal pressure was measured for every position outlined in Figure 4. The lowest measured pressure occurred when lying down supine. Using relaxed standing as the base of comparison (intradiscal pressure = 0.50 megapascal), straightening the back while standing increased the intradiscal pressure by 10%. Similarly, sitting with the back consciously straightened (as is typically recommended) increased the intradiscal pressure by 10%. The authors postulated that the difference in pressure readings was a result of increased muscle activity. An unexpected result of this study was the 10% decrease in pressure measured while sitting relaxed without backrest. The intradiscal pressure further decreased by 46% when slouching and resting against the chair backrest. It is assumed that the individual is relaxed in this position and that this relaxation causes the forces created by muscle activity and gravity to be transferred from the spine to the backrest of the chair. Another interesting finding outlined in this study was the effect of prolonged lying down on intradiscal pressure. After the lying down for seven hours, the intradiscal pressure increased by 140% (from 0.10 to 0.24 megapascal). Presumably, rehydration of the disc during relaxation or limited pressure is responsible for the increased hydrostatic pressure of the disc.

Beyond posture, the intervertebral discs can be greatly affected by what enters the body, specifically nicotine. The majority of the testing done in regards to the effects of smoking on the intervertebral discs and

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low back pain has been via animal studies. Utilizing rabbits as a model for studying degeneration, it was identified that nicotine in the blood resulted in necrosis (tissue death) and increased the stiffness of the nucleus pulposus. Similarly, a decrease in vascularity and narrowing of the vessels was seen in the annulus fibrosus. Necrosis in the disc decreases the ability to utilize oxygen, leading to an inability to synthesize collagen within the disc, ultimately causing degeneration.[9]

In addition to animal studies, there are many survey-based studies from general health organizations connecting the use of tobacco to increased low back pain. The United States collected self-report surveys from 502 adolescents; results indicated that smokers experienced low back pain more often than non-smokers.[10] Surveys completed by 73,507 Canadians revealed the prevalence of chronic low back pain in 23.3% of daily smokers compared to 15.7% in non-smokers.[11]

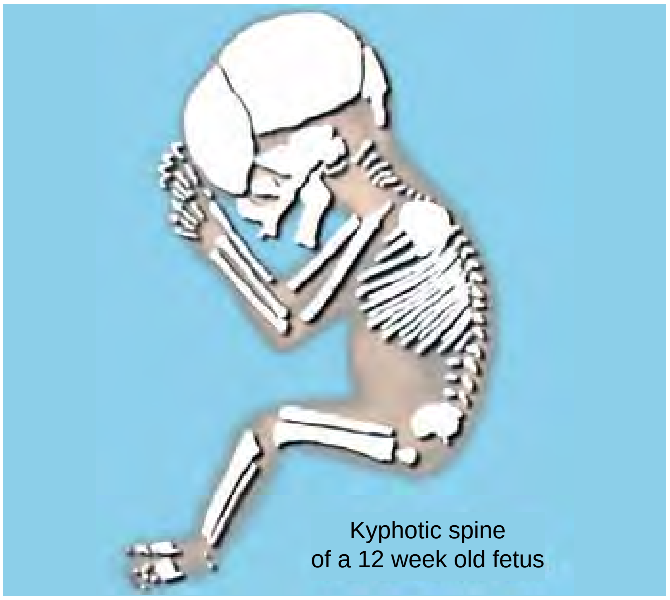

Figure 5. Fetus with C-shaped kyphotic spine. *Image provided by Medtronic, Inc.*

Sagittal Alignment

The sagittal view of the spine is a vertical plane that separates the body into a left and right side. This view shows the side of the spine and outlines the three distinct curves of the spinal column– the cervical, thoracic, and lumbar curves. The cervical and lumbar sections curve toward the front of the body (lordosis). The thoracic section of the spine curves toward the back of the body (kyphosis). These curvatures create the traditional S shape of the spine. Infants are born with a C-shaped curve; the shape of the adult spine develops progressively (Figure 5). As the infant learns to lift his or her head, sit, then crawl, the cervical lordosis forms as a results of the gravitational requirements of sustaining the neck posture. The second portion of the curvature, the lumbar lordosis, is created as the child begins to walk. The thoracic section maintains the kyphotic curvature that was present at birth. These three distinct curves in the spine are important to transmit the forces applied during all activities, acting as a shock absorber. The curves act as a spring and support more weight than if the spine were straight.[12] The physics of the spine shape increases resistance to axial compression (a compressive force applied from the head toward the feet). The increased number of curves in the spine actually increases the resistance to force one hundred fold in comparison to a straight spine. The curvature of the spine varies greatly with posture.

Sagittal alignment is an important portion of the biomechanics of the spine. If there is exaggerated lordosis or kyphosis in sections of the spine, it could increase the sheer forces seen within the vertebral joints or other portions of the spine. This increased in forces can result in increased wear on the vertebral bodies and degradation of the intervertebral discs. Sagittal imbalance is a common concern following surgical procedures that require a fusion of one or multiple levels of the spine. A fusion can alter the mechanics of the lumbar spine it two ways. First, it can alter the natural sagittal alignment, causing the spine to become straighter and increasing the pressure applied to discs and the spinal column. This is referred to as flat back syndrome. Second, it does not allow the fused vertebrae to be mobile, causing the resultant forces to be transferred to the next vertebra or the adjacent segment. The extra forces on the mobile segments can increase degeneration and wear.

Spinal Stability

It has been conceptualized that the stability of the spine is provided by the spinal column and the surrounding muscles. The structural components of the spine such as the discs, ligaments, and facet joints are essential for continued spinal stability. The facet joints are articulating joints located on the back of the spine and are the primary load bearing element within the vertebral body. These joints connect the two adjacent vertebral bodies and protect the discs from excessive flexion and axial rotation, thus limiting motion that would create forces potentially damaging to the spinal structures. During daily activity, approximately 75-97% of the compressive load applied to the lumbar spine is carried by the intervertebral discs, and 3-25% is carried by the posterior elements of the spine, including the facet joints (Figure 6).[13] When the spine is in flexion, 16% of a compressive load will be incorporated into the facet joint.[8]

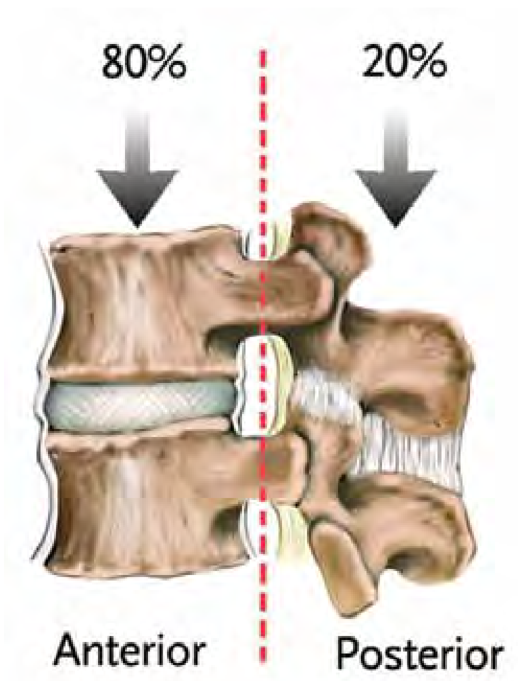

Figure 6. Weight distribution on the vertebrae. *Image provided by Medtronic, Inc.*

Muscles are essential to the stability of the spine. They provide a constant dynamic support and mechanical support to the spinal column. Spinal muscles are unique; such that they both stabilize and apply a compressive force on the spine during activation. The musculature provides stiffness to the spine that supports the spinal column; in fact a spine void of musculature is unstable at lighter loads[14]. If the spine is analyzed as a column with a large force located at the top, a thin unsupported column is likely to fall over or buckle due to the lack of support or lower stiffness. In comparison, if the column is stiffer it will take a greater force for the column to buckle.[15]

The final aspect of spinal stability is associated with the motion of the cervical spine. White et al. analyzed the stability by monitoring the spine when various anatomic elements were altered or completely removed.[16] All testing was done in a flexion or extension position with a physiologic load applied. Analysis was conducted on a loaded spine under one of the following conditions: the ligaments were sectioned, the facets were removed, or a vertebra was moved forward or rotated in relation to the adjacent vertebra. Sectioning of the ligaments resulted in minor changes followed by complete disruption of the spine. Removal of the facet joints resulted in angular and horizontal displacement; however complete degradation of spinal integrity was not reported. When the vertebral body was moved 3.5 mm horizontally or rotated more than 11 degrees, the cervical spine became clinically unstable. These biomechanical findings are beneficial clinically in understanding the best way to reconstruct an unstable cervical spine.

Discussion

So what does this mean clinically? Low back pain is a common medical problem. The Centers for Disease Control and Prevention stated that 30% of the adult population reported having back pain in 2009. The spine is a mechanical system; therefore, its function greatly depends on the maintenance of structure and resistance to forces. Increasing pressure onto the vertebral discs may decrease the discs ability to resist the forces applied to the spine. It is crucial that proper posture be maintained during daily activity, especially when heavy lifting is involved. The increase in mechanical forces can place an unbearable weight on the discs. This weight could result in anything from

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herniated discs to muscle strain. If improper posture or lifting is repeated continuously, this will fatigue or weaken the spinal structure increasing the chance of injury. The same continual exposure to force on the spine will cause general wear and tear on the spinal column as we age. This decreases the space between the vertebral bodies and allows the forces on the spine to affect the nerves and spinal column, ultimately resulting in increased pain and decreased function. As mentioned, musculature is essential for spinal stability to provide the constant forces that allows for stiff upright motion of the spine. Increasing muscle strength in both the back and abdominal core will help maintain the natural alignment of the spine and spinal stability.

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Spine Biomechanics and Age

Aakash Agarwal, Vikas Kaul, MS, Anand K. Agarwal, MD, Vijay K. Goel, PhD

From a biomechanical perspective, several skeletal components working in harmony allow us the day-to-day human experiences of walking, running, and, in some exceptional cases, hitting a perfect golf swing.[1] Our spine happens to be one of the critical components. The individual vertebrae, interconnecting ligaments, shock-absorbing discs, and facet joints– all play a role in the performance of these activities. However, as we age, each of these components starts to deteriorate, which is evidenced by its poor biomechanical characteristics. Ultimately, degenerative cascades result in diseases like osteoporosis, spinal stenosis, spondylolysis, and spondylolisthesis. The objective of this review is to provide: a) a very brief introduction to biomechanically-relevant anatomy, b) a concise synthesis of the accumulated biomechanical evidence demonstrating degeneration correlated with age, and c) appropriate surgical interventions in some age-related spinal diseases.[2] A discussion about muscular degeneration has been avoided in the interest of brevity, the overall context, and the focus of the review.

Anatomy

Normal Adult Anatomy

The vertebral column (spine) comprises the neck and the back. It forms a key part of the axial skeletal system: it protects the spinal cord, supports the weight of the trunk, provides posture, and offers a partially stiff and flexible axis for the body.[3]

The vertebral column in an adult consists of 33 vertebrae divided into five regions: 7 cervical (C1-C7), 12 thoracic (T1-T12), 5 lumbar (L1-L5), 5 sacral (S1-S5), and 4 coccygeal. The first 24 vertebrae are movable while the rest fuse by late adulthood. Intervertebral discs (IVD) between vertebrae contribute to the flexibility of the column (Figure 2). However, there is no IVD between the occiput and C1, or between C1 and C2. The vertebral column has four curvatures: cervical, thoracic, lumbar, and sacral. The thoracic and sacral curvatures are concave anteriorly

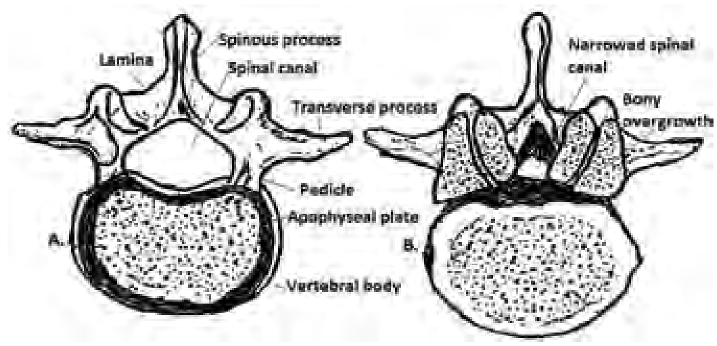

Figure 1: A. Transverse view of a vertebra showing different anatomical features; B. A vertebra showing spinal stenosis caused by hypertrophied bone around the spinal canal. *Modified and adapted from Primum non nocere. (2010). Spinal Stenosis. Retrieved July 27, 2012, from: http://gardenrain.wordpress.com/2009/03/19*

(kyphosis), while the cervical and lumbar curvatures are concave posteriorly (lordosis).[4, 5]

A vertebra consists of a vertebral body, a vertebral (neural) arch protecting the spinal cord, and several processes as sites for muscle attachment (Figure 1). The bony tissue in a vertebra is composed of cancellous and cortical bone. Cancellous bone is a highly porous structure consisting of a network of rod-and-plate shaped trabeculae surrounding an interconnected pore space that is filled with bone marrow. The main distinguishing factor between cortical and cancellous bone is their porosity: 5-20% and 40-95% for cortical and cancellous bone, respectively. The vertebral body is the anterior part of a vertebra that supports body weight and transmits ground reaction forces. A hyaline cartilage covers the cranial and caudal ends of the vertebral body. It also provides protection to the vertebral bodies and helps in diffusion of nutrients and waste fluids between the IVD and the vertebral body. [6, 7]

The superior and inferior processes of adjacent vertebrae– known as facets or zygapophyseal joints– articulate in a way to constrain motion. Depending on the position and orientation, these joints also bear part of the body weight and provide resistance to motion across the adjacent vertebrae, like slippage.[5]

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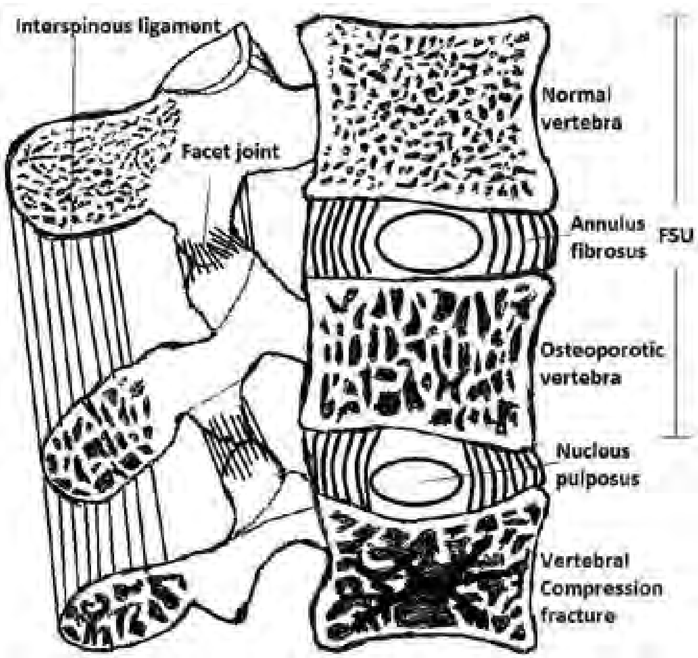

Figure 2: Bi-level spinal segment showing normal bone (top vertebra), osteoporotic bone (middle vertebra) and a vertebral compression fracture due to osteoporosis (bottom vertebra). The two adjoining vertebrae along with the ligaments and the intervertebral disc (consisting of gel-like nucleus pulposus surrounded by concentric layers of annulus fibrous) form a functional spinal unit– FSU. *Modified and adapted from Clinica Neuros. (2010). Vertebroplasty. Retrieved July 27, 2012, from: http://neuros.net/en/vertebroplasty.php*

IVD is somewhat cylindrical in shape and is made up of three structures: annulus fibrosus (AF), nucleus pulposus (NP), and cartilaginous end plates (CEPs). NP is the central hydrated region of the IVD and develops hydrostatic pressure due to the compressive stresses exerted on it.[7] NP is surrounded by laminated AF circumferentially and by CEPs at the cranial and caudal ends. AF and CEPs absorb the hydrostatic pressure developed by the NP and prevent it from protruding out to the adjoining areas like the spinal canal. IVD allows bending and rotation of the spine and helps in the transmission of loads all the while dissipating some of the energy.

The ligaments that stabilize the spine are passive structures: anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), ligamenta flava (LF), ligamentum nuchae (LN), interspinous ligament (ISL), intertransverse ligament (IL), and capsular ligament (CL). Apart from these, there are additional ligaments present in the upper cervical region.[8]

A functional spinal unit (FSU) consists of two adjacent vertebrae, the intervertebral disc and all adjoining ligaments between them (Figure 2). It is the smallest physiological motion segment of the spine to exhibit the key anatomical and biomechanical characteristics similar to those of the entire spine.[9]

Changes in Anatomy and Disease Manifestation with Age

With age, most of the spinal structures show degenerative changes and some of these are described below:

Trabecular Architecture and Cortical Thickness

In a vertebral body, trabecular bone tends to become more rod-like and its thickness decreases with age. Also, there is an increase in the anisotropy (the resistance to forces is no longer in all directions) of the trabecular structure. This increased anisotropy allows increased axial load carrying capacity. However, there is a down side: increased vulnerability to fractures due to off-axis impacts.[10]

Cortical thickness also changes with age and osteoporosis. In an osteoporotic spine, upper thoracic vertebral bodies have 15% thinner ventral cortical bone when compared with control specimens. Lower thoracic and lumbar vertebral bodies also show a 30% decrease in the dorsal cortical thickness compared to control. Even in a normal spine with no signs of osteoporosis, a significant decrease in the cortical thickness below the T8 vertebral body has been found.[11]

Osteoporosis and Vertebral Compression Fractures (VCF)

Osteoporosis is a condition of skeletal fragility in which bone strength gets reduced to the extent that fractures occur with minimal force, often during routine activities. Primary osteoporosis is classified into two major types: one related to menopausal estrogen loss (type-I) and the other to aging (type-II). Type I osteoporosis signifies a loss of trabecular bone after menopause in women, while type II osteoporosis suggests a loss of cortical and trabecular bone in both men and women as a result of age-related bone loss. One of the major predictors of osteoporosis is bone mineral density (BMD). On average, BMD reaches its peak at 24-25 years of age and decreases thereafter.[12-14]

A VCF is the collapse of a vertebra due to trauma or a weakened vertebra in a subject with osteoporosis (Figure 2). VCFs are associated with pain and progressive vertebral body collapse resulting in spinal kyphosis. The initial acute pain can be incapacitating and may become chronic in some cases. Chronic pain is a result of incomplete vertebral healing accompanied by progressive vertebral body collapse, pseudarthrosis at the involved region, or altered spinal kinematics. Prolonged inactivity after a VCF can lead to further bone loss, muscle attrition, and an increased risk of additional fracture.[12]

Disc Degeneration

IVDs undergo wear and tear with age, which is exacerbated by lower nutrition supply and waste exchange (Figure 3).[15, 16] Intervertebral disc degeneration (IDD) begins as early as 20 years of age, and autopsies suggest that 97% of individuals over 50 years of age have disc degeneration.[17-20] Manifestation of degeneration begins with decrease in the proteoglycan content of the NP and hence its water content, which results in reduced intradiscal pressure and height. Radial tears, fissures, protrusions, osteophyte formations, facet joint arthritis, and Schmorl's nodes (IVD protrusions into the vertebral body) may form along with pain, worsening the degree of degeneration.[15, 21] Disc degeneration is classified in terms of grades ranging from grades I to V: Grade I refers to disc with homogeneous and distinct NP and AF, with normal disc height. On the other extreme, grade V refers to inhomogeneous and indistinct NP and AF, with collapsed disc space.[22]

Annular Tear and Disc Herniation

Annular tear mostly accompanies IDD, but it could also occur early in the cascade due to strenuous activities (Figure 3). This condition leads to extrusion of disc nucleus into the spinal canal, leading to herniation. Confined herniation occurs from the protrusion of nucleus pulposus, with outermost layer of AF remaining intact.[23, 24]

Spinal Stenosis, Osteoarthritis, and Spondylolisthesis

Facet joints undergo degeneration due to overuse or high loading conditions. Typically, facet degeneration starts with degeneration of cartilage, leading to synovial space inflammation and joint space narrowing, ultimately resulting in osteophyte formation. This may lead to stenosis or spondylolisthesis.[25-27] It has been suggested that disc degeneration precedes facet degeneration.[26, 28, 29]

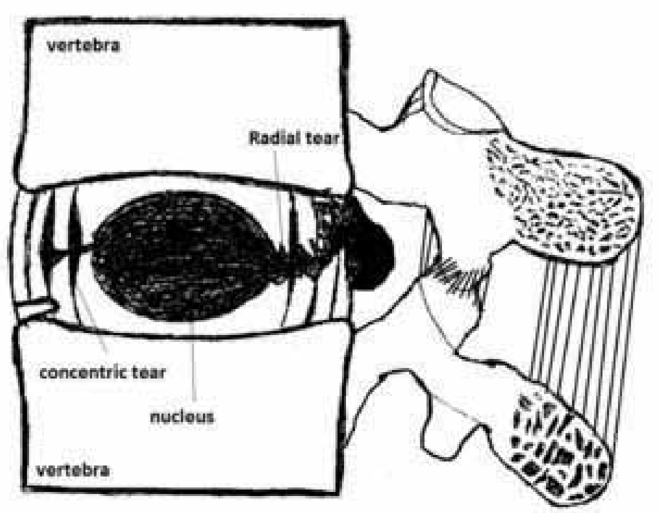

Figure 3: A diagram showing concentric and radial annular tears with nucleus pulposus extruding into spinal canal causing disc herniation. *Modified and adapted from Lynn Kerew Chiropractic Corporation. (2012). Annular Fissures: Definition and Treatment. Retrieved July 27, 2012, from: http://lynnkerewchiropractic.com/blog/annular-fissures-definition-and-treatment*

Hyaline cartilage traverses the synovial joint surface of a facet joint and is critical for its proper function. Its loss is a common finding with age. Radiographically, this can be seen as reduction in joint space on magnetic resonance imaging (MRI). In most cases, this loss is accompanied by a variable amount of inflammatory destruction of the cartilage and synovial lined joint capsule, known as inflammatory pannus. Depending on the severity and duration of the disease, the cartilage may be completely lost and the bare bones may start to rub against each other, leading to eburnation, i.e. new bone formation. It is achieved by increasing its surface area through osteophyte formation (Figure 4). This is called osteoarthritis.[30]

Spondylolisthesis is the slippage of one vertebra relative to the adjacent vertebra, and it often results from asymmetric degeneration of either the IVD or the facet joints. The imbalance in stresses, due to asymmetric degeneration of these joints, can lead to

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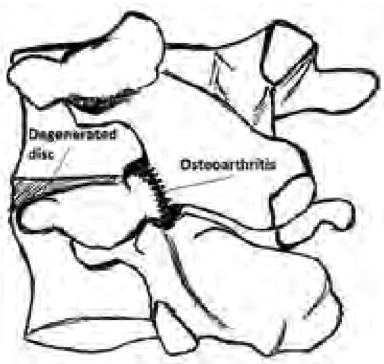

Figure 4: A diagram showing the eburnation of facet surfaces leading to osteoarthritis. Osteoarthritis of facets are normally is seen with a narrowed intervertebral disc at that level. *Modified and adapted from Skye Physiotherapy & Pilates. (2010). Lumbar Facet Joint Arthritis. Retrieved July 27, 2012, from: http://www.skyephysiopilates.com/article.php?aid=50*

an asymmetric deformity which further exacerbates the asymmetric loading. This becomes a closed loop cycle that promotes progression of instability. The deformity may occur along any of the three axes: vertical axis (axial rotation), lateral translation, or anterior translation (Figure 5). The degenerative changes that occur during spondylolisthesis can also lead to spinal stenosis.[31, 32]

Spinal stenosis is an abnormal narrowing of the spinal canal that could occur in any region of the vertebral column. IDD leads to altered local and segmental mechanics, generating compensatory changes like hypertrophy of bone, facets, and ligaments. Along with degenerative changes occurring within the normal aging spine, the surrounding musculature also undergo atrophy with age. Therefore the spinal column stability depends on the hypertrophied bone, facet joints, and ligaments. These hypertrophied structures result in the narrowing of the spinal canal or the foramen, which ubiquitously occurs in aging spine (Figure 1).[33]

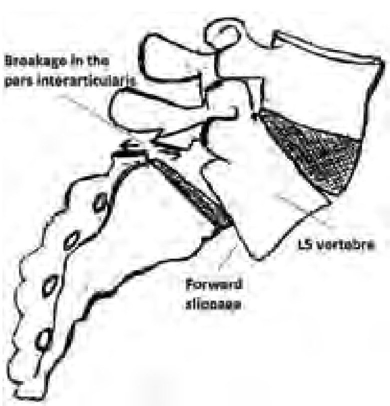

Figure 5: A diagram showing the spondylolisthesis of L5 vertebra. It occurs after the fracture of pars interarticularis, when vertebra is less resisted to forward slippage. *Modified and adapted from STANFORD Hospital and Clinics. (2012). Spondylolysis and Spondylolisthesis. Retrieved July 27, 2012, from: http://stanfordhospital.org/clinicsmedServices/COE/orthopaedics/spineCenter/patientEducation/spondylolysis.html.*

Biomechanical changes with age

Creep Characteristics of IVD

With the application of a sudden load, a non-degenerated disc creeps (i.e. deforms) slowly, as compared to a degenerated disc. This implies that the viscoelastic property (i.e., resistance to deformation and return to original shape) of an IVD attenuates with age as the disc degenerates. This will result in less shock absorption and uneven stress distribution (Figure 6).[34]

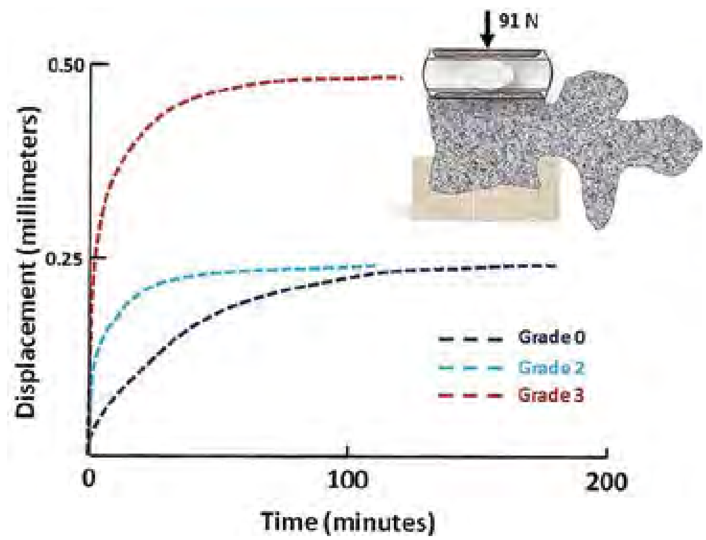

Figure 6: Temporal change in the displacement of an intervertebral disc under a constant load (i.e., creep) with different stages of degeneration. As degeneration worsens, two effects are observed: a) the final displacement increases and b) the rate of deformation increases significantly, in particular, immediately after the load is applied.[34] *Modified and adapted from Kazarian, L.E. Creep characteristics of the human spinal column. Orthop Clin North Am 6, 3-18 (1975).*

Kinematics of Functional Spinal Unit (FSU)

The instantaneous axis of rotation (IAR) of a normal FSU is confined to a small area in space but a degenerated FSU has its IAR spread out signifying instability (Figure 7).[35] The range of motion (ROM) increases in the initial stages of IDD, but decreases in the advanced stages. A spontaneous fusion between the vertebrae may occur if left untreated.[36-37] *In vivo* studies suggest that flexion-extension, lateral bending, and axial rotation decrease on an average by 23.3%,

Figure 7: In a normal FSU, the instantaneous center of rotation (COR) stays within a narrow region in the posterior aspect of the FSU (shown in the yellow circle; F: Flexion; E: Extension). In the case of a degenerated disc, the COR may vary over a wide area, even outside the FSU.[41] *Modified and adapted from Fujiwara, A. et al. The effect of disc degeneration and facet joint osteoarthritis on the segmental flexibility of the lumbar spine. Spine (Phila Pa 1976) 25, 3036-3044 (2000).*

30.6% and 25.1%, respectively for 50+ years of age compared to 20-29 years of age (Figure 8).[38] The IAR and ROM changes due to the degeneration of all of these following structures: ligament, facet joints, and IVD. These changes in the IAR and the ROM could lead to hypomobility, hypermobility, immobility, or paradoxical motion with age. Paradoxical motion implies that motion occurs in a direction opposite to the spinal bend.[39] For example, spondylolisthesis is related with

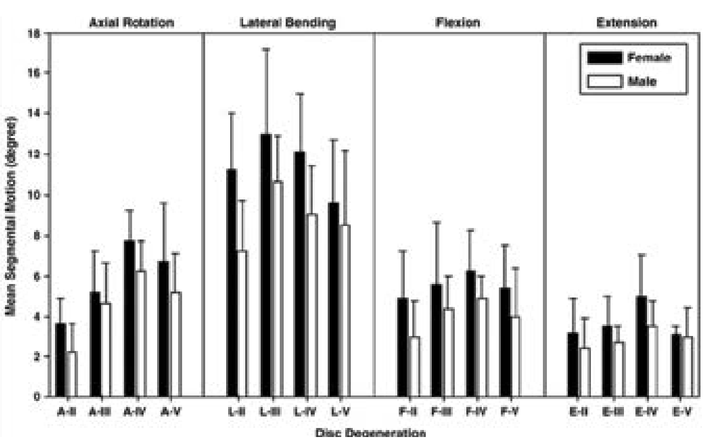

Figure 8: Variation in the intersegmental mobility with disc degeneration for men and women in three anatomical planes *(With permission from Fujiwara A, Lim TH, An HS, et al. The effect of disc degeneration and facet joint osteoarthritis on the segmental flexibility of the lumbar spine. Spine 1994;19(12):1371–80).*[42]

hypermobility in younger patients and hypomobility in older patients.[36, 40]

Stresses and Intradiscal Pressure Across IVD

The dehydration of the nucleus over time leads to an increase of stresses within AF and loss of disc height (Figure 9). The decrease in hydration also results in reduced intradiscal pressure, which in turn leaves the AF fibers with less tension, and hence most of the load transfers as compression through AF (Figure 10).[19, 43-45]

Compressive Strength of Vertebral Body

As a direct result of decrease in BMD with age, the maximum compressive strength at the central region of the vertebral body decreases.[14] The decrease in

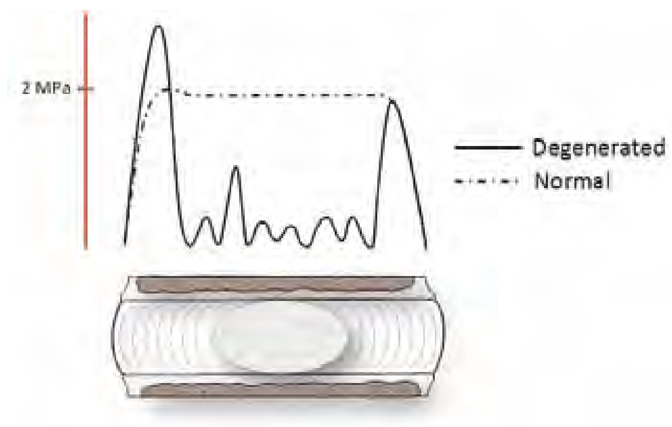

Figure 9: Comparison of the stress profiles between a normal and a degenerated disc. In a normal disc, a plateau in the stress profile is observed whereas, in the degenerated disc, spikes are seen in the annular regions and diminished stress profile is observed in the nucleus pulposus.[43] *Modified and adapted from McMillan, D.W., McNally, D.S., Garbutt, G. & Adams, M.A. Stress distributions inside intervertebral discs: the validity of experimental "stress profilometry'. Proc Inst Mech Eng H 210, 81-87 (1996).*

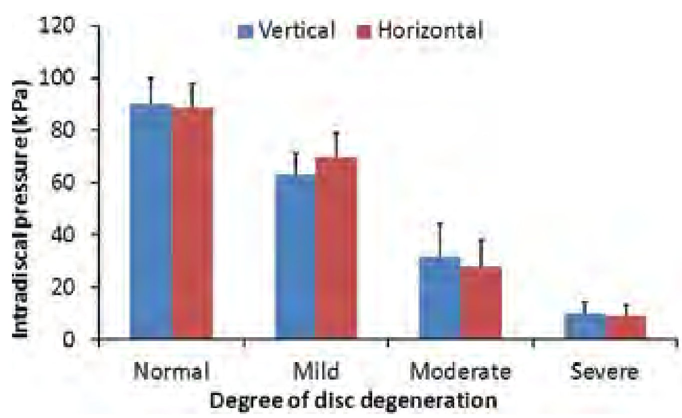

Figure 10: Decrease of intradiscal pressure with increasing grade of disc degeneration. The pressure measurements were taken in the prone body position. Horizontal and vertical refers to the alignment of the pressure-sensitive membrane of the pressure sensor.[45] *Modified and adapted from Sato, K., Kikuchi, S. & Yonezawa, T. In vivo intradiscal pressure measurement in healthy individuals and in patients with ongoing back problems. Spine (Phila Pa 1976) 24, 2468-2474 (1999).*

compressive strength along with the thinning of cortical bone may lead to VCF causing anterior wedging in the vertebral body. This moves the centre of gravity forward, resulting in a flexed posture which is hard to compensate by the muscles and ligaments alone.[46]

Load Sharing

IDD changes the structure and hence alters the load distribution resulting in excess loading of AF and the facet joints (Figure 11). The compressive load on the neural arch increases with age as a result of IDD. These FSUs with higher loads on the neural arches show bone loss within the vertebral body and hypertrophy in the facet joints and pars interarticularis.[47, 48]

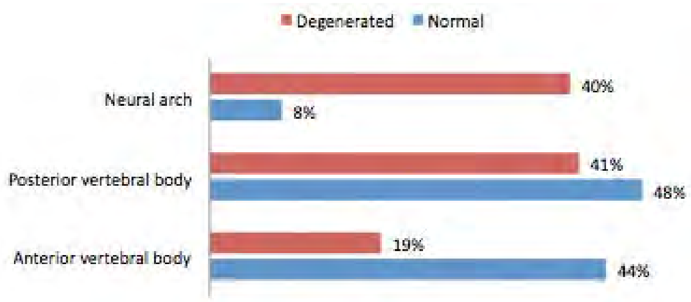

Figure 11: Effects of lumbar disc degeneration on compressive load sharing. In a normal disc, the neural arch resists only 8% of the applied compressive force, and the remainder is distributed between the anterior and posterior aspects of the vertebral body. Disc degeneration forces the neural arch to resist 40% of the applied compressive force, whereas the anterior vertebral body resists only 19%.[47]

Surgical Interventions

Vertebroplasty and Kyphoplasty

Vertebroplasty is a percutaneous technique to treat and stabilize a vertebral body fracture by injecting polymethymethacrylate (PMMA) in the vertebral body, under imaging guidance.[49] It eases pain in approximately 80% of patients. The main disadvantage associated with this technique is high percentage of extravertebral cement leakage, which could cause neurological damage. Also, with this technique, it is not possible to restore vertebral body height, which means that spinal deformity cannot be fully corrected.[50-52]

Kyphoplasty is a percutaneous technique where by inflatable balloon tamps are inserted into the vertebral body under fluoroscopic guidance. The balloons are then inflated and the end plates of the vertebral body are restored as close as possible to the original height. After this, the restored height is stabilized usually using PMMA.[53] The added benefits of kyphoplasty over vertebroplasty are restoration of vertebral body height, reduced kyphotic deformity, and less likelihood of cement leakage.[54, 55]

As mentioned previously, in a VCF the center of gravity of the body moves anterior, and thus a decrease of moment arm is compensated by increase of forces in the erector spinae. Even with injection of PMMA, this compensatory mechanism is not overtaken and it is stipulated that adjacent level VCFs (secondary VCFs) may be due to these higher forces. Therefore, restoration of height and angle is important to restore the natural biomechanics of the FSU and to mitigate secondary VCFs.[56]

Spinal Fusion and Dynamic Stabilization

Fusion, involving autografts, allografts, or man-made grafts, stabilizes the involved segments of the spine by supporting the anterior or posterior column. The fusion process may be augmented by using interbody cages with or without a rigid or dynamic fixation device. Overtime, the bone will grow around the porous cage forming a bone bridge that connects the vertebrae above and below. It is the most common procedure for disc degeneration, spondylolisthesis (with or without spinal stenosis), and low back pain. It is estimated that 200,000 spinal fusions were performed in 2002 in the US alone.[57] This procedure immobilizes the FSU, putting more stress on adjacent FSUs, and hence accelerates the degeneration of adjacent discs.

Stress must be applied to bones in order to promote fusion. Stress shielding is a major biomechanical problem which could lead to pseudarthrosis (non-union). This stress shielding could be due to the presence of intact facet joints at that level and pedicle-screw and rod system (Figure 12). On the contrary, if the spinal instrumentation is avoided, it may lead to migration of the cage (or bone graft). Recently, facet fixation with an interbody cage (or bone graft), or use of a semi-rigid pedicle-screw and rod system has been shown to increase the chances of union by reducing stress shielding.[57-59]

The philosophy behind dynamic stabilization is the restoration of physiological motion, load distribution, and intradiscal pressure. After lying supine at night or after a period of reduced gravity, the intradiscal pressure decreases (from 2.4MPa to 0.5MPa), and therefore leads to increase in its height and volume.[60] By analogy, mechanical decompression should lead to similar observations. Biomechanical tests conducted *in vitro* have shown disc pressure reduction and maintenance of lordosis using these dynamic stabilization systems.[16, 61]

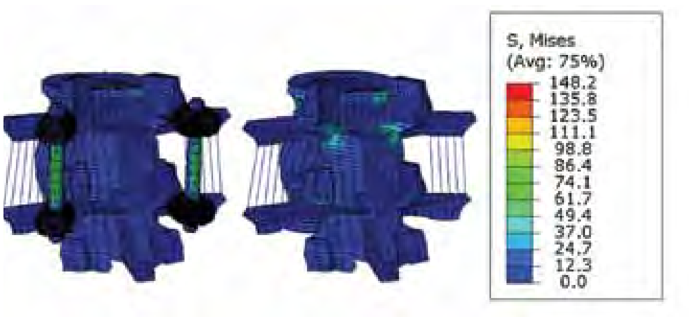

Figure 12: The figure above shows Von Mises stress (in MPa) contours of a validated L4-L5 spinal model with rigid (titanium) posterior instrumentation (left) and intact (right), for extension of 7.5Nm with 400N of follower load. The stress shielding of neural arch is seen in the case of posterior instrumentation (left) while intact (right) shows normal stresses on the neural arch.

Pedicle Screw Based Dynamic Stabilization Systems

This approach can be used for the treatment of facet joint pain, spinal stenosis, instability in general, or structural deformities- all due to disc degeneration.[62, 63] The Graf™ system is quite well known and established, but yet not accepted due to poor outcome and high revision rates. Studies on Dynesys™ have shown promising results like maintenance of disc height even after 26 months of implantation[64] and no progression of disc degeneration even after 34 months.[65] However, it was found that it shows less intradiscal pressure change in lateral bending when compared with intact and posteriorly destabilized units and almost no change during axial rotation and in neutral position (as shown by rigid fixation too).[66] The data also showed that this system doesn't affect the motion of adjacent vertebrae.[67] Screw loosening is a potential problem which develops with time.[64] Conflicting data is available in the literature as well.

Interspinous Spacers (ISS)

Some examples of ISS are Wallis (Abbott Spine, France), DIAM (Medtronic, USA), and X-Stop (St. Francis, USA). Typically, these are used for lumbar spinal stenosis as an alternative to laminectomy and spinal fusion, but can be used for other IDD related disorders.[68] After decompression, the ISS is inserted between the spinal processes using sizing distracter. Problems associated with ISS are fractures of the spinous processes, subsidence of the implant into the bone, and dislocation. Some authors claim it restricts motion instead of restoring it.[69]

Disc Arthroplasty and Nucleoplasty

Disc arthroplasty is a procedure in which the degenerated IVD is replaced with a disc prosthesis (or artificial disc such as CHARITÉ™, Depuy Spine, Inc. and ProDisc™, Synthes Spine, Inc.). Although studies suggest that they reduced pain up till 24 months from surgery, their long term effectiveness is unknown. Also, there is evidence of migration, prolapsed, and failure of prosthesis.[70, 71]

Studies on CHARITÉ™ arthroplasty have shown flexion-extension ROM ranging from 9 to 16 degrees at L4-L5 and 7 to 9 degrees at L5-S1.[72, 73] Similarly for ProDisc-L®, flexion-extension ROM obtained ranged from 6 to 7.7 degrees for functional spinal units between L3-S1.[74] As these ROMs are within physiological range for an intact spinal segment, these studies suggest that accelerated adjacent segment degeneration is mitigated.

Disc prostheses have different designs, leading to differences in their biomechanics after implantation. Single articulating prostheses have a static center of rotation, and therefore the motion of the FSU is constrained to a single IAR. This leads to stress concentration at the bone-implant interface and in the posterior elements with associated changes in the quality of motion. While dual articulating prostheses allow for mobility in the IAR dynamically over the range of motion, this motion may not be physiologic, due to lack

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of inherent stiffness as in native disc. Therefore, they lack flexural stiffness and shock absorption properties. Elastomeric prostheses (non-articulating) reproduce the dynamic position of the IAR in the human spine, while maintaining stiffness that may stabilize the motion of the IAR to approximate that of the native disc. They may provide both the normal motion with restrain and shock absorption.[75, 76]

Nucleoplasty is the replacement of the nucleus portion of the disc by a synthetic implant or hydrogel. This procedure is designed for an earlier stage of degeneration in which the AF is still intact. Various materials are utilized in these implants, including metals and ceramics, injectable fluids (NuCore™, Spine wave), hydrogels, inflatables, and elastic coils. In this method, most of AF and the endplates remain intact, preserving the tissue's natural structure and function. This approach is less invasive than a disc arthroplasty, and the major problem of implant fixation to the vertebrae through the endplate does not occur. The time required for this procedure is much shorter compared to the total disc replacement and may approach the time required for a discectomy.[77, 78]

Discectomy and Annular Closure

Discectomy is a minimally invasive procedure designed to reduce the pain caused by herniated disc tissue pressing against nerve roots in the spine. The aim is to remove pain and mitigate recurrent herniation. This procedure ends up damaging the AF. Suturing the AF was thought to be insufficient therefore many commercially available devices (like Xclose™ and INclose™) have an anchoring mechanism with suturing. These could only help contain NP in place but cannot compensate the damage made to the AF. Another commercially available device (Barricad™) can fully bridge the damage portion of AF and acts as a barrier for NP. Also, preliminary studies show that it reinforces the entire posterior portion of the AF and prevents further herniation. Hence, some authors consider it to be a novel device.[79, 80]

Conclusion

The cost of spine-related surgeries runs in billions of dollars every year.[81] With an aging population, these costs are bound to increase even further. In order for clinicians to choose the best solution for a given subject, it is imperative to they possess a basic understanding of the biomechanics involved. By the same token, engineers must have a deep background in the anatomy involved in surgery. By covering the biomechanically relevant anatomy of the spinal column, the changes in some key biomechanical characteristics with age, and appropriate surgical interventions, it is hoped that an interested clinician would feel at ease with some of the jargon and its clinical relevance.

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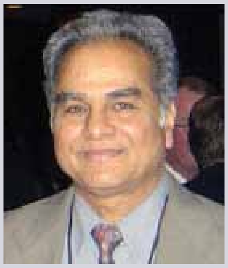

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As a researcher for over 35 years, Dr. Goel is considered a pioneer and global expert in the field of spine biomechanics. He currently serves as endowed chair and McMaster-Gardner professor of orthopedic bioengineering in the College of Engineering and the College of Medicine at Toledo University, as well as the co-director at the Engineering Center for Orthopaedic Research Excellence (E-CORE). He has two major textbooks, over 300 full-length peer-reviewed publications, and over 550 conference presentations to his credit. Dr. Goel is the President and CEO of GAMMA Spine, LLC as well as the vice president of Research and Design for Turning Point, LLC. He serves on the editorial boards for several prestigious scientific journals such as SPINE, Journal of Spinal Disorders, European Spine Journal, and the International Journal of Spine Surgery. Dr. Goel is also an international guest lecturer and visiting professor.

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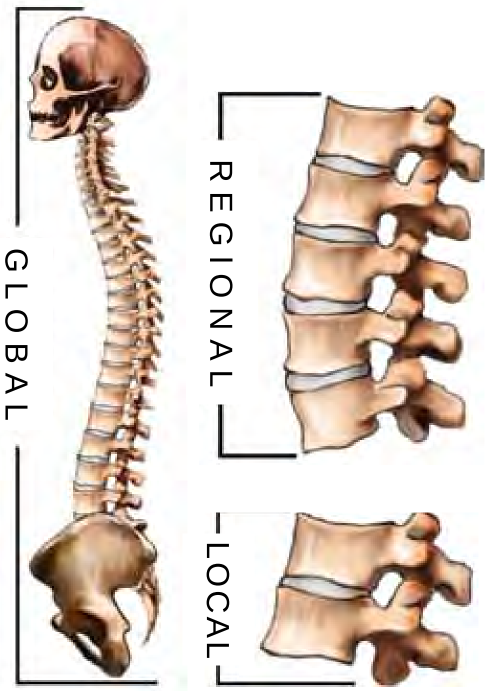
Spines in Motion Glossary

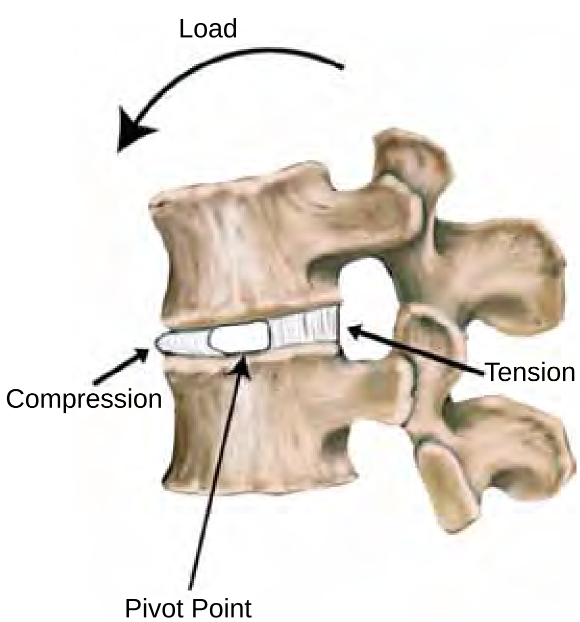


Spine Biomechanics: Perspectives

Global: The global perspective is all-inclusive; the entire skull, spinal column, and pelvis are in view.

Regional: The regional perspective is more narrowly focused; however, the region varies in size, it could include the entire cervicothoracic region (C1-T12), just the thoracic region (T1-T12), or only multiple thoracic segments (T4-T9).

Local: The local perspective usually pertains to a single motion segment-the functioning unit of the spine.



Global Biomechanics: Forces

Force: An action applied to a body which results in a change of state or movement.

Compression: A force that acts along the axis of the spine to push material together; the intervertebral discs act as shock absorbers and are flattened by compressive forces, such as gravity.

Tension: A force that acts along the axis of the spine to pull material apart, elongating the material; vertebral bodies and intervertebral discs are elongated by tension forces.

Shear: A force acting perpendicular to the surface it is acting on; a shear force acting on the spine may result in spondylolisthesis (anterior displacement or forward slippage of a vertebra in relation to the vertebra below).

Torque: Rotational forces perpendicular to the axis of the spine; an example would be twisting from side to side; excessive torque can result in torsional fractures.

Creep: The gradual deformation of a body due to a constant application of a load over a period of time; deformed intervertebral discs may occur as a result of continual loads and stress placed on the spine.

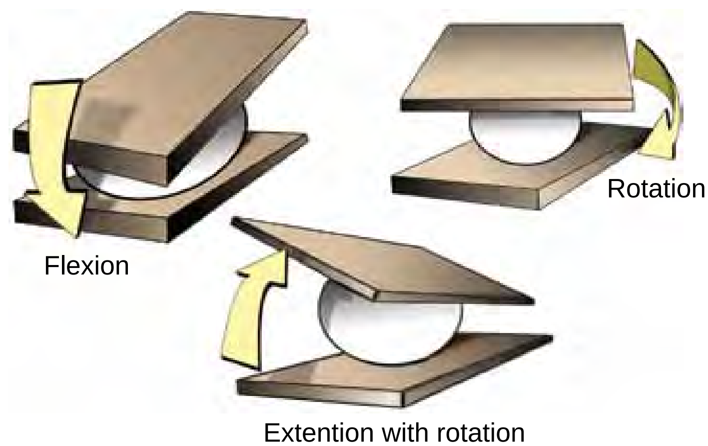
Relaxation: A reduction in stress or load overtime, but strain and deformation remains constant.

Global Biomechanics: Movement

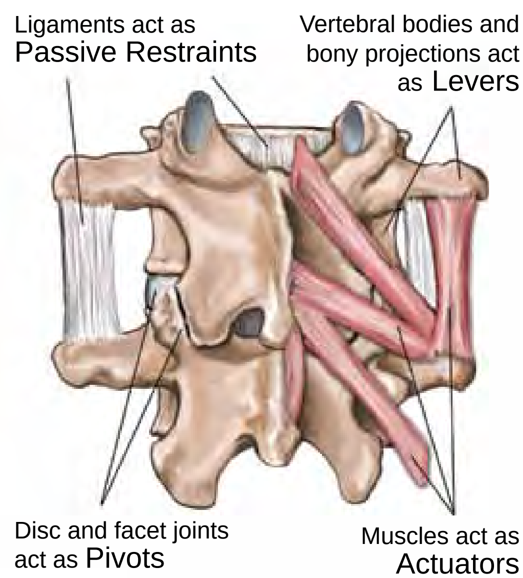
Flexion: A bending motion that results in decreasing the angle of a joint; flexion of the spine refers to the act of bending forward.

Extension: A bending motion that results in increasing the angle of a joint; extension of the spine refers to standing straight from a forward bend; extension is the opposite of flexion.

Rotation: Movement that moves around a longitudinal axis; for example, by turning your head to look to your right or left, you are rotating your spine.



Local Biomechanics: The Motion Segment



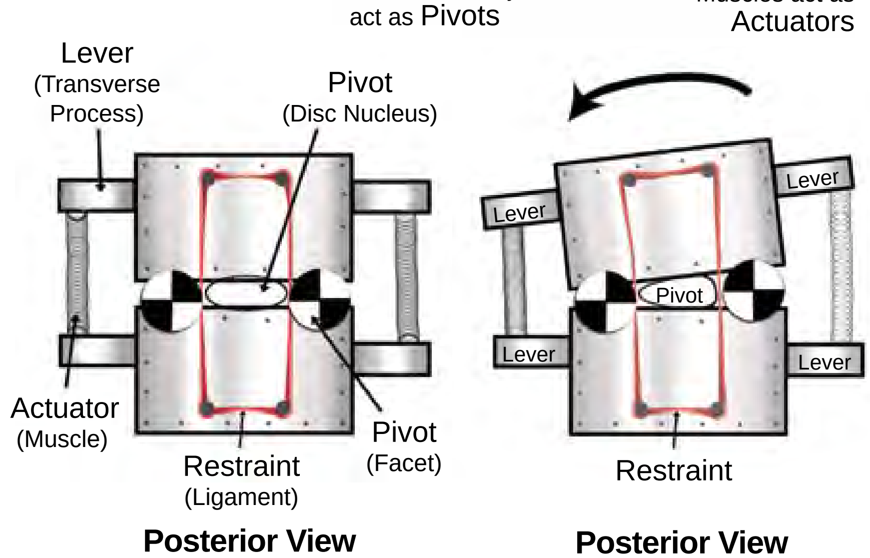
Motion Segment: The functional component of the spine that includes two adjacent vertebral bodies, the common intervertebral disc, and the facet joints that allow for three degrees of freedom (rotation, flexion/extension, lateral bending).

Actuators: The active forces that drive the movement of the motion segment; the anterior and posterior muscles exert active control on the levers.

Levers: Serve as attachment sites for actuators and restraints; the vertebral body and bony processes are insertion points for the muscles and ligaments.

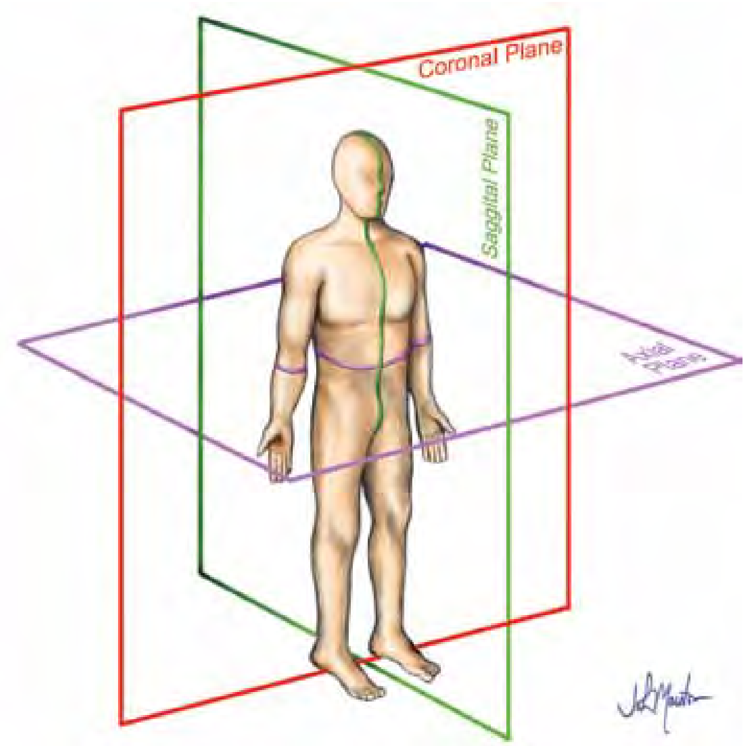
Pivots: The points that allow for rotation; the intervertebral discs and facet joints are pivot points that allow the vertebral bodies to have rotational movement around their axes.

Restraints: The forces opposing the actuators; provide stability and prevent excessive motion beyond normal ranges; the ligaments of the motion segments provide passive restraint on the levers.



Images courtesy of Medtronic, Inc.

Spine Glossary



Anatomical Planes

Axial plane: Divides the body into upper and lower parts, inferior and superior portions; also referred to as the transverse plane.

Coronal plane: Divides the body into front and back parts, anterior and posterior portions; also referred to as the frontal plane.

Sagittal plane: Divides the body into left and right parts; is referred to as the midsagittal or median plane when the body is bisected along the midline into equal halves.

Anatomical Views

Anterior: References the front surface of the body; located more towards the front portion of the body relative to another structure; for example: the nose is anterior to the ears.

Posterior: References the back surface of the body; located more towards the back portion of the body relative to another structure; the opposite of anterior; for example: the spine is posterior to the abdomen.

Distal: Further distance from a point of reference; typically applied to an extremity; for example: the wrist is distal to the elbow.

Proximal: Closer distance from a point of reference; typically applied to an extremity; the opposite of distal; for example: the knee is proximal to the toes.

Inferior: Located below a point of reference; directed downward closer to the feet; for example: the knees are inferior to the hips.

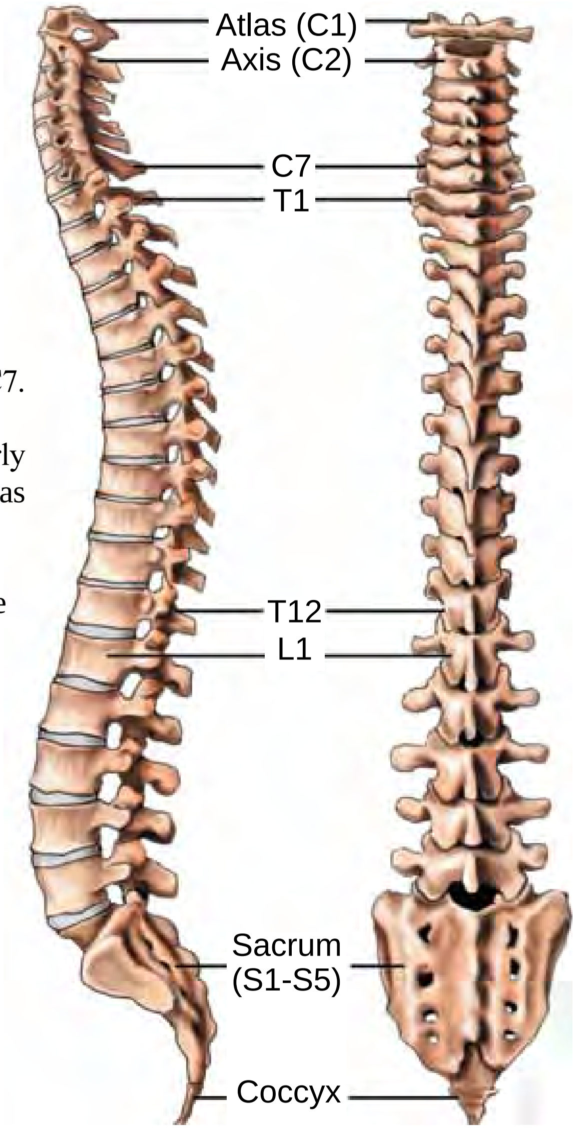
Superior: Located above a point of reference; directed upward closer to the head; opposite of inferior; for example: the head is superior to the shoulders.

Lateral: Located away from the midline of the body; for example: the shoulder is located lateral to the sternum.

Medial: Located closer to the midline of the body; opposite of lateral; for example: the belly button is medial to the hips.

Spinal Anatomy

Spinal column: The vertebral column extending from the base of the skull to the tailbone; consists of 33 bones including seven cervical vertebrae, twelve thoracic vertebrae, five lumbar vertebrae, five fused sacrum vertebrae.



Regions

Cervical: Relating to the neck or cervix; the first seven vertebrae; C1-C7.

Thoracic: Relating to the thorax; the twelve vertebrae located inferiorly to the cervical region and superiorly to the lumbar region; serves as attachment points for ribs; T1-T12.

Lumbar: Relating to section of the spine between the ribs and the pelvis; the five vertebrae superior to the sacrum; L1-L5.

Sacrum: An inverted triangle-shaped bone composed of five fused vertebrae without intervertebral discs; articulates with the lumbar spine at the lumbosacral joint; articulates with the hip bone at the sacroiliac joint; superior to the coccyx; S1-S5.

Coccyx: The small triangle-shaped bone composed of four to five fused rudimentary vertebrae; adjacent to the sacrum; known as the tailbone.

Ilium: Large upper part of the pelvis that serves as an articulation point for the sacrum; iliac bone frequently serves as a source for autogenous bone grafts.

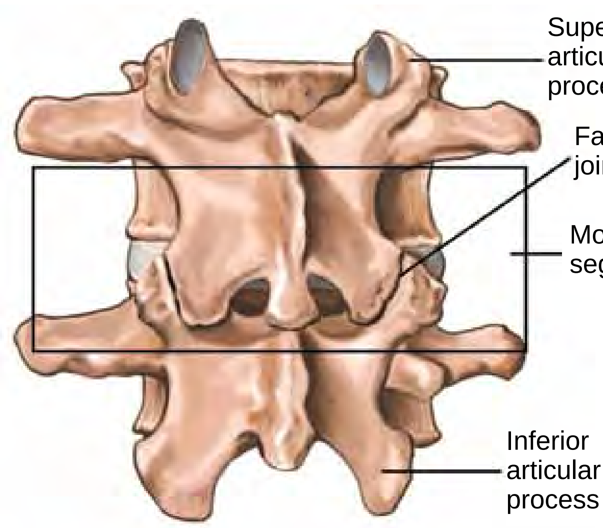
Curvature

Kyphosis: Spinal curvature of the thoracic and sacral regions; from a sagittal view, there is anterior concavity and posterior convexity; normal thoracic kyphosis is 20° to 40°; there is a wide range of sacral kyphosis.

Lordosis: Spinal curvature of the cervical and lumbar regions; from a sagittal view, there is anterior convexity and posterior concavity; normal cervical lordosis is 20° to 40°; normal lumbar lordosis is 30° to 50°.

Vertebral Anatomy

Articular process: There are four articular processes- two superior and two inferior- that extend posteriorly from each vertebra at the junction between the pedicle and the lamina.

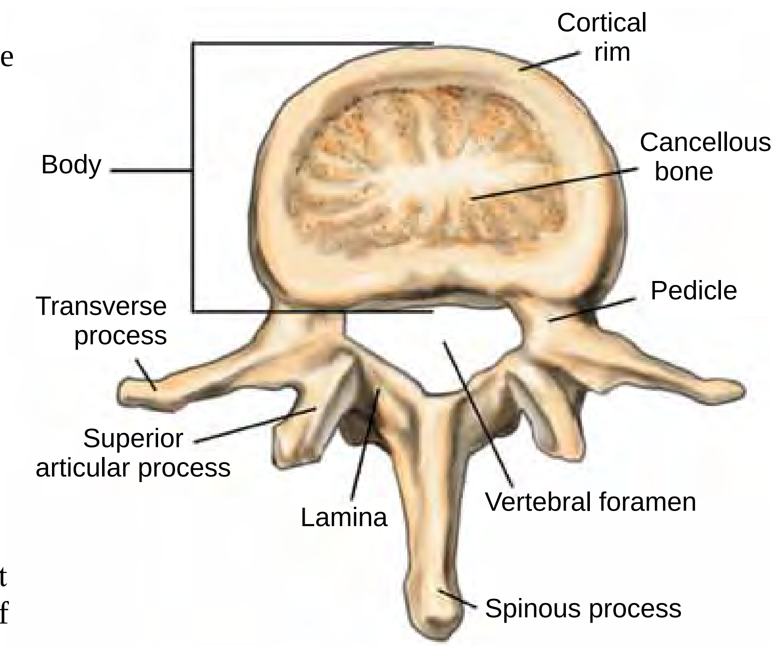


Facet joints: A synovial joint formed by the superior articular process and the inferior process of adjacent vertebrae; also known as the zygapophyseal joint.

Lamina: Each vertebra has two laminae which are flattened bony plates extending medially from the pedicles to the spinous process.

Motion Segment: The functional component of the spine that includes two adjacent vertebral bodies, the common intervertebral disc, and the facet joints that allow for three degrees of freedom-rotation, flexion/extension, lateral bending.

Pedicle: Each vertebra has two pedicles, which are bony processes connecting the dorsal side of the vertebral body with the laminae.



Spinous process: Bony projection extending posteriorly from the midline of the vertebra; serves as an insertion point for ligaments.

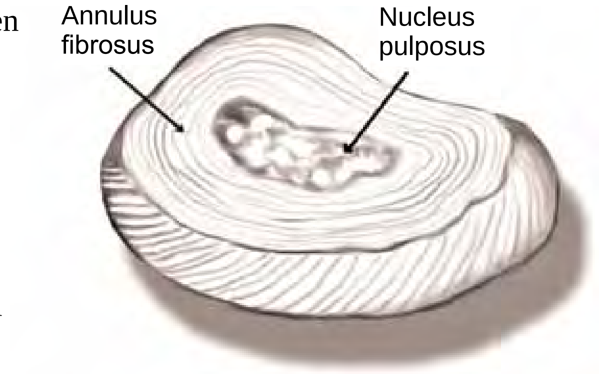
Transverse process: The left and right processes extending laterally from each pedicle on the vertebra.

Vertebral body: The main weight-bearing segment of the vertebra located anterior to the spinal cord; its cavity is composed of cancellous bone encircled by a protective cortical rim; the flat top and bottom surfaces are the attachment sites of the intervertebral discs.

Vertebral foramen: The opening formed by the anterior and posterior vertebral arches encasing the spinal cord and nerve roots. The vertebral foramen forms the spinal canal by stacking the vertebrae from the first cervical vertebra to the last lumbar vertebra.

Intervertebral Disc Anatomy

Intervertebral Disc: Fibrocartilagenous structure located between adjacent vertebrae; serves as a cartilaginous ligament by holding the vertebrae together; also has elastic properties to allow some movement at each vertebral level; there are a total of 23 discs.

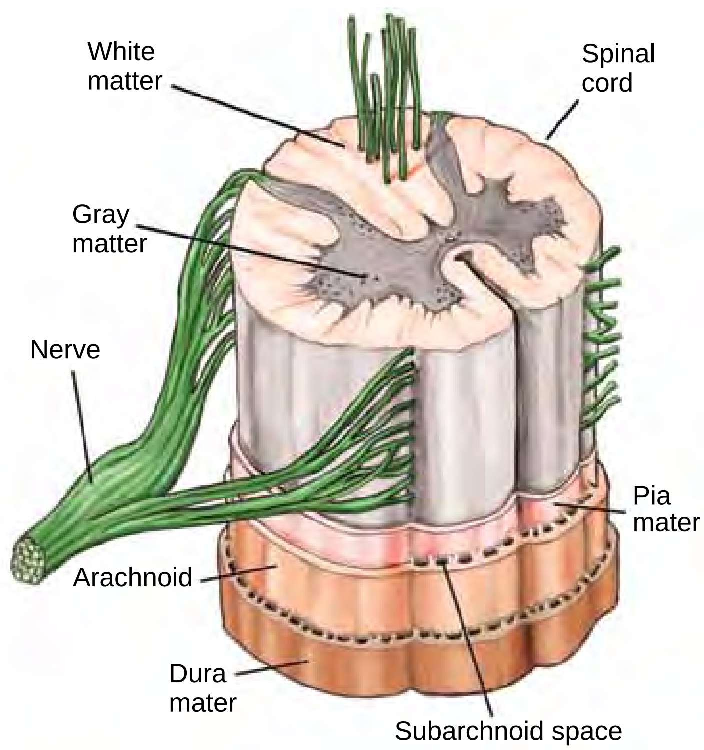


Annulus fibrosus: The outer protective layer of the intervertebral discs that surrounds the nucleus pulposus and is composed of rings of collagen fibers.

Nucleus pulposus: The inner gel-like portion of the intervertebral discs that holds most of the water content of the discs.

Nervous Tissue

Spinal cord: Part of the central nervous system; bundle of grey and white nervous tissue that extends from the medulla oblongata at the base of the brain, runs through the spinal canal, and terminates at the conus medullaris at the first lumbar vertebra. The spinal cord functions to relay sensory and motor information to and from the brain, and also acts independently of the brain to regulate certain reflexes.



Cauda equina: Bundle of spinal nerve roots in the spinal canal that extend below the conus medullaris.

Cerebrospinal fluid: Clear, colorless fluid produced in the brain and spinal cord; this fluid circulates throughout the central nervous system to deliver nutrients, remove waste, and give protection to the brain and spinal cord by acting as a shock absorber.

Anatomy

Pia mater: The delicate, innermost layer of the meninges-protective membranes covering of the brain and spinal cord.

Subarachnoid space: The cerebrospinal fluid filled space between the pia mater and the arachnoid mater.

Arachnoid mater: The middle of the three meningeal layers; named for its spider web-like filaments that extend through the subarachnoid space to the pia mater.

Subdural space: The small space located between the arachnoid mater and the dura mater.

Dura mater: The tough, outermost later of the coverings of the central nervous system.

Epidural space: The outermost layer of the spinal canal, located outside the dura mater.

*To learn more about your spinal health, please visit *www.spinerf.org. Images courtesy of Medtronic, Inc.*

Neck and Back Pain Affects Millions

The Spinal Research Foundation is a non-profit organization dedicated to improving spinal health care through research, education, and patient advocacy. Located in Reston, Virginia, 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.

The Spinal Research Foundation has made remarkable progress in scientific research associated with neck and back pain. 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 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 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.***

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.

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- 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.

www.SpineRF.org






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Straight Talk about Spinal Health

If you are concerned about spinal health, and want more information than what is available on a commercial medical website, the Spinal Research Foundation can help.

Our free resources and active online community are available 24/7 to support you and inform you about spinal health, spinal conditions, treatment options, exercise and wellness, and hope for living pain free.

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SRF SPINAL RESEARCH FOUNDATION

Spinal Research Foundation Research Partners

The Spinal Research Foundation has named 24 Research Partners across the country that share one core mission: improving spinal health care through research, education, and patient advocacy. These centers offer the best quality spinal health care while focusing on research programs designed to advance spinal treatments and techniques.

Allegheny Brain and Spine Surgeon
James P. Burke, MD, PhD
201 Howard Ave, Building E-1
Altoona, PA 16601
814-946-9150
centralpabrainandspinesurgeons.com

Atlanta Brain and Spine Care
Regis W. Haid, Jr., MD
2001 Peachtree Rd, NE, Ste 575
Atlanta, GA 30309
404-350-0106
atlantabrainandspine.com

Colorado Comprehensive Spine Institute
George A. Frey, MD
3277 South Lincoln St
Englewood, CO 80113
303-762-0808
coloradospineinstitute.com

The Hughston Clinic
J. Kenneth Burkus, MD
6262 Veterans Parkway
Columbus, GA 31909
706-324-6661
hughston.com

Indiana Spine Group
Rick C. Sasso, MD
13225 N. Meridian St
Carmel, IN 46032
317-228-7000
indianaspinegroup.com

Inova Research Center
Zobair M. Younossi, MD, MPH
3300 Gallows Rd
Falls Church, VA 22042
703-776-2580

Menlo Medical Clinic
Allan Mishra, MD
1300 Crane St
Menlo Park, CA 94025
650-498-6500

MUSC Darby Children's Research Institute
Inderjit Singh, PhD
59 Bee St, MSC 201
Charleston, SC 29425
1-800-424-MUSC

New England Neurosurgical Associates, LLC
Christopher H. Comey, MD
300 Carew St, Ste One
Springfield, MA 01104
413-781-2211

Oregon Neurosurgery Specialists
Robert J. Hacker, MD
Andrea Halliday, MD
3355 RiverBend Dr, Ste 400
Springfield, OR 97477
541-686-8353
oregonneurosurgery.com

The Orthopaedic and Sports Medicine Center
Gerard J. Girasole, MD
888 White Plains Rd
Trumbull, CT 06611
203-268-2882
osmcenter.com

The Orthopedic Center of St. Louis
Matthew F. Gornet, MD
14825 N. Outer Forty Rd, Ste 200
Chesterfield, MO 63017
314-336-2555
toc-stl.com

Princeton Brain and Spine Care
Mark R. McLaughlin, MD, FACS
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Langhorne, PA 19047
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princetonbrainandspine.com

River City Orthopaedic Surgeons
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Louisville, KY 40272
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rivercityortho.com

Rutgers University
Department of Biomedical Engineering
Noshir A. Langrana, PhD, PE
599 Taylor Rd
Piscataway, NJ 08854
732-445-4500

South Coast Orthopaedic Associates
Aleksandar Curcin, MD, MBA
2699 N. 17th St
Coos Bay, OR 97420
541-266-3600
scoastortho.com

Southern Brain and Spine
Najeeb M. Thomas, MD
4228 Houma Blvd, Ste 510
Metairie, LA 70006
504-889-7200
sbsdocs.net

Spine Colorado
Jim A. Youssef, MD
Douglas G. Orndorff, MD
1 Mercado St, Ste 100
Durango, CO 81301
970-375-3697
spinecolorado.com

The Spine Clinic of Los Angeles
Larry T. Khoo, MD
1245 Wilshire Blvd, Ste 717
Los Angeles, CA 90017
213-481-8500
spineclinicla.com

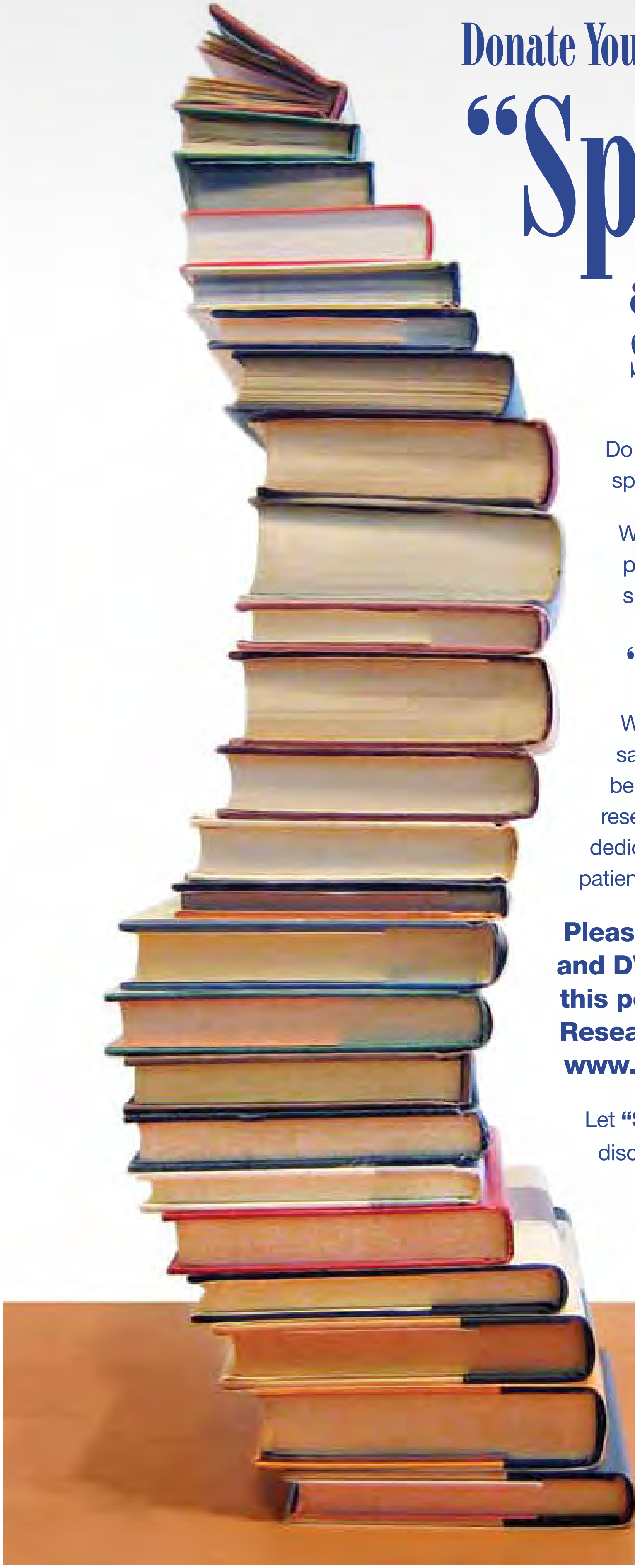
SpineCare Medical Group
Paul J. Slosar, Jr., MD
San Francisco Spine Institute
1850 Sullivan Ave
Daly City, CA 94015
650-985-7500
spinecare.com

Twin Cities Spine Center
James D. Schwender, MD
913 East 26th St, Ste 600
Minneapolis, MN 55404
612-775-6200
tcspine.com

University of Minnesota Medical Center, Fairview
David W. Polly, Jr., MD
2450 Riverside Ave, South
Minneapolis, MN 55454
612-672-7575

The Virginia Spine Institute
Thomas C. Schuler, MD, FACS, President
Brian R. Subach. MD, FACS
Director of Research
1831 Wiehle Ave
Reston, VA 20190
703-709-1114
spinemd.com

Virginia Therapy & Fitness Center
Richard A. Banton, PT, DPT, ATC
E. Larry Grine, PT, MSPT, ATC, CSCS
1831 Wiehle Ave
Reston, VA 20190
703-709-1116
vtfc.com



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Journal of the Spinal Research Foundation
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Reston, VA 20190

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I would prefer to receive this publication

- ❑ Less often
- ❑ More often
- ❑ As is (twice a year)

Of the last four issues of the *Journal* (Success of Spinal Health Care, Evolution of Spine Health Care, Obesity and Disease, Spines of Service), how many have you read?

❑ Zero ❑ One ❑ Two ❑ Three ❑ Four

Which articles from this issue did you read?
(Check all that apply)

- ❑ Editor's Note
- ❑ President's Note
- ❑ Issue Overview
- ❑ We've Got Your Back: Reston, VA
- ❑ Spine Tale: Scott
- ❑ Spine Tale: Ferguson
- ❑ Ask the Expert
- ❑ Biomechanics of the Spine
- ❑ Sporting Activities and the Lumbar Spine
- ❑ Spinal Biomechanics of the Golf Swing
- ❑ Force Transfer in the Spine
- ❑ Spinal Biomechanics by Age

On a scale of 1 (not interested) to 5 (very interested), what is your interest level on the following topics:

	1 (not interested)	2	3	4	5 (very interested)
Spine Conditions	❑	❑	❑	❑	❑
Treatment Options	❑	❑	❑	❑	❑
Patient Stories	❑	❑	❑	❑	❑
Ask the Expert	❑	❑	❑	❑	❑
Research Updates	❑	❑	❑	❑	❑

What other features/topics are you interested in seeing in future issues?

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On a scale of 1 (very bad) to 5 (excellent), how would you rate the following aspects of the *Journal*:

	1 (very bad)	2	3	4	5 (excellent)
Text Size	❑	❑	❑	❑	❑
Images	❑	❑	❑	❑	❑
Overall Content	❑	❑	❑	❑	❑
Length	❑	❑	❑	❑	❑
Depth of Explanation	❑	❑	❑	❑	❑
Level of Difficulty	❑	❑	❑	❑	❑

On a scale of 1 (not interested) to 5 (very interested), how would you rate your overall interest with the *Journal*?

1	2	3	4	5
❑	❑	❑	❑	❑

Have you visited the Spinal Research Foundation's Website (www.spinerf.org)?

❑ Yes ❑ No

Which of the following best describes you?

- ❑ I suffer or have suffered from a spine condition
- ❑ I know someone who has suffered from a spine condition
- ❑ I am a medical professional
- ❑ None of the Above

What is your age group?

- ❑ Under 30
- ❑ 30 to 39
- ❑ 40 to 49
- ❑ 50 to 59
- ❑ 60 to 69
- ❑ Over 70

What is your gender?

❑ Male ❑ Female

Do you have any additional comments or concerns?

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"It has been my pleasure and passion to care for patients with spinal problems throughout my career. Finding better ways to diagnose and treat these problems has been the driving force behind my clinical care and my research. Today the greatest challenge is figuring out how to define the value of this care and helping patients who are in need maintain access to care that can help them."

SPINAL HERO

David W. Polly, Jr., MD

Professor, Chief of Spine Service
Department of Orthopaedic Surgery
University of Minnesota

The Spinal Research Foundation recognizes our outstanding clinicians and researchers in the field of spinal health care and 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 David W. Polly, Jr., MD as a Spinal Hero.

Thank You!

The Board of Directors of The Spinal Research Foundation is grateful for the continued investment of our donors and extends its appreciation to all who have contributed.

Through the generous support of our donors, The Spinal Research Foundation has been able to significantly expand the scope of our scientific research and educational programs. These gifts have been utilized to embark on projects geared toward understanding the mechanisms of spinal diseases and developing new treatments for these conditions. This work would not be possible without the support of our donors.

To make a donation in order to improve the quality of spinal health care in America visit:

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