Transformation of Spinal Deformity Treatment

Abstract

Treatment of spinal conditions dates back to ancient times. There has been a long history of treatment of scoliosis and other spinal deformities using both non-operative and operative techniques. One of the most common techniques used by spine surgeons to correct spinal problems is spine fusion. The purpose of a spinal fusion is to create a rigid union between two separate segments of the spine to correct malalignment or instability. Many different types of spinal instrumentation have been developed to help facilitate spine fusion, including devices such as rods, plates, hooks, wires, and screws.

Treatment of spinal deformity has improved due the development of enhanced spine imaging, advanced surgical techniques, and improved spinal instrumentation. These advances allow surgeons to help their patients maximize their quality of life while striving to minimize the potential for complications. Advances in the past few decades have improved correction of spinal deformity and decreased the morbidity of surgical procedures, while allowing for earlier return to activity after surgery. Current research focuses on improving and developing motion preserving surgical techniques and safer, less invasive surgical options.

History of Spinal Deformity

There are records of spinal treatments dated back to thousands of years ago. Fractures of the bones of the neck causing paralysis have been documented as early as 1550 B.C. in ancient Egyptian writings. At that time, patients were treated by priests who applied bandages and helped patients to rest. Hippocrates (460–337 B.C.) was an ancient Greek physician who is considered to be the father of western medicine. Hippocrates worked to develop methods for treating fractures of the spine by positioning patients in such a way as to correct a deformity that developed after a spinal fracture. Using his techniques, therapists used wooden constructs to place forces against the patient’s spine in order to correct or reposition fractures. A number of physicians built off of Hippocrates’ early work to develop more advanced techniques for treating fractures with a variety of traction or spinal manipulation devices. These included techniques such as hanging patients on a ladder or placing patients on a table with ropes attached around the torso and ankles.

Scoliosis, another condition which causes deformity, is derived from a Greek word meaning a lateral curvature of the spine. The word scoliosis was coined by Galen of Pergamon (129 to 200 A.D.). Scoliosis is an abnormal curvature of the spine that affects 1 to 3% of the general population of the United States, or approximately seven million people. Bracing is used to prevent and/or limit progression of scoliosis curves during childhood and adolescence. This often involves wearing a brace or orthotic device to help maintain the corrected posture.

Figure 1. The Hippocratic board was used to place corrective forces on the spine using bands and straps to correct spinal deformities. Image source: the illustrated comments of Apollonius of Kitium on the Hippocratic treatise On Articulations. Bibliotheca Medica Laurenziana, Florence.

Figure 2. The Hippocratic ladder was used for the correction of spinal deformities with the head pointing downwards. Image source: the illustrated comments of Apollonius of Kitium on the Hippocratic treatise On Articulations. Bibliotheca Medica Laurenziana, Florence.
periods of maximal patient growth for moderate curves (generally between 25° to 45°). Surgical treatment is considered for patients with curves greater than 40° to 50°. There has been a documented risk for continued curve progression from 0.5° to 2° per year for curves greater than 50° in adults.

Patients with spinal deformities may have complaints related to cosmesis including difficulties with rib hump, shoulder height, pelvic obliquity, or truncal shift. If curves are left untreated, more severe conditions may develop. Pulmonary function has been shown to decrease as curves increase in size. Pulmonary function becomes significantly limited as thoracic scoliosis becomes more severe, particularly for curves that are greater than 80°.4

Figure 3. Patients with spinal deformities may notice changes in their alignment including rib hump, shoulder height, pelvic obliquity, or truncal shift. Image courtesy of Medtronic, Inc.

Evolution of Spine Surgery

Operative intervention for spinal conditions was initially slow to develop because of difficulties with infections. This situation changed beginning in 1867 when antisepsis became a standard practice, which increased safety of operative procedures. Surgical intervention was also greatly advanced with the development of local anesthesia and general anesthesia.1 The benefits of surgical intervention include the ability to release pressure on neurologic elements as well as stabilization of the spine to allow for early patient mobilization. Decreasing the length of bed rest has been influential in minimizing further complications that can result from prolonged inactivity including pneumonia, blood clot, pulmonary embolism, and pressure sores.

The first laminectomy was performed in the United States in 1829 when Dr. Alban Gilpin Smith removed a fractured spine bone to treat a patient with progressive leg weakness. This patient reportedly recovered well and improved neurologically. Later in 1888, Dr. Smith successfully removed a spinal tumor that was causing neurolologic compression and was able to perform more involved surgeries to correct vertebral bones damaged by tuberculosis infections.4 Because tuberculosis was so common in the United States at the time, most spinal surgeries were performed for this reason. However, as time progressed, surgery also began to be used for other conditions including spinal deformities, fractures, and tumors.

History of Spine Fusion

The purpose of a spinal fusion is to create a rigid union between two separate segments of the spine to correct segmental malalignment or instability. This is similar to trying to get two edges of a broken bone to heal together after a fracture. Fusion does eliminate motion at that segment; however, this may be appropriate for patients with instability or deformity.

Spinal fusion was initially performed by placing bone graft along the bones of the spine and fusing the spine “in situ.” That is, fusing the spine in its current position without an attempt of correcting spinal alignment. The earliest fusion procedures were performed without the use of instrumentation. In order to support the spine and avoid motion while the fusion was healing, patients were placed in casts, traction, or braces after their surgeries. This technique required prolonged periods of bed rest and immobility ranging from six months to one year while patients were in casts or traction and ultimately led to very high rates pseudarthrosis (an area of the fusion that did not heal). Russell Hibbs performed the first spinal fusion for scoliosis in 1914. The pseudarthrosis rate of initial spinal fusion surgeries performed by Dr. Hibbs was approximately 60%. Starting in the 1940s, there was a period of approximately twenty to thirty years when posterior fusion and cast immobilization were the standard of care. As fusion techniques improved, pseudarthrosis rates were typically around 45%.

Spine fusion was also used during this time to treat fractures of the spine. Spine trauma can result in instability as a result of a fracture to the bone or an injury to the ligaments that support the bones of the spine. Many fractures can be treated conservatively with...
bracing or casting; however, with specific instability patterns, surgical intervention has been recommended.

**Spinal Instrumentation**

Surgery for scoliosis was the first widespread application of spinal instrumentation. Over the years, many different types of techniques and instrumentation have been developed to help correct spinal curvatures and facilitate fusion. Specific instrumentation types include: metal plates, rods, hooks, wires, and screws which join together to support the spine during the time that it is fusing. The use of metallic implants to stabilize segments allows for faster and more effective fusion. The early instrumentation systems functioned to act as an “internal splint” which held the spine in position until the surgically applied bone graft developed into a fusion mass.

There are many goals that are achieved by spinal instrumentation. For patients with spinal deformities, implants should maintain correction of the deformity after surgery until spinal fusion can occur. Solid immobilization with spinal instrumentation enhances the rates of bony fusion. For patients with instability or fractures, spinal instrumentation allows for stabilization of this instability and facilitates early mobilization to help avoid potential side effects of prolonged bed rest. In recent years, the number and types of spinal implants available has greatly increased. To best understand the use of instrumentation, one must fully understand the spinal disorder that is to be treated and the specific goals of treatment.

The evolution of modern spinal instrumentation systems began in the late 1950s with the development of the Harrington hook and rod system. At this time, this was a major medical breakthrough that allowed for enhanced stability and curve correction for patients with spinal deformity. The Harrington rod and hook system consisted of a rod with a hook at either end. These hooks attached to the spine at the top and the bottom of the curvature. By distracting across the rod, surgeons were able to partially reduce spinal deformities. This technique was most commonly used to treat paralytic scoliosis resulting from poliomyelitis which was very common at that time. This system was limited in that it only attached to the spine in two locations. Additionally, this did not allow surgeons to accurately re-create a normal spinal alignment, particularly in the sagittal plane (viewed from the side) because the rod was straight and not curved as the spine is naturally.

Harrington distraction instrumentation did address the frontal (S-shaped) curve of the scoliosis pattern; however, the sagittal contour of the patient was often negatively influenced, particularly the lumbar spine. The distraction forces of the Harrington instrumentation tended to decrease the amount of lumbar lordosis (swayback) which led some patients to develop a “flat-back syndrome.” These patients developed low back pain and a loss of normal standing alignment when viewed from the side.5,6

Segmental instrumentation was first introduced by Eduardo Luque of Mexico in 1973. He used a two-rod system in the back of the spine which was attached to the spinal bones with wires at each level of spine. These rods were contoured in multiple planes which did allow for surgeons to fuse the spine in a more normal alignment. By attaching the implants to the spine at multiple levels, the force exerted on individual level was reduced, and the overall potential for spinal correction was increased. By using these powerful techniques, Dr. Luque was able to treat many of his patients without the use of long-term casting or bracing after surgery.
Dr. Luque reported on a series of 322 patients treated with his techniques in 1982. Failure of the instrumentation occurred in 27 of these patients and 5% of the patients developed a pseudoarthrosis. This was a particularly low rate at that time, especially considering that the majority of Dr. Luque’s patients were treated for neuromuscular conditions including poliomyelitis and cerebral palsy and were therefore at a high risk for postoperative problems.\(^7\)

Segmental fixation with wires did improve correction of the frontal plane and allowed for the maintenance of a physiologic sagittal contour; however, spinal deformities occur in three dimensions, and none of these early techniques allowed for rotational correction during surgery. In the 1980s, a new treatment system was introduced using the Cotrell-Dubousset instrumentation system (CD). The CD instrumentation system allowed for multiple fixation points along the spine using a variety of hook and rod combinations. This instrumentation system allowed for correction of the spine in the coronal, sagittal, and axial (rotational) planes during spinal reconstructions, which was a major technical advancement.

In Dr. Cotrell’s original report of 250 patients, no patient was treated with postoperative bracing or casting. The average correction of scoliosis was 66%, and sagittal contour was also improved. Less than 5% loss of the correction was noted over long-term follow-up. No failures of the instrumentation were noted.\(^8\)

Another advancement in spinal instrumentation was the development of crosslinking devices. Cross-links are simple transverse implants that connect between rods that are placed on each side of the spine. These devices provide additional stability to spinal instrumentation. The TSRH implant system was the first to utilize cross-links and was developed at the Texas Scottish Right Hospital in 1983. This system also made extension of a previously implanted system to another system possible.\(^9\)
Recent Surgical Advances

Surgical techniques have developed to be able to access and attach to the spine and correct deformities from the front (anterior) as well as the back (posterior) side of the spine. The early benefit of surgeries performed through the front of the spine was that they allowed direct access to the bones and discs in the front of the spine and offered the benefit that fewer total levels of the spine needed to be fused in cases of scoliosis. As techniques improved for surgery on the front of the spine, implants were also developed to help fill bone defects resulting from infections or tumors. A variety of titanium cages, bone grafts, and other devices have been developed for this purpose.

Advancements in spinal technologies and spinal surgery technologies continued in the 1990s. These new systems have developed techniques that allow for the spine to be fixed segmentally, meaning that attachment of metal implants to the rod is achieved at every level that is being addressed. Stronger segmental fixation of the spine has allowed for better correction of spinal deformities, increased rates of bone healing or fusion after surgery, and decreased rates of instrumentation failure. Most recently, a trend has been towards an increased use of pedicle screw instrumentation to allow for spinal fixation. Pedicle screws are placed into a specific anatomic area of the spine from a posterior approach. Surgeons began using pedicles screws in 1988. The initial constructs were pedicle screws in the lower lumbar spine where they were easier to place due to larger bone size, with continued use of hook and wire patterns in the upper end of scoliosis reconstruction.

Figure 7. Crosslinks are transverse implants that connect between rods that are placed on each side of the spine to provide additional stability to spinal instrumentation. Image courtesy of Medtronic, Inc.

Figure 8. Scoliosis correction using segmental pedicle screw fixation at each level of the spine.
These rigid segmental fixation systems allow most patients to be mobile immediately after surgery without postoperative immobilization which is a benefit not offered by previous systems. However, there are some disadvantages to the newer instrumentation systems. First, increased correction of spinal deformity can be associated with an increase in neurologic injuries. In addition, the instrumentation systems were more bulky than previous implants and were noted underneath the skin, particularly in very thin patients. Finally, as more implants are utilized for each surgery, the overall cost of each surgery is more expensive.

Pedicle screw fixation is more rigid than previous hook, rod, or wire implants and has therefore allowed for improved correction of spinal curvatures and higher fusion rates. Another benefit of pedicle screw implants is that they require fewer segments to be instrumented and fused during deformity correction. In 1995, Se-II et al. reported an average scoliosis correction of 72% with all pedicle screw constructs, and a loss of correction over time at only 1% versus 6% previously documented with hooks. They also noticed an increased rotational correction at 59% with pedicle screws versus a 19% correction with hook construct.

Kim et al. subsequently evaluated the safety of pedicle screw placement in the thoracic spine over a ten-year period with of 3,204 screws implanted. Screws were analyzed by a computerized tomography (CT) scan, and 6.2% of screws were noted to have some moderate cortical perforation. Of these screws, none were associated with any neurologic, vascular, or visceral complications. Kim et al. also evaluated the average number of levels fused comparing hooks versus screw systems. They noted that the pedicle screws saved an average 0.8 levels per patient when compared with hook constructs.

The use of pedicle screw implants has also allowed surgeons to perform more complex spinal reconstructions including spinal osteotomies. With these procedures, complex and rigid spinal curvatures can be addressed by cutting away portions of the spine bone (osteotomy) that are involved in the deformity, allowing a greater re-approximation of normal coronal and sagittal contours.

Ongoing Research

Current research is also focused on the use of non-fusion techniques, particularly for young patients with spinal deformity. New techniques have been developed that allow for a partial correction of spinal deformity without a fusion until the completion of spinal growth. These techniques have included the use of vertebral stapling, growing rods, and Vertical Expandable Prosthetic Titanium Rib (VEPTR) placement.

Vertebral stapling is a procedure that is used for teenagers with progressive moderate scoliosis. During the procedure, staples are placed on the convexity.
Back to the Future

Robotic Spine Surgery

Robot-guided spinal surgery offers many potential advantages to patients and surgeons including improving the safety of minimally invasive as well as complex surgical procedures, improving the accuracy of spinal instrumentation, and minimizing the use of radiation during surgery. Robot-guided spine surgery utilizes highly accurate, state-of-the-art technology for the treatment of many spinal conditions including degenerative spinal conditions, spine tumors, and spinal deformities.

How It Works

The Mazor Robotics Renaissance™ system is one of the only robotic guidance products in the United States used for implanting devices during spine surgery. The Mazor Robotics system allows the surgeon to use the images from a CT scan that are taken before surgery to create a blueprint for each surgical procedure. The CT scan information is loaded into a computerized 3D planning system which allows the surgeon to plan the surgical procedure with a high degree of precision before ever entering the operating room.

Figure 11. Growing rods are attached to the spine at the top and the bottom of the curvature, but do not fuse the spine in the motion segments in the middle. These rods are periodically lengthened, which allows for continued spinal growth at the non-fused segments. Case courtesy of Lawrence G. Lenke, MD.
In the operating room, the surgeon does all of the actual work of the surgery. The robot-guidance system is a tool that helps to guide the surgeon’s instruments, based on the previous planning, to place spinal implants with a high degree of accuracy. During the surgery, the robot is placed near the patient either by attaching it to the bed or directly to the spine of the patient. The robot is approximately the size of a 12-ounce beverage can with a small arm attached. The robot has the ability to bend and rotate in order to place its arm on the spine in a very specific location and trajectory. This highly accurate guidance can improve the surgeon’s ability to safely place implants, particularly when working through very small incisions (minimally invasive surgery) or when dealing with complex anatomy (spinal deformity or previous spine surgery).

Scoliosis Correction Surgery

Surgery for scoliosis involves the use of spinal instrumentation such as screws, rods, hooks, and wires which are placed along the spine. Surgery treats but does not cure scoliosis; it corrects the abnormal curvature and prevents further progression of the disease. Surgical treatment of scoliosis requires a high degree of planning and precision. Each specific curve pattern is

---

**Figure 12.** CT scan images of the spine are taken prior to surgery and the exact location of spinal implants is blueprinted with 3D software. The orange and purple lines represent screws that are to be placed into the bones of the spine.

**Figure 13.** The Mazor Robot is attached to the spine of the patient and the arm is helping to guide the surgeon’s hand during a minimally invasive surgery. Image courtesy Mazor Robotics, Ltd.
unique, and many patients with scoliosis have unusually shaped bones of the spine which make surgery more challenging.

Robot-guided scoliosis correction offers increased precision of instrumentation placement and therefore an increase in the safety of the surgical procedure. It offers the surgeon the ability to carefully plan ahead before entering the operating room and design the ideal procedure for each patient. Studies have validated superior clinical results for adolescent scoliosis with robotic technology based on improved accuracy of implant placement and safety. In a recent study of 120 teenagers with scoliosis, robot-guided surgery was found to achieve 99.7% accuracy of 1,815 implants placed.4

Figure 14. The x-ray on the left shows a patient with thoracolumbar scoliosis. The middle image demonstrates the pre-operative blueprint showing the location where screws will be placed during scoliosis correction surgery. The x-ray on the right shows the final location of the implants after surgical correction.

Figure 15. X-rays taken before and after scoliosis correction surgery.
Robot-guided spine surgery is a promising new technology that has many advantages and may allow surgeons to perform less invasive surgical procedures with smaller incisions, less bleeding, faster recovery, and shorter hospital stays. Robot-guidance can also increase the accuracy and safety of surgical procedures and allow procedures to be performed with less intraoperative radiation exposure to patients and health care providers.

**Conclusion**

Treatment of spinal deformity has improved due the development of advanced surgical techniques and improved spinal instrumentation. These advances allow surgeons to help their patients maximize their quality of life while striving to minimize the potential for complications. Advances in the past few decades have improved correction of spinal deformity and decreased the morbidity of surgical procedures, while allowing for earlier return to activity after surgery. Current research focuses on improving and developing motion preserving surgical techniques and less invasive surgical options.

**REFERENCES**


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

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

Blair K. Simonetti, P.A.-C.

Blair is a physician assistant at the Virginia Spine Institute. She obtained a Bachelor of Science in Physician Assistant Studies from Long Island University-Brooklyn, NY and a Bachelor of Science in Biology from Loyola College, MD. Her residency and fellowship focused specifically on medical and surgical management of spinal disorders and she holds licenses from both the Virginia and Maryland Boards of Medicine.