Evolution in the Treatment of Spinal Deformity and Spinal Instrumentation

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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 presently 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 to 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, decreased the morbidity of surgical procedures, and allowed for earlier return to activity after surgery. Current research focuses on improving and developing motion preserving surgical techniques and less invasive surgical options.

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History of Spinal Deformity

The treatment of spinal conditions dates back to ancient times. 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, therapist used wooden constructs to place forces against the patient's spine in order to correct or reposition fractures (Figure 1A). 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 (Figure 1B).

Scoliosis is an abnormal curvature of the spine that affects 1% to 3% of the general population, or approximately seven million people in the United States. Bracing is used to prevent and/or limit progression of scoliosis curves during periods of patient growth for moderate curves (generally between 25° to 45°). Surgical treatment is considered...
for patients with curves greater than 40 to 50º. There has been a documented risk for continued curve progression from 0.5 to 2º per year for curves greater than 50º in adults.

Patients with spinal deformities may have complaints related to cosmesis including difficulties with rib hump, shoulder height, pelvic obliquity, or truncal shift (Figure 2). 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 80º.²,³

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 the 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 to stabilize the spine to allow for early patient mobilization. This has been important in order to help decrease further complications that can result from prolonged bed rest 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 and improved neurologically. Later in 1888, Dr. Smith successfully removed a spinal tumor that was causing neurologic 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 behind 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. This fusion procedure 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 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 6 months to 1 year while patients were in casts or traction and ultimately led to very high rates of 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%.

Spinal fusion was also used during this time to treat fractures of the spine. Spine trauma can result in instability due to a fracture of 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 is 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, and wires and screws that 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 as an “internal splint” which held the spine in position until the surgically applied bone graft developed into a fusion mass.

Spinal instrumentation achieves many goals. 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 of patients to help avoid potential side effects of prolonged bed rest. The number and types of spinal implants available has greatly increased in recent years. 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 the time, this was a major medical breakthrough which 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 (Figure 4). 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. It was also limited in the fact that the rod was straight and this did not allow surgeons to accurately re-create a normal spinal alignment, particularly in the sagittal plane (viewed from the side).

In 1973, Dr. Harrington published an eleven-year follow-up of 578 patients who were treated with spinal instrumentation. The average correction of the scoliosis curve in the frontal plane was 54%. He published a 4% rate of pseudarthrosis or non-union which was a significant improvement when compared with previous fusions performed without instrumentation. These techniques were not without significant complications which included fracture or failure of the instrumentation as well
as degeneration or instability affecting portions of the spine above or below the instrumentation.\textsuperscript{5,6}

Harrington’s distraction instrumentation did address the frontal curve of the scoliosis pattern; however, the sagittal contour of the patient was often negatively influenced, particularly in 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.

Segmental instrumentation was first introduced by Edwardo 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 the spine. These rods were contoured in multiple planes which did allow for surgeons to fuse the spine in a more normal alignment (Figure 5). By attaching the implants to the spine at multiple levels, the force at each individual level is 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 pseudarthrosis. 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.\textsuperscript{7}

Segmental fixation with wires did improve correction of the frontal plane as well as allow 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 planes (rotation) during spinal reconstructions. This was a major technical advancement (Figure 6).

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. Crosslinks are simple transverse implants that connect between rods that are placed on each side of the spine (Figure 7). 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 been developed to correct spinal deformities from the front (anterior) as well as the back (posterior) 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 did offer the benefit of fewer total levels of the spine that 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 surgery technology continued on into the 1990s. These new systems have developed techniques that allow for the spine to be fixed segmentally, meaning that the attachment of metal implants to the rod is achieved at every level 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, there has been a trend towards increased use of pedicle screw instrumentation to allow for spinal fixation (Figure 8). Pedicle screws are placed into a specific anatomic area of the spine from a posterior approach (Figure 9). Surgeons began using pedicle screws in 1988. These were initially used in the lower lumbar spine where they were easier to place because of the size of the bones with the continued use of
hook and wire patterns in the upper end of scoliosis reconstruction.

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 initial 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, Suk 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 of 59% with pedicle screws versus a 19% correction with the hook construct.10

Kim et al. subsequently evaluated the safety of pedicle screw placement in the thoracic spine over a ten-year period consisting of 3,204 screws. Screws were analyzed by 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.11 Kim et al. also evaluated the average number of levels fused comparing hooks versus screw systems. He noted that the pedicle screws saved an average 0.8 levels per patient when compared with hook constructs.12

The use of all pedicle screw implants has also allowed surgeons to perform more complex spinal reconstructions, including spinal osteotomies. Using these procedures, complex and rigid spinal curvatures can be addressed by cutting away portions of the bone that are involved in the deformity, thereby 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 rod 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 (outside) of the curve without performing a fusion. These staples tether growth on the “long” side of the spine while allowing further growth on the “short” side (Figure 10). As growth continues, a curvature may be halted or even straightened as the two sides become more equal in length.13

Growing rods are also utilized for children with progressive curvatures who have significant growth remaining. They 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, this allows for continued spinal growth at the non-fused segments (Figure 11). The rods are periodically lengthened as the child grows which allows for growth of the spine while slowing the progression of a curvature.14

Another technique that has been used in children with progressive curvatures if the Vertical Expandable Prosthetic Titanium Rib or “VEPTR” approach. The VEPTR device works to expand and support a deformed chest wall cavity by using telescoping titanium rods. These rods hook to the ribs or pelvis and can help to separate and support the chest. This device may slow the progression of a spinal curvature and avoid a spinal fusion in young children until they have neared the end of their growth.15

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, decreased the morbidity of surgical procedures, and allowed for earlier return to activity after surgery. Current research focuses on improving and developing motion preserving surgical techniques and less invasive surgical options. 

References


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Dr. Good 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.