J Turk Spinal Surg 2026;37(Suppl 1):1-5
DOI: 10.4274/jtss.galenos.2026.26349

THE HISTORY OF SPINAL FUSION AND INSTRUMENTATION

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ABSTRACT

Spinal instrumentation techniques have evolved significantly to provide stability in the treatment of spinal deformities, trauma, tumors, and degenerative diseases. In earlier periods, external immobilization methods were used, whereas internal fixation and spinal fusion techniques began to be developed in the early 20th century. The modern era of spinal instrumentation, which started with Harrington rod systems, has advanced considerably with the introduction of pedicle screw systems, minimally invasive surgery, navigation technologies, and robot-assisted applications. This review discusses the historical development of spinal fusion and fixation techniques chronologically.

Keywords: Spinal instrumentation, spine surgery, pedicle screw, spinal fusion

INTRODUCTION

Approaches to the treatment of spinal disorders have evolved throughout history in line with differing medical concepts and technological advancements. The earliest records related to this field date back to the Edwin Smith Papyrus, described around 1550 BC[1]. Insufficient knowledge of the anatomical structure and functional characteristics of the spine led to persistently high morbidity rates associated with spinal injuries for a long period in history. During the Ancient Greek era, spinal anatomy began to be described more accurately. Although human dissection was prohibited in Greek society, anatomical knowledge was obtained through observation of athletes in gymnasiums and examination of cadavers on battlefields[2]. Early treatment approaches primarily consisted of recommending rest and applying wound dressings, whereas contemporary management has evolved into modern fusion surgeries. Naturally, the development of surgical techniques and instrumentation alone was not sufficient; Joseph Lister's development of antiseptic surgery and William Morton's pioneering work in anesthesia played a d ecisive role in advancing this process by significantly improving the safety of surgical procedures[3-5].

Pre-surgical Era

In the 5th century BC, Hippocrates was the first to describe the anatomy of the spine, its diseases, and deformities, and he published these observations along with treatment methods in his work On Joints[2]. He defined kyphosis as a deformity resulting from disease or injury. Hippocrates advocated that such deformities could be treated by applying pressure to the spine under traction using a wooden bench made of oak that he personally designed. This traction-based method continued to be used by many clinicians until the 15th century (Figure 1)[2]. Another Greek physician, Galen, in the 2nd century BC, introduced the terms scoliosis, kyphosis, and lordosis, and provided more detailed descriptions of spinal anatomy, particularly the spinal nerves[6,7]. He also argued that applying direct pressure under axial traction could be used to treat spinal deformities. Between the 5th and 11th centuries, during the Dark Ages, almost no progress was made[8].

In the 11th century, Avicenna (Ibn Sīnā), who lived in the Middle East, made substantial contributions to medicine and osteopathic approaches, and employed axial traction-based methods in his clinical practice. Nevertheless, the limited success of these treatments, and the development of paraplegia in many patients, led to a gradual decline in interest in mechanically correcting spinal deformities[8].

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Received: 23.01.2026 **Accepted:** 03.02.2026 **Publication Date:** 13.02.2026
Cite this article as: Aydın M, Erel N, Serin E, Alıcı E. The history of spinal fusion and instrumentation. J Turk Spinal Surg. 2026;37(Suppl 1):1-5

In the 15th century, the Turkish physician Şerafeddin Sabuncuoğlu described the use of traction and cauterization methods for spinal injuries in his work *Cerrahiyetü'l-Haniyye*[9].

Approaching the Renaissance, in the 15th century, Leonardo da Vinci was the first to systematically elucidate the relationships between vertebrae and conducted highly valuable studies on spinal anatomy and biomechanics[10]. In the mid-16th century, Ambroise Paré described the first iron brace for the correction of scoliosis[11].

In the 17th century, Giovanni Alfonso Borelli, regarded as the father of spinal biomechanics, authored *De Motu Animalium*, considered one of the earliest works addressing biomechanical principles[10].

Surgical Era

Non-instrumented Fusion

While treatments based on corsets and non-surgical traction mechanisms were developing, in 1885, German physicist Wilhelm Roentgen discovered X-rays and introduced them to the medical world, resulting in extensive knowledge about the form and function of the human skeleton. These developments paved the way for surgeons to use materials such as metal and bone in fusion surgeries[12].

In 1891, Hadra[13] from Galveston successfully treated a case of cervical spine fracture-dislocation by using wires wrapped around adjacent spinous processes, an intervention that is considered the first attempt at spinal stabilization. Hadra modestly referenced Dr. W. Wilkins, who had previously performed a similar operation at the twelfth thoracic and first lumbar vertebrae. Fritz Lange[14] from Munich attempted to stabilize the spine in 1909 by first using silk, then steel wire, to attach celluloid rods and later steel rods to the sides of the spinous processes. These studies were conducted at a time when inert metals were not yet in use, and bone resorption occurred around internal fixation devices when metal was employed. Despite this limitation, Fritz Lange's concept of securing steel rods to the spine with wires interestingly served as an inspiration for modern fusion techniques used today[15].

Figure 1. Oak traction bench designed by Hippocrates

In 1900, Miller et al.[16] Hibbs focused on tuberculosis, a disease responsible for widespread mortality in Western societies, and established a center dedicated to treating patients with tuberculosis, particularly those with Pott's disease. In 1911, inspired by his previous knee arthrodesis procedures, he described interspinous arthrodesis using illustrative drawings[16]. This technique was initially applied in patients with Pott's disease who were rapidly developing deformities, and later in trauma patients. The method, which became known as the Hibbs technique, yielded favorable outcomes especially in pediatric patients. However, in adult patients, clinical outcomes deteriorated over time, with increased rates of pseudoarthrosis and loss of deformity correction. Many surgeons attempted to prevent these situations by including the iliac crests in spinal fusion, but they were not very successful, and the use of this method gradually declined[15].

In 1914, Albee[17] employed a similar technique but achieved spinal fusion by creating grooves in the spinous processes and inserting thin, rod-shaped autologous tibial grafts. He even designed a sterilizable saw specifically for harvesting tibial grafts and, for many years, did not use grafts from any other donor site[17].

This technique was modified by Watkins[18], who in his 1953 publication described a posterolateral incision to allow placement of bone grafts between the transverse processes. This spinal fusion method remains a viable option today, particularly for surgeons aiming to perform minimally invasive lumbar fusion procedures[19].

In 1932, Capener[20] described the treatment of patients by placing a bone dowel between L5 and the sacrum to help reduce anterior displacement of the L5 vertebra. During the same period, Burns[21] performed an anterior lumbar interbody fusion in a 14-year-old boy with traumatic spondylolisthesis, achieving fusion between L5 and the sacrum using a bone dowel harvested from the patient's tibia[22]. Rather than approaching the intervertebral disc space anteriorly, Briggs and Milligan[23] described a posterolateral approach to the disc space in 1944. To support the developing fusion mass, a bone peg was placed into the intervertebral disc space; this technique can be considered a precursor of modern posterior lumbar interbody fusion.

Parallel to these surgical advancements, John Cobb continued his nonoperative research and defined the types of coronal spinal deformities and their measurement methods on anteroposterior radiographs, which remain in use today[24].

In the mid-20th century, Risser[25] demonstrated the necessity of postoperative brace use to ensure immobilization following fusion procedures. During the same period, Walker Blount and Albert Schmidt developed the "Milwaukee Brace" an orthosis designed to minimize scoliosis progression in the postoperative period. This brace continues to be used in clinical practice today[26].

Until the mid-20th century, many surgeons attempted to develop their own techniques, but the length of the 6-9 month immobilization period required for spinal fusion, infections, failure of fusion, and loss of correction were the most common difficulties.

Instrumented Fusion

Harrington Instrumentation System

In 1953, Paul Harrington began developing the rod system that bears his name, primarily for use in rapidly progressive neuromuscular scoliosis (Figure 2). The initial surgical approach included placement of facet screws to correct facet joint alignment. Although early postoperative outcomes were favorable, longer-term follow-up revealed that the results were not as satisfactory as initially expected[27].

In the subsequent period, Harrington enhanced his system by incorporating hooks and stainless steel rods to achieve a more rigid construct and successfully corrected scoliotic deformities using the concave distraction technique. Although early clinical outcomes appeared promising, long-term follow-up studies reported recurrence of the deformity, rod breakage, and the development of flat-back syndrome in these patients[28]. The Harrington rod instrumentation system provided a long and rigid construct; however, it had the potential to disrupt normal sagittal alignment in the thoracolumbar region and was insufficient in maintaining the required lordosis at the thoracolumbar junction or providing adequate rotational control[29].

Other complications associated with this system included hook dislodgement, hook-rod disengagement, and laminar fractures. Laminar fractures could also occur as a result of osteoporosis, extensive laminotomy, or excessive distraction[29]. Another notable complication was dural injury during placement of laminar hooks[29]. Harrington initially applied this system in cases of scoliosis and later expanded its use to the treatment of traumatic injuries, degenerative spinal diseases, and tumoral pathologies[29]. Despite the relatively high rate of complications, the Harrington rod represented a novel method for achieving thoracic stabilization. Patients treated with this system were followed postoperatively, and their outcomes were systematically analyzed. These studies demonstrated that, regardless of the skill and strength of the construct, thoracic stabilization without adjunctive fusion would inevitably result in implant (hardware) failure (Figure 2)[28].

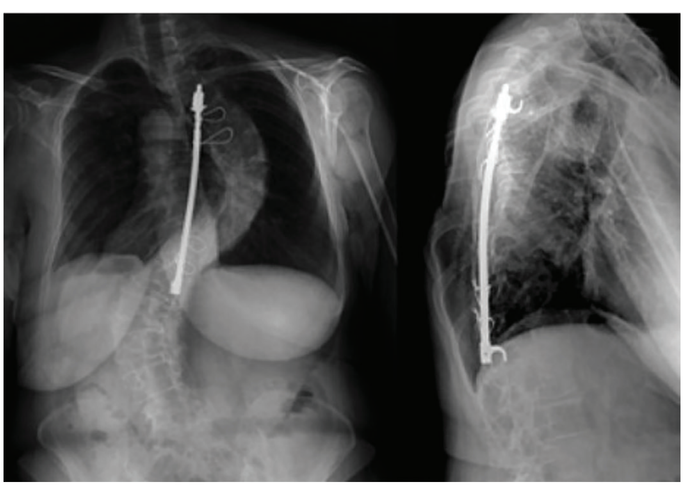

Figure 2. Harrington rod system

Luque (Segmental) Instrumentation System

In 1976, Eduardo Luque used more flexible rods and connected them to the vertebrae at multiple levels using 16-18 gauge wires passed sublaminarly. Following this technique, postoperative brace use was not required in many patients. By anchoring the rods at multiple points, this system achieved significantly higher fusion rates and better overall outcomes compared with the Harrington system. However, the risk of neurological injury during passage of the wires through the spinal canal was considerably high[29,30]. Approximately 10% of patients developed dysesthesia, and in some cases, paraplegia due to spinal cord ischemia occurred, necessitating reoperation for removal of the wires (Figure 3)[29].

As various instrumentation systems were being developed to increase fusion rates, Boucher HH[31] emphasized the strength of interpedicular fixation[32]. In the early 1970s, Roy-Camille et al.[33] was the first to describe screws placed through the facet joints or pedicles, followed by chromium-cobalt alloy plates used to connect these screws[32]. Similar systems supporting all three spinal columns are still in use today[34].

Cotrel-dubousset Instrumentation

In 1984, two French orthopedic surgeons, Yves Cotrel and Jean Dubousset, developed a contoured dual-rod system fixed to the

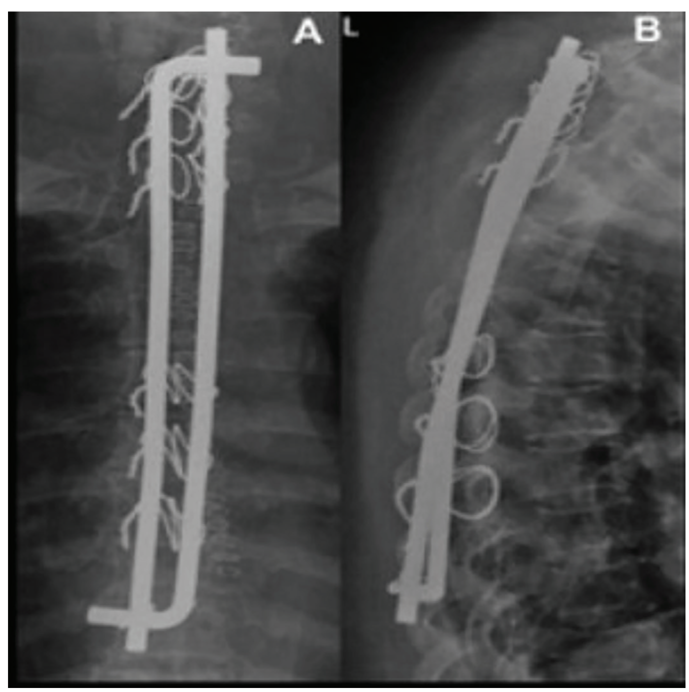

Figure 3. Luque segmental instrumentation system

spine using multiple hooks and screws. This system was the first to address the thoracic "rib hump" deformity associated with vertebral body rotation and paved the way for the development of modern fixation systems currently used in clinical practice[35].

Cervical Instrumentation

Posterior Approaches

Internal fixation of the cervical spine was first performed in 1891 by Hadra[13] using interspinous wiring in a patient with traumatic C6-C7 instability. He later applied the same technique to deformities caused by Pott's disease[13-36]. Over subsequent decades, various methods were developed to stabilize the cervical spine, including wiring techniques (interspinous, facet, interlaminar clamp), lateral mass screw-plate systems, lateral mass screw-rod systems, and ultimately cervical pedicle screw systems[36].

Wiring Techniques

In 1942, Rogers[37] utilized interspinous wiring for the treatment of post-traumatic injuries; in this technique, holes were drilled into the spinous processes, through which wires were passed and secured. Subsequently, McAfee[38] succeeded in stabilizing multiple levels using the triple-wire technique. Facet wiring was first described in 1977 by Callahan et al.[39] for use in cases where the spinous processes or laminae were not suitable. In this method, wires were passed through holes drilled in the lateral masses and secured to an autologous bone graft placed longitudinally over the lateral masses, thereby facilitating fusion. In 1983, Cahill et al.[40] described a new method in which the lateral masses and spinous processes could be wired together.

One of the most significant advances in wiring techniques was the replacement of monofilament rigid wires with multifilament wires that were more flexible, softer, and more durable[36]. This change reduced complications such as dural tears and spinal cord injury during sublaminar wire passage, while also providing stronger and longer-lasting stabilization with more durable materials[36].

Interlaminar Clamp

The interlaminar clamp was first used in 1975 for single-level C1-C2 stabilization. This technique required intact laminae, and the placement of sublaminar clamps carried a risk of neurological deficits, particularly in patients with a congenitally narrow spinal canal[41].

Lateral Mass Screws (Plate and Rod Systems)

Toward the late 1980s, following Roy-Camille's description of lateral mass screws and integrated plates, various modifications regarding screw entry points and trajectories were published by Magerl, Anderson, and An[36]. The use of plates was technically challenging in complex deformities or severe traumatic listhesis. With technological advances in screw systems, polyaxial screws and screw-rod constructs were developed, greatly facilitating posterior instrumentation in nearly all deformities and traumatic conditions.

Cervical Pedicle Screws

Based on animal models and human cadaver studies demonstrating greater stability and higher resistance to screw pullout compared with lateral mass screws, cervical pedicle screws were first used clinically by Abumi et al.[42] in 1991 in a patient with traumatic cervical instability. Similar to the thoracolumbar region, this method provided three-column stability; however, it presented several technical challenges. Accurate selection of the screw entry point was critical, a medial angulation of 25-45 degrees in the transverse plane was required, and pedicle diameters were relatively small. Consequently, there was a significant risk of vascular (vertebral artery) and neurological (nerve root or dural) injury during screw placement[36].

Anterior Approaches

The anterior approach to the cervical spine was first proposed by Leroy Abbott in 1952 during his visit to the clinic of Bailey and Badgley[43], and this approach was subsequently used on numerous occasions. Anterior cervical fusion was first described in the 1950s by Robinson and Smith[44]. This method, based on anterior fusion following removal of disc material and osteophytes, remains in use today with minor modifications. Cloward later modified the technique by recommending the use of a bone dowel for fusion[45]. Boni et al.[46] applied this technique at multiple levels and described anterior corpectomy with fusion using autologous grafts.

The earliest examples of anterior cervical plates were used by Orozco Delclos and Llovet Tapies[47] in 1970 in trauma patients. Caspar et al.[48] subsequently refined these plates and also applied them in traumatic cases. The addition of a plate to anterior cervical fusion provided rapid stabilization, prevented graft displacement and collapse, assisted in restoring sagittal alignment, and reduced both the duration of external immobilization and the need for supplemental posterior instrumentation[49]. The initially described plates required bicortical screw purchase; to eliminate this requirement, plate systems with screws that lock into the plate, still widely used today, were subsequently developed[50].

Acknowledgements

The authors wish to honor the memory of Prof. Dr. Emin Alıcı, whose invaluable contributions to the establishment and development of the Turkish Spine Society and the Journal of Turkish Spinal Surgery laid the foundation for scientific progress in our field. His leadership, mentorship, and dedication continue to guide future generations. This work is dedicated to his memory with deepest respect.

Footnotes

Authorship Contributions

Concept: M.A., Design: M.A., N.E., E.S., Data Collection or Processing: M.A., Analysis or Interpretation: M.A., Literature Search: M.A., N.E., Writing: M.A., N.E., E.S.

Conflict of Interest: No conflict of interest was declared by the authors.
Financial Disclosure: The authors declared that this study received no financial support.

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