Thoracolumbar spinal deformity: Part I. A historical passage to 1990

Historical vignette

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ANTHROPOLOGICAL and historical evidence of human spinal deformity and its treatment dates back at least 7 millennia. Skeletal remains and archeological artifacts of prehistoric man exhibit graphic depictions of spinal anomalies and pathological curvature. Ancient works dating back to before 3500 BC summon images of individuals with disfigured spinal columns who wore the burden of ridicule and odium in modern-day tales of religion and myth.18

It was Hippocrates, in the 5th century BC, who described scoliosis for the first time with scientific prudence.1 He originally noted its incidence in trauma, but observed the phenomenon to uniquely occur idiopathically as well (Fig. 1):

Curvature of the spine occurs even in healthy persons in many ways for such a condition is connected with it [sic] nature and use and besides there is a giving away in old age and on account of pain. But the outward curvature due to falls usually occurs when the patient comes down on his buttocks or falls on his shoulders and in this curvature, one of the vertebrae necessarily appears to stand out more prominently.24

Hippocrates further noted the association between curvature progression and skeletal growth and attempted to remedy the disorder with axial distraction via an extension device that was painful yet effective at first, but lacked long-term effectiveness.28 The device was used to suspend a patient in an inverted position with a rope attached to the top of a vertical ladder and lowering them until the rope became taught—therapeutically imparting deceleratory reduction forces to promote spinal straightening.36 Not unexpectedly, outcomes were subjected to limited scrutiny, as a detailed understanding of spinal anatomy and biomechanics had yet to be realized.

Here the matter rested for centuries, with little more than philosophical mention, until the Greek physician Galen coined the descriptive terms of spinal deformity in the 2nd century AD: scoliosis, lordosis, and kyphosis. As physician to the gladiators of Pergamon, Galen performed anatomical studies and acquired surgical experience with both living and cadaveric forms of the human spinal column.44 Using the same principles conceived by Hippocrates, Galen used longitudinal distraction techniques to straighten the deformed spine. Noting the progressive nature of the malady, he attempted to halt its evolution with the application of rigid jackets and chest binders. He further surmised a relationship between the spinal column and the surrounding rib cage musculature and advocated breathing exercises and singing to aide in the correction of thoracic distortion. He introduced the “blow bottle” to encourage deep inspiration and pulmonary toilet. Yet again, after Galen’s death, the understanding and treatment of spinal deformity suffered a delay, with little ingenuity or revelation through the Dark Ages.
Concepts of analogous mechanical traction devices were developed and abandoned for centuries, until the 16th century when Leonardo da Vinci studied and described the anatomical principles and relationships of the spinal column to its adjacent soft tissues and bone. In particular, da Vinci scrupulously illustrated the vertebral column, its curvatures and articulations, and the biomechanical significance of its evolution. Incorporating this newly acquired anatomical knowledge 1000 years after Hippocrates’ initiative, Paulus Aegineta endeavored to correct spinal deformity by bandaging the body to splints. In 1579 Ambroise Paré was the first to apply a supportive trunk orthosis with anterior and posterior iron corset plates made by armorers. He understood the progressive nature of the disorder and recommended that new breast plates be made as the individual grew. Paré also appreciated the sensitivity of the underlying spinal cord and that its compression by spinal deformity could
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lead to neurological sequelae. He further recognized that bracing had little use once a patient reached skeletal maturity.

Scoliosis steadily became recognized as a pathological entity, promoting the creation of a variety of ingenious, yet often inhumane, traction devices and body braces. Francis Glisson introduced the first British device, the Glisson sling, in the mid-1600s. This contraption was used to suspend the patient aloft while providing posterior thoracic rod traction to the apex of the curve during dorsal arm and shoulder counter-translations. In time, it became difficult to discern which was more dreadful, the disease or its treatment. Moreover, despite the increasing intricacy and ingenuity of these devices, as was evidenced by Hippocrates’ efforts as well, curvature correction appeared possible but not sustainable.

Concurrent with evolving treatment paradigms for spinal deformity were hypotheses of its etiology. Giovanni Borelli was credited with the first scientific publication addressing the intricate significance of spinal biomechanics, memorialized in the first text on the topic: De Motu Animalium. The term “orthopedia” was coined by Nicholas Andre in 1741, literally meaning “straight child.” Adolescent, or “idiopathic,” scoliosis was thought due to a muscular imbalance caused by poor posture and sitting habits, and thus invoking the redesign of school chairs and desks to prevent its occurrence. Andre further prescribed periods of recumbence, vertical halter stretches, and exercises in combination with assorted body braces and halter head caps to correct the musculoskeletal imbalance.

The “jurymast” brace was introduced in 1768 by François le Vacher. It was the first axial distraction brace that allowed the patient to maintain an upright position by utilizing a suspension cap attached to a posterior bar stemming from the brace’s backside. Spinal deformity received increasing attention during this time period, and whole institutions were built and dedicated to its treatment. In 1780 Jean-Andre Venel founded one such hospital and created a traction bed and brace that applied horizontal and extension forces not only to straighten the spine, but also to de-rotate it.

Surgical attempts at deformity correction were reported as early as the 19th century. In 1839 Jules Guerin claimed that bracing in conjunction with percutaneous myotomies in the vertebral musculature yielded curve correction. These results were not reproducible by his colleagues and so were challenged by Malgaigne and Volpau to the point that Guerin was banned from practicing medicine in France. During this period of scientific appraisal and criticism, Malgaigne noted the concept of evidence-based medicine that holds true even today:

We have found too many examples of how enthusiasts can be deceived in their appreciation of their own success and how accomplishments are far removed from hopes, desires from realities. It is hard in such a case to recognize that one has deceived himself, but it is a sacrifice of the ego that the greatest have not blushed to make for science. . . . It is important to know what to do, but no less important to know what not to do.

In the late 1840s Edward Lonsdale of London composed an essay on the treatment of scoliotic curvatures of the spine. He attributed the female predominance of spinal deformity as a consequence of women’s sedentary lifestyle (for example, posture while sewing), developmental patterns (for example, rapid adolescent growth), and maternal requisites (for example, feeding and cradling infants and children in their arms). He advocated the use of spinal support pelvic hoops secured to an axillary crutch with spring pads abutting the ribs, a device effectively similar to the Barr-Buschenfeldt brace of the 20th century.

The father of American orthopedic surgery, Lewis Albert Sayer was the first credited with the creation of an orthosis capable of both deformity correction and maintenance: the plaster-of-Paris body jacket. The cast was applied to a patient standing in a vertical suspension device that applied forces to correct both lateral and rotational deformities. It proved to be remarkably simple yet demonstrably effective and earned Sayer the title as the leading spine surgeon of his era.

The advent of the roentgenogram in 1895 paved the way for a new epoch in spinal deformity visualization and correction. It enabled testing of etiological hypotheses and a means of quantitatively monitoring disease progression as well as objectively evaluating any corrective measures. Twentieth century advances were quick to follow, particularly in the ambit of surgical correction procedures involving fusion principles.

In 1902 Fritz Lange used foreign implants to replace mechanical structures involved in spinal movement and support. He anchored 4-mm steel wires to the spinous processes and attached them to steel rods bilaterally to treat a tuberculosis-induced kyphotic deformity. Inflammation and infection from the sharp metal wires impelled him to perform a series of animal studies, seeking an alternative to the harmful wires. In 1908 he used 5-mm tin-coated wires with blunted end knobs and paraffin-sublimate silk fasteners, yielding less morbidity and a decisively improved outcome in comparison with brace therapy alone. Similar treatment paradigms were applied by Fred Albee in 1911 for the treatment of Pott disease; he secured a tibial autograft into split spinous process; fixation of the spine. Others used this technique with complementarily unique grafting constituents, such as the scapula, which was used by DeQuervain and Hoesly.

In that same year, Russell Hibbs performed a spinal fusion for the treatment of a patient also deformed by tuberculosis, pioneering the technique of osseous fusion without instrumentation. He extrapolated the technique in 1914 and became the first to perform a spinal fusion to treat scoliosis. He presented his results 10 years later in scholarly manner, with follow-up data revealing a 25% reoperation rate for fusion extensions and a 2% mortality rate. His laudable findings were the result of a combination of both surgical ingenuity and supplementary pre- and postoperative immobilization casts worn for up to 1 year. Surgical pearls included subperiosteal dissection, facet excision, and laminar grafts to bridge adjacent segments. He reported satisfactory results in 84% of cases, initially concluding that fusion procedures were a valid
treatment strategy to halt the progression, if not the full correction, of spinal deformity.

Over subsequent years, Hibbs and his pupil Joseph Risser performed more than 360 fusion procedures for spinal deformity, modifying their technique as their experience increased. They began using a turnbuckle cast preoperatively, with hinges in the orthogonal planes to generate traction and bending forces to maximize correction (Fig. 2). They created a window in the cast’s dorsum through which they could operate. They concluded that despite a 50% cessation in curve progression, inadequate fusion levels led to ensuing deformity in 30% of cases. Furthermore, chest wall deformities created by the localizing forces were often more detrimental to a patient’s pulmonary status than the initial spinal deformity (Fig. 3). Varying results obtained by others utilizing Hibbs’ fusion techniques and immobilizing casts reported pseudarthrosis rates ranging from 14 to 60%.16,27

Such varied results prompted a multicenter review committee to further evaluate the use of fusion for the treatment of scoliosis.50 In 1941, following a review of 425 cases, one-half treated with fusion and one-half with nonoperative means, researchers concluded that surgical fusion in combination with the turnbuckle cast yielded results superior to those following other treatment measures. However, only one-third of the patients treated surgically reported good or excellent results, leaving significant room for improvement in the years to follow.

A growing population of patients burdened with debilitating spinal deformity was born of the polio epidemic and resultant neuromuscular scoliosis.39 The increasing necessity for spinal fusion procedures inspired an evolution in technique and accompanying immobilization devices. In the early 1950s, Risser introduced the localizer cast, providing both head and pelvic traction in conjunction with a posterolateral localizer to apply pressure at the ribs to use correction at the time of cast application. This technique enabled immediate postoperative mobilization, limiting the obligatory bed rest and pressure sores of past methods. Just as Ambroise Paré had understood nearly 400 years earlier, Risser also recognized the plasticity of the adolescent spine and advocated the early use of his localizing cast in an attempt to treat a deformity by nonoperative means if applied early enough in the disease course.

Another major voice in spinal fusion during this era was that of John Cobb. His method for measuring radiographic curve magnitude in patients with scoliosis was popularized in 1948 and remains in clinical use today. In 1952 he reported on his 15-year experience in performing > 670 fusions, yielding a remarkable pseudarthrosis rate of only 4.3%—results he attributed to a meticulous surgical technique and supplemental cancellous bone as well as preoperative cast correction and 6–9 months of postoperative bed rest.8

It was around this time that Walter Blount and Albert Schmidt introduced a revolutionary removable distraction jacket for the treatment of progressive idiopathic spinal curvature: the Milwaukee brace (Fig. 4).3 The brace was initially intended simply to provide postoperative immobilization. It consisted of a circular neck ring with an occipital and chin-padded collar attached to a molded-leather and plaster pelvic girdle with adjustable rib pressure pads, all joined by turnbuckles. Over the years, modifications were made to make the brace more aesthetically appealing and reduce the jaw and dentition deformities due to the bite-distorting distraction chin pad. The neck ring and chin rest were replaced with a throat mold, and the brace was soon worn for prolonged periods in lieu of surgical fusion. Serial studies revealed that moderate curves could be treated with the Milwaukee brace alone if applied prior to skeletal maturity and worn throughout pubertal growth. More severe curves required its use in combination with surgical fusion for comparable results.
Despite the effectiveness of the Milwaukee brace, patient compliance was poor due to its restrictive nature, overt visibility, and the duration of treatment often exceeding several years. Alas, a pseudarthrosis rate of nearly 39% following the use of the brace along with spinal fusion was encountered, but it was hypothesized to be due to a failure in surgical technique (that is, deficient facet fusion and length of immobilization) rather than in the brace itself. Regardless, the Milwaukee brace set the benchmark to which all others would be compared in regards to halting the natural history of curve progression.\(^3\)\(^4\)

Attention once again returned to a meticulous surgical technique, as highlighted by John Moe, a major contributor in the advancement of scoliosis treatment, research, and education. He emphasized the importance of bone graft placement in the facetectomy defect and hinged transverse process fragmentation and rotation.\(^\)\(^\)\(^4\)\(^\)\(^0\) Moe also advocated for longer constructs, recommending that the fusion begin and end with neutral vertebrae at the proximal and distal ends of the curve. Moe’s procedural adaptations were believed to be responsible for the dramatic improvement in fusion success rates to nearly 85%.\(^\)\(^3\)\(^7\) His teachings initiated an array of rapidly proliferating innovative systems and techniques, including the reemergence of internal fixation methodologies.

An intertransverse expandable jack, placed between the uppermost and lowest vertebrae within the concavity of the curve, was introduced by Allan in 1955.\(^2\) Gruca\(^1\)\(^5\) combined concave distraction with transverse process springs placed on the convex side. He also transected the ostensibly hyperactive muscle along the curve’s concavity, hoping to equalize the forces rendered disparate by the weakened convex musculature. In 1956 Hodgson demonstrated the utility of anterior approaches in deformity correction and arthrodesis, paving the way for a new era in spinal decompression and kyphosis correction.\(^\)\(^\)\(^2\)\(^5\)\(^2\)\(^6\)

The mounting polio population inevitably exploited the use of these fixation techniques as cardiopulmonary frailty rendered casting measures a morbid option.\(^3\)\(^3\) Paul Harrington’s distraction instrumentation signified a milestone in deformity surgery, providing and maintaining maximal curve correction when combined with arthrodesis, despite his initial intentions to devise a system that functioned sans fusion.\(^\)\(^9\)\(^\)\(^\)\(^1\)\(^9\)\(^\)\(^\)\(^2\)\(^1\) His exploits began with facet screw fixation, a technique originally described by Don King in 1944.\(^2\)\(^1\) Harrington then added posterior element hooks made of stainless steel. Results were initially promising but short-lived given the hooks’ lack of intrinsic strength when subjected to repetitive stresses. Like Moe, Harrington appreciated the necessity for fusion extension to normal vertebrae and advocated for instrumentation 1 level above and 2 levels below the end of the curvature.\(^\)\(^2\)\(^0\) He worked with mechanical and material engineers ultimately to mark the inauguration of what we know today as modern spinal instrumentation technique.

In 1966 Moe and Valuska\(^4\)\(^2\) performed a scholarly comparison between Harrington’s fixation techniques and Risser’s cast correction with fusion. In sum, instrumentation yielded superior deformity correction and a quicker return to normal activity, but at the expense of infections and mechanical failures, which were reported in up to 15% of patients (Fig. 5). Moe summarily concluded at the Société Internationale de Chirurgie Orthopédique et de Traumatologie 10th Congress in Paris: “a good result of surgical treatment was that the patient at the end of growth had the same curve degree as when treatment started.”\(^5\)\(^2\)

As Harrington’s fusions aged, unique maladies were observed, often due to the rapid correction of such se-
vere, rigid deformities. Given that only posterior instrumentation was applied, long constructs without segmental fixation were required, leading to hardware loosening and reoperation for rod removal after fusion. The long constructs often involved the entire lumbar spine, leading to a loss of lordosis and flat back syndrome. These confounds were met with equally unique remedies and modifications; for example, Moe treated the iatrogenic loss of lumbar lordosis with a square-ended rod and hook to restore sagittal balance.

Halo devices, initially developed by Nickel and Perry in 1959, were similarly fashioned by Moe, DeWald, and Stagnara and were worn preoperatively to make the corrective transition more gradual. Similar efforts were being conducted in Europe, led by the auspices of Pierre Stagnara and Yves Cotrel, the latter of whose investigations led to the catapulting of segmental fixation systems years later. As international interest and experience grew, it became apparent that societal affiliations across the globe were needed to help cultivate the dissemination of information, expertise, and research in the field of scoliotic deformity, and thus was born the Scoliosis Research Society in 1966, with John Moe presiding as the founding president elect.

Anterior approaches gained credence in the late 1960s with Dwyer and colleagues' segmental cable compression system (Fig. 6). This novel approach proved to be a major advance in the field, enabling superior curvature correction with shorter constructs. The system used titanium screws in the vertebrae along the curve’s convexity through which a titanium cable was threaded and progressive tension applied to straighten the deformity. As with any new methodology, however, came new complications. The compressive forces of anterior fixation created a distinct kyphotic deformity of the lumbar spine.

Klaus Zielke attempted to remedy this quandary by creating a firmer construct, making use of flexible rods in place of Dwyer’s cables and placing the screws more posteriorly to enhance de-rotation and reduce kyphosis. This strategy provided more durable fixation with spinal de-rotation and fewer fixed segments and therefore fewer flat backs, ultimately leading to superior sagittal alignment as well. Early enthusiasm was once again blunted by criticism as long-term results revealed pseudarthrosis and hardware failure rates of 23%, likely due to the limited durability of a single rod system. Hall attempted to strengthen the fusion construct by modifying Moe’s facet technique, curetting away the articulating cartilage and filling the space with cancellous bone. This method proved to be time saving and an otherwise equally effective adaptation. The Kaneda et al. system later attempted to remedy this flaw with the placement of a second rod.

The evolution of spinal instrumentation devices and surgical techniques continued throughout the 1970s with the valiant goal of correction maintenance devoid of external immobilization. Luque introduced the next major advancement by capitalizing on the principles of load sharing by multiple vertebral levels: segmental stabilization. He accomplished this by affixing sublaminar wires...
and coupled crossbars to his prebent L-shaped rods, providing added strength, rotational control, and biomechanical durability (Fig. 7). Drummond further modified the technique by passing the wires through a drilled hole at the base of each spinous process to reduce the neurological risks associated with sublaminar wire placement but maintain the principle integrity of segmental fixation.

Despite the impetus during this decade to eliminate the need for postoperative immobilization, its necessity endured, prompting Hall and Miller to construct a more aesthetically appealing lower-profile version to encourage patient tolerance and compliance: the Boston brace. This new brace was studied in a prospective multicenter controlled trial by the Scoliosis Research Society and found to prevent mild to moderate curve progression and all but eradicated the need for surgery in patients with < 35° of curvature. It was also uniquely created as a modular device and could be expanded to provide orthosis to varying levels of the cervicothoracic and/or lumbosacral spine.

In the early 1980s, less conventional alternative practices were attempted in the mix of treatments for spinal deformity. Chiropractic manipulation and electrical stimulation devices were studied, yielding controversial results. Therapeutic measures soon returned to
forms of posterior fixation in regards to pullout strength and joined the rods via crosslinks, maximizing rigidity in both the coronal and sagittal planes while minimizing profile and device bulk (Fig. 8). The ideology of this system relied on the premise that stronger internal implants required less external support. Transpedicular instrumentation proved to be biomechanically superior to all other forms of posterior fixation in regards to pullout strength and load-bearing capacity. It was the first system to access and fixate all 3 columns to enable total segmental rotation, compression, and distraction prior to fusion. Propagation of segmental fixation principles developed further throughout the following decade, yielding an array of system modifications, surgical adaptations, construct materials, and technological advancements that are the focus of Part II in this series on the history of spinal deformity.

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