The European Contribution to the Surgical Management of Spinal Cord Injury: An Historical Perspective

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Abstract

European scientists gave a fundamental contribution to a better understanding of the pathophysiology of spinal cord injury (SCI), and consequently defined the best-suited treatment for this disease. The historical course of the management of SCI during the last two centuries goes through intuitive open-minded practitioners, physicians, neurologists, orthopedics, and neurosurgeons, which lived and operated in the European countries. Starting from a purely conservative approach, advocated since the dawn of civilization, they deepened their anatomical knowledge overcoming the initial therapeutic nihilism and improving the dismal prognosis ascribed to damage to the spinal cord. Their achievements have driven to the actual managing protocols for the victims of this disabling disease.

INTRODUCTION

Spinal cord injury (SCI) has a worldwide incidence of up to 83 cases per million/year [1], ranging between 16 and 19.4 new cases per million inhabitants/year in Europe, with motor-vehicle accidents and violence-related injuries among the most frequent etiologies [2]. Taking this into account, it’s evident how the impact of SCI is enormous from economic, psychological, and social perspectives. Notwithstanding, although the lethal nature of SCI has been already illustrated in Egyptian papyri [3], and even in Homer’s Odyssey [4], the development of the surgical treatment of the spine was belated by the difficulty in defining the real essence of this pathology and overcome its dismal outcome. Scientifically based approach of diseases involving the spine did not emerge until the last decade of the 19th century. The modern concept of spinal management advanced from observation, closed reduction techniques to decompression procedures, coming to complex spinal reconstruction and internal stabilization. Spine neurosurgery developed within the last 25 years, thanks to improvements in neuroimaging, new instrumentation technologies, and mostly thanks to brilliant open-minded European scientists who deepened their knowledge in this field.

Historical Background: From the Therapeutic Nihilism to the Development of Surgical Strategies

The first known historical documentation of traumatic spinal cord disorders dates back to roughly 2,500 years BC, being reported into the Egyptian Edwin Smith papyrus [3], the oldest book on surgery. Among the traumatic cases described in the scroll, 6 involved the cervical spine, and spine injury was related to paralysis and recognized as a serious, fatal illness. Rather than a surgical approach, the Egyptian author argued for closed stabilization. This “conservative” management went on in the Greek period with the Hippocratic School. Spine injuries were very frequent at that time because of the numerous battles, and Hippocrates described detailed anatomical features in his writings, although with the lack of graphic illustrations and without using specific medical terms, which will be later introduced by Galen. Notwithstanding, Hippocrates gave interesting proofs on the early practice of spine injuries describing fractures and vertebral dislocations and...
their correlation to paralysis associated with bladder and bowel difficulties [5]. But surgery on the spine was not favoured because of the poor outcome: SCI was believed a serious disease, and the consequent urinary retention was considered as indicators of the gravity of the injury destining these patients to die. Interestingly, Hippocrates hypothesized that a cure may be feasible if anterior reduction of the fracture was possible, anticipating the concept of anterior surgical decompression [5]. Anyway, he only advisable special diets to purify the body and stabilization of the spine [5]. External traction and immobilization was the treatment of choice and the devices he described have been used up to few decades ago (Figure 1).

The Latin culture gave it’s contribute thanks to Aulus Cornelius Celsus and Galen of Pergamon.

Celsus (25 BC–50 AD), gallic counselor to the emperors Tiberius and Caligula, in his book De Re Medicina, recognized that a cervical spine fracture could lead to difficulty in breathing and rapid death [6]. This is thought to be the first reference to the spinal cord addressing not only the vertebral pathology. Moreover, following the Hippocratic doctrine, Celsus recommend only stabilization and immobilization.

Galen of Pergamon (129–200) lived and worked in Rome during the emperors Antoninus Pius and Marcus Aurelius. He performed the first experimental transections of the spinal cord at different levels, which led him to describe loss of function below the level of the lesion [7]. In his work On Anatomical Procedures and On Affected Areas he firstly identified the structural role of the spinal cord and noted that the upper sections were more severe than the lower [7]. Moreover, he found that transverse incisions, unlike the longitudinal ones, led to loss of function below the level of the lesion, and firstly anticipated the description of the Pott disease correctly attributing it to tuberculosis. He also detailed a hemiplegia with a contralateral sensory loss in a patient in whom there is hemisection of the cord, known today as the Brown–Séquard syndrome. Galen advocated, but not performed, decompression procedures recommending the removal of bone fragments pressing into the spine.

The first who removed bone fragments in patients with vertebral fractures was the Greek Paulus of Aegina (625–690), hypothesizing the concept of decompressive surgery and laminectomy [8]. This procedure, however, was not universally accepted, because the prognosis continued to be dismal.

Surgeons noticed that a closed reduction could reveal dangerous and surgical therapy futile for patients with complete paralysis [6]. SCI remained “an ailment not to be treated” [3]. This conception of therapeutic nihilism was followed up until the early part of the 20th century.

After the fall of the Roman Empire, the Arabic and Byzantine populations centralized the culture and the medical art. In the medieval period Europe remained quiescent and, rather than progress in medical and surgical treatment, the schools limited themselves to codifying manuscripts from the Greek and Roman period to transmit them. Medicine was prerogative of dergency until the Council of Tours (1169), when the Church prohibited them from the study and practice of surgery. The edict “Ecclesia abhorret a sanguine” restricted the art of surgery into the hands of practitioners [9].

Medical advancements in the understanding of human anatomy, physiology, and diseases continued to languish until the 13th century, when formal medical education was established in Salerno (Italy). The Schola Medica Salernitana became the centre where physicians were trained and medical studies flourished. Notwithstanding, Roger of Salerno, leader of the Schola Medica, in his book Practica chirurgiae went on in favoring stabilization procedures in cases of spinal subluxation.

A contemporary Italian surgeon, William of Saliceto, professor at the University of Bologna, wrote Chirurgia, the first original book because not inspired by previous writings. Unfortunately, SCI remained for him a rarely treatable lesion, confirming the already established conservative management [10].

Lack of true anatomical knowledge and poor surgical outcomes led physicians to go on in recommending against operating on spine.

In the same setting, during the 13th century, anatomical dissections of executed criminals provided for a more thorough understanding of human anatomy. In the text Chirurgia de Theodor, Theodoric of Bologna (ca. 1205–1298) described how to examine a patient with a cervical spine injury to determine whether he had to be treated or not. Theodoric stated that the presence, type, and level of spinal cord injury were essentials for deciding whether a patient should be treated or not. But the treatment continued to be conservative: he advised the reestablishment of proper alignment of vertebral bodies by reduction and stabilization [11].

The same strategy based on the poor prognosis was present in France with Guy de Chauliac (1300–1368), considered by many as the father of modern surgery [6]. Great advancements in the knowledge and management of SCI came from the battlefields.

Ambroise Paré, a famous French army surgeon, in his Dix-Livres de Chirurgie (1564) described an aggressive approach by the resection of depressed bone fragments impinging on the cord [6]. Fabricius Hildanus (1646) was the first to introduce the open reduction of cervical fracture/dislocations following the failure of the closed one, applying a traction clamp inserted through the nuchae and spinous processes of the cervical vertebrae (Figure 2); only at the failure of that, he advocated open decompressive surgery and internal reduction of the dislocation [6]. A noted
feature in this period is the lack of further understanding of the spinal cord disease, therapy remaining on treatments aimed at the damaged osseous elements.

**Controversies towards a Surgical Approach**

The 18th century was characterized by favourable trends toward surgery. After the surgical drainage of a paravertebral abscess caused by tuberculosis performed by Sir Percival Pott [11], James (1745) and Heister (1768) advocated operative intervention for spinal dislocation [6]. Geraud (1753) reported the removal of a bullet from the L-3 region, with improved neurological outcome. In a similar fashion, Louis (1762) described an analogous case in which lumbar decompression resulted in complete functional recovery of lower-extremity movements. Enthusiasm for surgical intervention increased even more during this period as evidenced by the writings of Desault in 1796, in which he claims for decompression of the spine for SCI, even in the absence of vertebral fractures [6].

In 1815 was reported a surgical procedure performed by Henry Cline Jr. at St. Thomas' Hospital. He operated on a paraplegic patient 1 day after injury. Cutting into the spinous processes of the thoracic region, Cline removed the bone fragments and sawed off the transverse processes to reduce the dislocation (decompressive laminectomy). He recommended a controversial new procedure: the removal of the fractured spines and laminae. Although the patient failed to improve and died 5 days later, he stated that the spine could “bear very considerable violence without any dangerous consequences” [12]. Debate raged about the efficacy of surgery for SCI, which tempered the initial enthusiasm. The controversy arose between two British surgeons, Sir Astley Cooper and Sir Charles Bell [13] (Figure 3). The “interventionist” Cooper (1827) lectured that it would be “unmanly” to refuse to perform an operation arguing that, because death was inevitable without surgery, nothing was to be lost.

On the other hand, Tyrell, in 1827, reported dismal results after surgical intervention in patients with SCI [6], so the “conservatives” Charles Bell and Benjamin Brodie condemned aggressive surgeries and referred to inaccurate diagnoses and careless techniques. In fact, for the most part, treatment was still limited to the ancient methods of closed reduction and bed rest, or occasional exploration and removal of a musket ball or bone fragments. Moreover, in 1824 Bell, as English neurologist, described different types of neurological derangements that resulted from trauma: he distinguished between flaccid and spastic paralysis, and proposed the concept of spinal shock [6]. On this basis, he posited that surgery only increased the risk of death, and could further damage nerves that might have the potential to improve [14].

During a series of lectures exposed at the Royal College of Surgeons in 1858, Charles Edward Brown-Séquard advocated surgical intervention for fractures and SCI. He showed that opening the spinal canal and exposing meninges and cord to the air was not dangerous: most fractures contained bone splinters that irritated the cord and, hence, removal of the bone was strongly advocated [15].

Innovations in basic and clinical neuroscience, in anatomy and neurophysiology, the emergence of neurology as a specialty during the next half century resulted in significant changes in the treatment of patients with SCI.
The Modern Concept of SCI Surgery

It was not until the second half of the 19th century, with the introduction of antisepsis thanks to Pasteur’s and Lister’s work in 1867 [8], and the development of the anesthesiologic techniques, that the surgeons were encouraged to intervene with a great impact on survival after SCI.

In an article published in 1884, William Thorburn, surgeon in Manchester, recommended an aggressive surgery in patients with compound fractures or compressive lesions, basing on his large experience of 9,000 patients with accidental injuries who were admitted every year to the Manchester Royal Infirmary. Thorburn preferred the term “laminectomy” rather than the older “trephining the spine” [16].

In 1886 Mac Ewen documented the first laminectomy but, because of still poor outcome, the general tendency in the treatment of SCI, through the remaining decades of the 19th century, was generally conservative [8] and surgery was overall considered “bloody, dangerous and unjustifiable” [17].

Early attempts to produce experimental spinal trauma were unsophisticated and reported in the work of Schmaus in rabbits in 1890. He noted degeneration and cavitation in the traumatized spinal cord, but he faced with the lack of standardization and quantification of experimental lesions [17]. Hence, therapeutic options could not have been tested in reproducible manner.

In 1890, Sir Victor Horsley presented his achievements for spinal lesions to the British Medical Association [18]. Soon after in 1895, William Roentgen submitted to the Würzburg Physical Medical Society the use of x-rays which became immediately mandatory for trauma cases [19] and opened the further scenario of their application to myelography [20].

In 1909, Fritz Lang proved that internal fixation induced more timely healing than immobilization therapy alone. He affixed rigid celluloid rods to either side of the spinous processes by using silk thread and steel wires to stabilize the spine [21]. Nonetheless, these therapies were used to halt the progression of a spinal deformity rather than to the correction of SCI.

Although always more evidences in favor of the operative management, civil and military surgeons still agreed that surgery was useless in patients with complete injuries. The question was whether surgery was effective for patients with incomplete lesions and how to determine if an injury was incomplete. As a result, there was a potentially large population of patients with incomplete SCI in whom surgical intervention was mandatory. During the First World War, F. M. R. Walshe, Henry Head, and George Riddoch, observed that the reappearance of reflexes below the level of the lesion did not give evidence of returning function, and they incidentally remove the false premise upon which an estimate of recovery has often been based [16]. At the von Eiselsberg Clinic in Vienna, Marburg and Ramzi waited at least 4 or 5 weeks before performing a laminectomy, whereas Guillain and Barré in the French Fifth Army advocated immediate spine surgery on all injured [16]. The same opinion had one of the most experienced British medical officers in France was Colonel Henry Gray, surgeon and consultant to the British Third Army. He believed that if there is an incomplete lesion with positive findings on x-ray films, then surgery should be performed as soon as possible [16].

From this time onwards, the management of SCI was centred on the feasibility of surgery. This prevailed until the last decade of the 20th century, when pharmacologic treatments made their appearance [22].

The issue of surgery became predominant thanks to discoveries in imaging, and spinal instrumentation have had a significant impact on making surgery safer and easier: the development of computerized tomography (CT) scanning [23], and magnetic resonance imaging (MRI) allowed the surgeons to have more knowledge of the pathology prior to operating [24], and the introduction of the microscope in the early 1970s allowed for better intraoperative visualization. Nevertheless, when a neurological deficit was present, the current prognosis paralleled that of a millennium ago. As we have seen, early treatment for spinal injuries began with closed methods.

Spinal traction initially described both in the Edwin Smith papyrus [3] and later on by Hippocrates [5], was further developed in the 20th century by Sir Geoffrey Jefferson, who utilized halter traction, and Sir Reginald Watson-Jones, who placed the patient in the prone position between 2 tables [25].

In 1933, W. Gayle Crutchfield first described skeletal traction [26] and, in 1955, Vernon Nickel and colleagues applied the same principle by using the halo vest [27]. These methods provided to obtain closed reduction and maintained the alignment of the spine, whether the patient was treated operatively or not. However, in spite of the poor results obtained with surgical attempts, surgical treatment of SCI was still not overall diffused. Finally, surgery improved, providing better reduction of deformity and stabilization over the last 50 years.

A fundamental step in the progress of SCI management was made by the German Sir Ludwig Guttmann who, in 1944, was placed in charge of the SCI Unit at the Stoke Mandeville Hospital, UK. Guttmann introduced postural reduction, divided the neurological lesions into complete and incomplete, and then subdivided the patients into improved, unchanged, and deteriorated. Guttmann highlighted the prognostic implications of these differences [28] and his SCI Unit became a model for future centres. Great believer in wheelchair sports, he is still remembered for founding the Paralympics [29].

Later, his concept was expanded by Frankel, pupil and co-worker of Guttmann, who reported clinical data from the Mandeville Hospital series introducing a scale of neurological involvement, which is now universally known as the Frankel Scale [30].

After 1944, in order to meet the needs of the spinal cord injured veterans of the Second World War, numerous centres for the cure of paralysis were founded all over the world but, according to the current view of that time and the early experience of Guttmann [28], the treatment was primarily conservative.

Beginning with the American Paul Harrington (1911–1980), a system of distraction and compression rods and hooks intended for the treatment of scoliosis [31] was introduced and adapted to the treatment of spinal fractures and dislocations, particularly at the thoracolumbar level [32].
The real “modern” treatment of spinal injury could be achieved only after the concept of spinal instability had been defined and modern spinal fixation systems developed. In this sense, although American surgeons such as Hadra and Albee had been pioneers in proposing, respectively, posterior wiring and parsaginal plates [33,34], European surgeons provided a tremendous contribution.

In 1962, Sir Frank Hold’s worth proposed the first modern definition of spinal stability, introducing the two-column model of the spine [35]. He published on the treatment of more than 1,000 cases of spinal fracture with and without neurological deficits. Hohl’s worth’s column model would be later adjusted by Denis with the introduction of a middle column; however, the concept of placing a screw in the pedicle to provide stability to both the anterior and posterior compartments of the spinal unit results from the introduction of this new awareness of spinal biomechanics.

Most notably, the revolution of the pedicle-screw system was initiated in 1963 by the French surgeon Raymond Roy-Camille [36], who managed a seventeen-year-old girl with a severe dislocation of the fourth and fifth lumbar vertebrae and cauda equina syndrome as the result of a traffic accident. The patient had previously had a laminectomy and presented with spinal instability. Roy-Camille reduced the instability; however, the absence of spinous processes and laminae prevented the placement of wires and plates conventionally used at that time. Being also an anatomist, Roy-Camille understood that the insertion of a screw through the pedicle offered a significant biomechanical advantage, thereby creating the conditions for a revolution and opening the way to the modern principles of spinal surgery. Since the development of pedicle screw fixation described by Roy-Camille, there has been a rapid evolution in the number and complexity of systems available for posterior spinal stabilization (Figure 4 A-C). The era of spinal instrumentation systems has been opened.

The French Renè Louis created a semi-rigid plate system associated with pedicle screws for the treatment of thoracolumbar and lumbosacral fractures [37]. Compared with the Roy-Camille system, Louis reduced the distance between holes in the plates and added oblique holes for the sacrum. As regards grafting, he developed facet joint fusion using the spinous processes.

In 1983 Yves Cotrel and Jean Dubousset introduced the first modern instrumentation system composed of a pedicle screw and sub laminar hooks connected, at any position, level, or degree of rotation, to two posterior rods. The solidity of this construct was significant, allowing the patient prompt mobilization without the necessity of a post-surgical brace [38].

Soon after, Magerl developed an external fixator that led to the construction of internal fixators based on the ideas of Dick and Kluger [39]. The “fixateur interne” was composed of long Schanz screws inserted through the pedicles into the body of the two vertebrae just adjacent to the lesion. The advantages of this system consisted in: excellent repositioning by the long lever-arm of the Schanz screws; immobilization of only two segments, and therefore good mobility of the residual spine; stability against flexion forces better than with Harrington distraction rods; additional rotational stability; and fixation in lordosis or kyphosis as is desired (Figure 4D-F). This Swiss group made other significant contributions: Magerl proposed a classification system [Magerl FP, Harms H, Gertzbein SD, Aebi M. Classification of spinal fractures. Presented at the American Academy of Orthopedic Surgeons, Vail, Colorado, 1989], subsequently modified by Gertzbein [40], that combined both mechanistic and morphologic characteristics of thoracolumbar fractures. Injuries were divided into three main groups on the basis of common morphologic changes and mechanism of injury: compression, distraction, and multidirectional injury with translation. This classification helped the surgeon to understand the forces that caused the trauma and select the best treatment approach [i.e., whether a specific fracture should be strut grafted anteriorly, or a posterior short-segment pedicle-screw-based instrumentation was sufficient).

Moreover, in 1992, Jeanneret and Magerl [41] developed the use of transarticular screws for odontoid fractures.

European surgeons provided other significant contributions to the development of surgical approaches to the cervical spine. Derayemaeker and Muller published a description of the anterior approach to the cervical spine in 1956 [15], independently from the description by Smith and Robinson, that was published in 1958 [42].

Among many advancements of spinal surgery, Verbiest [43] first applied the anterior approach initially described by Bailey and Badgley [44] as well as the technique of total removal of the vertebral body described by Cloward to treat cervical fractures [45].

Caspar standardized the anterior fusion technique and the use of plate-and-screw stabilization [46], a procedure first described by the German surgeon Herrmann, developing a commercially available system [47].

Lesoin and colleagues suggested the use of a transcervical approach and screw fixation to treat upper cervical spine pathology, describing the direct osteosynthesis for odontoid fractures and atlantoaxial stabilization using a screw fixation of the articular processes [48].

Decompression of the cervico-medullary junction through a transoral approach has been widely developed by Alan Crockard [49], and, lastly, Bernard George developed the antero-lateral approach to the cranio-cervical junction [50] and to the V1 segment of the vertebral artery [51].

In the last decade, minimally invasive spine surgical (MISS) techniques have been diffusely used in trauma patients. The goal of MISS techniques is to decrease surgical morbidity through muscles and soft tissues sparing approaches, achieving the same efficacy afforded by classic open surgery techniques. Such techniques are represented by percutaneous posterior pedicle fixation, vertebral body augmentation, and utilization of endoscopic and thoracoscopic techniques. The limit of MISS techniques in trauma seems to be still the need of spinal cord or roots decompression in case of more complex vertebral fractures. Although the literature is still lacking evidence-based quality papers comparing these newer techniques to classic
open treatments, an increasing number of studies are reporting encouraging clinical and radiological outcomes with these MISS techniques [52,53].

Nowadays, future scenarios are opened thanks to the first attempts at employing the stem cells in spine injured experimental settings [34], the studies performed on antibodies anti-myelin to promote nerve regeneration [54]. But modern neurosciences are evolving also towards neuromuscular stimulation in order to help the patient in performing movements under electrical signals [55-56].

CONCLUSION

Despite the advances in surgical instruments and techniques, the argument that began with Cooper and Bell is not completely resolved today. Patients managed without surgery can also have favourable outcomes making the treatment of SCI a great challenge; on the other hand, the consequences of SCI are still traumatic and disabling. Recent advancements in research and technology may play a pivotal role in the future management.

REFERENCES


