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REVIEW

History of cervical spine surgery: from nihilism to advanced reconstructive surgery

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Study design: Review of literature.
Objectives: To review and analyze the evolution of cervical spine surgery from ancient times to current practice. The aim is to present an accessible overview, primarily intended for a broad readership.
Methods: Descriptive literature review and analysis of the development of cervical spine surgery from the prehistoric era until today.
Results: The first evidence for surgical treatment of spinal disorders dates back to approximately 1500 BC. Conservative approaches to treatment have been the hallmark for thousands of years, but over the past 50 years progress has been rapid. We illustrate how nations have added elements to this complex subject and how knowledge has surpassed borders and language barriers. Transferral of knowledge occurred from Babylon (Bagdad) to Old Egypt, to the Greek and Roman empires and finally via the Middle East (Bagdad and Damascus) back to Europe. Recent advances in the field of anesthesia, imaging and spinal instrumentation have changed long-standing nihilism in the treatment of cervical spine pathologies to the current practice of advanced reconstructive surgery of the cervical spine. A critical approach to the evaluation of benefits and complications of these advanced surgical techniques for treatment of cervical spine disorders is required.
Conclusion: Advances in surgery now permit full mechanical reconstruction of the cervical spine. However, despite substantial experimental progress, spinal cord repair and restoration of lost functions remain a challenge. Modern surgeons are still looking for the best way to manage spine disorders.
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Keywords: cervical spine; history; surgery; spine; instrumentation

INTRODUCTION

The treatment of spinal disorders poses complex challenges. The search for an effective treatment dates back to prehistoric times.

Early Egyptian (1550 BC), Greek, Roman and Arabic texts on medicine show efforts to treat spinal disorders, but generally a nihilistic approach prevailed.[1] The complex anatomy of the spine and its contents, combined with a presumed poor prognosis, has caused surgeons to be very conservative for thousands of years. There are only isolated reports from ancient history of surgically treated cases, mainly in trauma. Interestingly, these reports document the same treatment principles upon which current practice is based: re-alignment of the spine, removal of foreign bodies, stabilization and decompression of the spinal cord.

The development of spinal surgery was further discouraged by legislation on medical errors dating back to the Babylons (1955–1912 BC), and known as Hammurabi's Code,[2] which could end up detrimental for the surgeon: 'The surgeon that operates with a bronze knife and saves the patient - he will be compensated with silver pieces according to the importance of the patient. On the other hand the one that operates a patient with a metal knife for several wounds and causes his death, his hand will be cut off'. This reward/punishment rule may be perceived as illustrating the adverse effects of a more 'result-oriented' than 'effort-oriented' evaluation of medical practice. Alternatively, the punishment imposed upon the use of a 'metal' rather than a 'bronze' knife may indicate attempts to promote quality by discouraging the use of inferior instruments.

Operative procedures for lumbar spine surgery were initiated in the nineteenth century. Cervical spine surgery started to develop later around 1950. This later development is logical, as surgery in the cervical region is more complex and risky than in the lumbar region. Progress has been rapid since then following advances in imaging, surgical techniques and implant technology, which has been industry driven with the development of many different methods for spinal instrumentation.

Various manuscripts have reviewed and summarized the history of spine surgery in general.[1,3–5] Some of these have concentrated on old history, others on modern history. To our knowledge, none have addressed the history of cervical spine surgery from the prehistoric period up to modern times in detail. Although spine surgeons are generally familiar with the development of spinal surgery, we consider it timely to provide an accessible overview for the larger audience of non-surgical spinal cord injury experts. The aim of this manuscript is to review the rapid development of cervical spine surgery from long-standing nihilism to the current practice of advanced reconstructive surgery of the cervical spine.

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EARLY HISTORY OF THE MANAGEMENT OF SPINAL DISORDERS

The Ebers Papyrus,[6,7] considered one of the oldest and most important medical papyri of ancient Egypt (1550 BC), report dissections to increase knowledge about the anatomy of the spine and in particular of the spinal cord, named Djed in the hieroglyphic language.[6] (The Ebers Papyrus is an Egyptian medical papyrus dating to circa 1550 BC. Among the oldest and most important medical papyri of ancient Egypt, it was purchased by Georg Ebers (1873–74). In 1930 James Henry Breasted, an American Egyptologist and archeologist translated the papyrus from the original in the possession of the New York Historical Society and published a new limited edition.)[9] This oldest book in surgery includes cases of injuries to the spine and cranium and shows that these were considered to be very dangerous both for the patient and for the treating physician, being mostly fatal for the patient and in some cases for the treating physician as well. This re-emphasized the existing nihilism. Each case report in this book includes a description of diagnosis and prognosis. Some descriptions of removal of bone fragments or foreign objects from the extradural space exist, but none on intradural surgery. Despite the anatomical dissections, no direct connection was established between the anatomy and the functionality of the spinal cord.

A strong impulse to understand and to teach neurological disorders as well as surgery of the spine started in Greece around the fifth century BC, a period called the Golden Age of Greece.[7] A more rational analysis of diseases was adopted, aimed to understand the individual clinical presentation, combined with a more scientific approach to treatment. In this context some surgical techniques were described, including laminectomy of the spine.

Hippocrates (ca. 460–370 BC) described the clinical picture of a spinal cord injury related to a vertebral fracture when he documented paralysis of the limb on the same side as the spinal cord injury. He also wrote about back pain and sciatica. This is why some authors consider Hippocrates as the 'Father of spine surgery'.[8]

Five hundred years after Hippocrates, *Aurelius Cornelius Celsus* (ca 25 BC–50 AD), a Roman encyclopedist, documented neurological lesions after spinal cord injuries,[3] stating that 'injury to upper spine (cervical spine fracture) may cause breathing disturbances, vomiting and death.[2] Injury to the lower spine may provoke urinary disorders and weakness or paralysis of the lower limbs'.

This is the first documentation of the understanding of spinal cord function and the relation between the location of the lesion and its clinical consequences. It signals the initiation of more rational approaches to treatment of spinal diseases. *Galen of Pergamon*, a Roman physician of Greek origin (129–210 AD), performed experiments in which the spinal cord was interrupted at different levels and noted that lesions in the upper cervical region caused loss of sensation and movement below the level of the lesion, including the diaphragm and respiratory muscles.[9] Lesions of the lower cervical region were found to cause loss of sensation and movement below the level of the lesion, but had less effect on the diaphragm and intercostal muscles. Lesions of the thoracic spinal cord did not affect the arms. His studies in anatomy and physiology were supplemented with anatomical illustrations and descriptions of the clinical and physiological changes related to spinal cord injury.[9]

In the Byzantine era several medical achievements were accomplished: *Paulus of Aegineta* (625–690 AD) designed instruments for neurosurgical use, like elevators, bone biters and raspatories. Besides his knowledge of wound management and antiseptic methods (for example, using wine to sterilize wounds), he also developed the technique of spinal cord decompression and convinced other surgeons to perform such operations. He published a Medical Compendium of seven books that includes a chapter on head and spine injury.[2,10] This encyclopedia has been translated into Arabic by *Hunayn ibn Ishaq* (809–873 AD) and one of his most famous papers is *De morbis acutis et chronicis*.[10]

TRANSFER AND ENRICHMENT OF KNOWLEDGE

Avicenna (Ibn Sina) (980–1037 AD), known as 'second doctor' (the title of 'first doctor' was attributed to Aristotle), presented in his book, Canon,[11] a very clear anatomical and physiological description of the cervical spine, and this increased understanding facilitated the development of surgery. He illustrated the cervical vertebrae including atlas and axis, the muscles, ligaments and nerves with appropriate interpretation of their function.[12] Thanks to him, the first steps in anesthesia were initiated: he was the first to use inhalation anesthesia and administered opium, mandragora, belladonna and other substances. This approach facilitated further developments in surgery. Around that time *Rhazes* (Abu Bakr Muhammad Ibn Zakariya al-Razl; 865–925 AD) described spina bifida.[13]

Substantial progress in medicine resulted from Arabic doctors who developed pharmaceutical and surgical products. *Abu al-Qasim al-Zahrawi* (Albucasis; 936–1013 AD) described in his book *Al-Tasrif*, dated 1000 AD, novel developments including plaster and adhesive bandages for the treatment of fractures, catgut for internal stitching and various surgical instruments.[14] Interestingly, cotton was also advised for surgery in order to obtain hemostasis. Although he advocated mostly conservative management, similar to his predecessors, in the form of reduction and immobilization of the injured spine segment(s),[14] the better understanding of function and disease pathology combined with technological progress offered better opportunities for treatment.

RENAISSANCE OF MEDICINE IN EUROPE

In Europe, the medical books from Arabic and Latin were translated in the eleventh century. *Constantinus Africanus* (1020–1087 AD), who studied in Bagdad, was one of the first to transfer this knowledge at his school in Salerno.[2,15] The Arabic medical knowledge slowly spread through Europe, and Lanfranchi of Milan[12] wrote a surgical text book (Chirurgia Magna) in 1296 based on translated Arabic texts. In modern times, with its immense communication network and immediate information exchange by internet, such a transferral would have been instantaneous. However, in the absence of communication and fast transport it took centuries. Each medical book was copied by hand, which needs months or even years to be completed.

The works of *Guy de Chauliac* (1300–1368 AD) covering various medical fields ranging from anatomy to drugs, diseases and treatment were also partly based on knowledge from Arabic medicine.[2,16]

More insight into the anatomy of the spine was gained in the fifteenth century. *Andreas Vesalius* (1514–1564 AD) described the spinal column and intervertebral disc and *Giovanni Morgagni* (1682–1771 AD) reported that pressure on the spinal cord can cause paralysis of the lower extremities.[4]

MODERN HISTORY: FROM LUMBAR TO CERVICAL SPINE

The development of modern spinal surgery started in the nineteenth century, following the introduction of antisepsis and anesthesia. The basis for every clinical decision became a detailed neurological examination.

Initially, efforts concentrated on the management of lumbar disorders and in particular lumbar disc degeneration. In 1829, *AG Smith* performed the first laminectomy. *Rudolf Virchow* (1821–1902) described a traumatic rupture of an intervertebral disc.[4] In 1909 *Alfred Taylor* was the first to use a unilateral laminectomy, and *Fedor Krause* successfully removed a lumbar hernia.[4] Between 1927 and 1931 *Schmorl*, a German pathologist, established the modern basis for understanding of the intervertebral disc. The stage was set for developing spinal surgery.

Success in lumbar surgery encouraged surgeons to also perform operations on the cervical spine: *Charles Elsberg* was one of the first to remove a cervical disc by a posterior approach in 1925.[4] It was recognized that the risks involved in posterior approaches to the disc were much greater in the cervical than in the lumbar region, as manipulation of the spinal cord needed to be avoided. This may explain at least in part the later development of cervical spine surgery.

MODERN HISTORY: INFLUENCE OF TECHNOLOGICAL ADVANCES

Improvement of cervical spine surgery was stimulated by the evolution of physical examination, diagnostic imaging, the development of surgical techniques and spinal instrumentation. In the sixties, important developments in medical technology were initiated. For example, new horizons in diagnosis of spine pathologies were achieved with the introduction of computed tomography scanning for clinical use in 1972 by Hounsfield.[17] The first intraoperative microscope was used around the same time.[18] The use of magnetic resonance imaging in the clinical setting was initiated in 1976.

In addition, instrumentation technologies were developed and refined,[19] followed by techniques for minimally invasive surgery later on.

Progress in spinal surgery was associated with the development and implementation of neurophysiological monitoring of the spinal cord and nerve roots. The aim of these techniques was to provide an early alarm to warn the surgeon about risks in the operating field, and thus to protect the integrity of the spinal cord and nerve root function. Monitoring of somatosensory evoked potentials was first used in the 1970s during the surgical correction of scoliosis. In 1980, monitoring of motor evoked potentials became available, and was preferred by many surgeons, as they permit early warning of impending risks to the corticospinal tract and in practice are more reliable than somatosensory evoked potentials. Electromyography and triggered electromyography have been used for over 20 years to monitor the function of nerve roots, specifically during the placement of pedicle screws in spinal fixation.

Thanks to the revolution of computer technology in the eighties, biomechanics of the spine was studied more closely. We came to better understand the relative contribution of the various cervical segments (occiput–C1; C1–C2; C3–C7) in regards to mobility in particular to their contribution to the flexion/extension, axial rotation and lateral bending of the cervical spine. This improved understanding and the realization that pathological changes in these segments can lead to rigidity, hypermobility or instability at one or more levels, influencing the spinal cord and foraminae (different degrees of compression), heralded a strong focus on biomechanical aspects.

POSTERIOR APPROACHES

In the early fifties, all surgical procedures of the cervical spine were performed using a posterior approach. Anterior approaches were initially avoided for fear of damage to vital structures, such as the esophagus, carotid artery, jugular vein and vagal nerve. Decompressive surgery of the spinal cord and radices was performed through large posterior incisions and consisted of laminectomies or hemilaminectomies with or without opening of the dura, sometimes cutting the ligamentum denticulata.[5]

The risk of instability following laminectomy, particularly in children, has led to the development of open-door laminoplasty first described by Hirabayashi and Satomi in 1977.[20] Laminoplasty describes the process of increasing the space available for the spinal cord by reconstruction of the laminar arch via a posterior approach and must be distinguished from:

- laminotomy, which is the partial surgical reduction of the laminae in a horizontal fashion;
- laminectomy, which describes the removal of the lamina and the spinous process;
- partial or hemilaminectomy, which is the removal of the lamina, the ipsilateral facet joint on one side and the lateral aspect of the base of the spinous process.

These techniques of laminoplasty have been developed in Japan from 1970 onward for the treatment of ossification of the posterior longitudinal ligament (OPLL) and degenerative spinal canal stenosis.[21] The Japanese population has a higher incidence of OPLL, and the anterior approach for the operative treatment of OPLL had significant complications. Different technical variations of the same surgical principle have been developed. However, all described techniques of laminoplasty aim for the reconstruction of the spinal canal, to achieve immediate relief of cord compression and to avoid any recurrence.[22]

Procedures to stabilize the cervical spine were initially mainly performed by posterior approaches. The first attempts of posterior spinal fixation were already developed by Hadra in 1891.[23] He used interspinous wiring without grafting, which often led to failure. In 1953, Holdsworth and Hardy reported better results by using interspinous wiring and grafting.[24]

Lateral mass screws in posterior stabilization of the cervical spine have become an option for treating instability of the lower cervical spine.[25] Several techniques of lateral screw placement have been described.[26–29] Each of these techniques has its unique entrance point for screw insertion, screw trajectory and risk of complications. They have in common a high rate of fusion and offer equal or even greater biomechanical stability in comparison with anterior plating or interspinous wiring techniques. The main complications of lateral mass screw insertion are injury/ies to the adjacent nerve roots, the vertebral arteries and screw fixation failure.

Fixation of the unstable atlantoaxial complex has been a challenge for many years and a number of fixation techniques have been developed, like posterior wiring techniques, posterior clamps, C1–C2 transarticular screw fixation, posterior C1 lateral mass screw with C2 pars or pedicle screw fixation, and anterior transoral C1 lateral mass to C2 vertebral body fixation.

The first C1/C2 fusion techniques were described by Mixter and Osgood in 1910.[30] Gallie[31] described in 1939 the posterior cervical wiring of the lamina of C1 and C2, which was modified by Brooks and Jenkins in 1978[32] and Dickman *et al*. in 1991.[33] Interlaminar clamps for posterior C1–C2 fixation became fashionable in the 1980s.[34]

The latest development of the C1–C2 fusion techniques is the posterior screw fixation, utilizing C1–C2 transarticular screws and C1 lateral mass screws with C2 pars screws. These techniques have

Table 1 Overview of cervical disc prosthesis

Disc prosthesis	*Manufacturer*	*Year*	*Type*	*Publication results*
Cummins Bristol disc	Medical Engineering Department, Frenchay Hospital Bristol	1991	Metal on metal	Cummins *et al.*[49]
Pointillart disc prosthesis	(abandoned)	1998	Carbon surface sliding on the upper end plate	Pointillart *et al.*[50]
Bryan disc prosthesis	Medtronic	2000	Plastic on metal	Goffin *et al.*[45]
Prestige disc prosthesis	Medtronic sofamor	2002	Metal on metal	Le *et al.*[51]
Prodisc-C prosthesis	Synthes spine paoli, PA	2002	Metal polyethylene ball-in-socket with 2 metal plates	Bertagnoli *et al.*[48, 52]
PCM disc prosthesis	Cervitech, inc	2003	Plastic (polyethylene) on metal	Afee *et al.*[53]
Cervicore disc prosthesis	Strycker	2005 (USA)	Metal on metal	Le *et al.*[51]
M6 cervical disc prosthesis	Spinal kinetics	2005	A viscoelastic polymer (artificial nucleus), which serves as an artificial annulus and titanium endplates	Reyers *et al.*[47]

been further developed for computer-assisted surgery.[35] The transoral approach can be used for stabilization of the unstable craniovertebral region, but is used only in highly specialized spine centers.

ANTERIOR APPROACHES

At the end of the 1950s, the anterior cervical fusion with disectomy, curettage, holes in the end plates and the use of tricortical bone graft was developed by Smith and Robinson.[19] The development of anterior approaches to the cervical spine was largely initiated by recognition of the risks involved in posterior approaches to the vertebral body and intervertebral disc space. Advances in surgical techniques and use of the microscope with better lighting made anterior approaches safer and feasible. Anterior approaches would allow disc removal and interbody fusion without any manipulation of the spinal cord. This technique is still used today and appreciated by many spine surgeons. Cloward[36] modified this technique and reported the use of instrumentation to achieve interbody fusion in 1958: a cylindrical fragment of autologous bone was placed in a cylindrical hole in the intervertebral disc space. He used modifications of instruments originally designed for posterior interbody fusion.

Surgeons had to tackle the vertebral body instead of the posterior elements owing to its importance in absorbing compression forces. The increasing focus on biomechanical aspects stimulated initiatives to develop new systems, which could simulate the elasticity of the normal disc and preserve the mobility of the spine.[37,38] New techniques for cervical fusion were described with the use of various types of synthetic bone and biochemical graft materials. Advances in technology have led to the invention of 'bone morphogenic proteins'. In the beginning, this artificial bone was placed in metal cages, but these caused artifacts on computed tomography and MR imaging. Titanium spacers produced fewer artifacts on computed tomography and magnetic resonance imaging, but the hard structure of titanium could lead to the collapse of the vertebrae. Because of this, other materials were developed. The most commonly used material nowadays is polyetheretherketone, which is known to be light, radiolucent and less hard than titanium.

Recent studies have permitted the development of bioabsorbable cages. (They stay in place until the fusion and are re-absorbed by the body after several months.)

Successes obtained in knee and hip joint arthroplasty further inspired the search for improved disc arthroplasty techniques, but the big challenge for spinal disc implants was not only to preserve the mobility of the disc itself, but in particular not to impair the adequate function of the facet joints and to maintain a normal spinal axis. Because of the risks involved in spine surgery, there was a strong desire to avoid possible complications and revision operations.[39] Challenges included searching for biocompatible materials that could remain *in situ* life-long without any long-term inflammatory reaction, while preserving normal biomechanics of the spine.[40] Initially, most of the efforts concentrated on lumbar spine arthroplasty.

Fernström in 1966 and *Reitz* and *Joubert* pioneered human prostheses.[41] Results were disappointing owing to segmental hypermobility and migration of the prosthesis. Nevertheless, despite these failures, surgeons continued to further develop prostheses. The *Charité* in Berlin, Germany, developed three generations of the SB Charité lumbar prothesi.[40]

In the same period, the *Acroflex lumbar disc* was introduced but quickly abandoned because of the potential carcinogenic effect of the rubber used in this type of prosthesis.[42]

Based on these pioneer studies various devices have been proposed for cervical disc arthroplasty (Table 1).

These extensive and rapid developments highlight a strong focus on biomechanical properties. This focus is also evident in the various publications reporting results of disc prostheses.[43–48]

RESTORATION OF SPINAL CORD FUNCTION

The advances in cervical spine surgery over the past decades have been impressive, with an evolution from relatively simple decompressive and stabilizing procedures to complex surgery, including 360° vertebral reconstruction and cervical deformity surgery. To a large extent, the rigid mechanical reconstruction of the cervical spine has been mastered. These developments are of great significance as they can prevent the occurrence of secondary damage and optimize favorable conditions for restoration of nervous function. Active approaches to restoration of function and repair of the spinal cord remain, however, a major challenge.

Advances in basic science offer hope for further reconstruction of the spinal cord in the future. Progress is continuing with the development of genetic repair treatments, the introduction of chitosan channels for rebuilding the spinal cord structure, and stem cell transplantations and neurotrophic factors to stimulate spinal cord repair. In addition, developments in nanotechnology and bionics offer new opportunities for restoration of function in paralyzed sections.

CONCLUSIONS

The first evidence for surgical treatment of spinal disorders dates back to approximately 1500 BC. Currently, surgical advances and the development of osteosynthesis material and artificial discs have facilitated the implementation of complex 360° cervical spine surgery

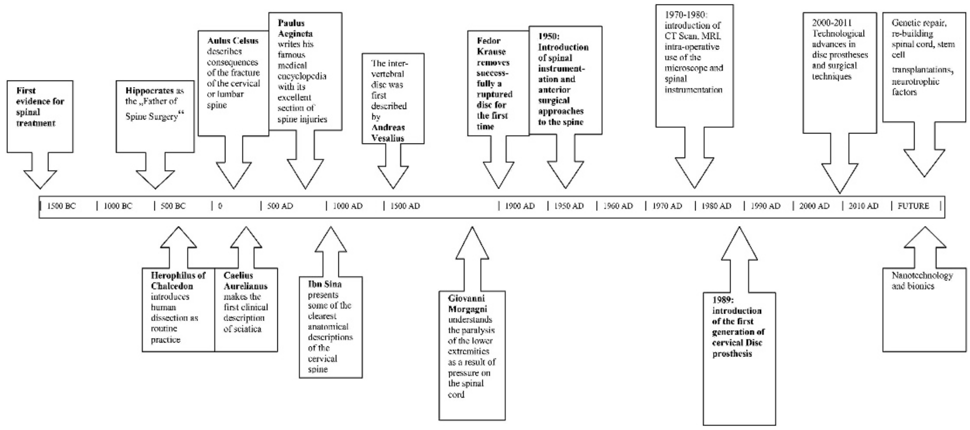

Figure 1 Major milestones in the development of cervical spine surgery.

for treatment of inflammatory, degenerative, oncologic and traumatic lesions to the cervical spine and spinal cord. Major milestones in the development of spinal surgery are summarized in Figure 1.

The Egyptian period has helped to understand anatomy. The Greek and Byzantine period provided descriptions of clinical symptoms, and techniques like laminectomy were described. Overall, a conservative approach was recommended under the general principle of '*primum non nocere*': first, do no harm. The Arabic/Islamic period was a transitional period, in which many works were translated and enriched, and some techniques and instruments were developed. Teaching of medicine in Europe started in the eleventh century, but little change occurred in the management of spinal diseases.

The complexity of spine diseases and absence of antiseptics, anesthesia and good instruments discouraged surgeons from performing operations on the spine. Modern development of spinal surgery started in the nineteenth century, after the introduction of antisepsis, anesthesia and proper neurological examination.

It is, however, only in the last 10–20 years that cervical spine surgery has really advanced with the development of imaging methods (computed tomography scan, magnetic resonance imaging), implants for osteosynthesis and cervical disc arthroplasty. These advances nowadays permit a safe release of the spinal cord, vertebral fixation and, with the disc arthroplasty, conservation of the function of the involved level. The concept is to preserve the anatomy and physiology of the cervical spine as with a normal intervertebral disc, avoiding the complications and failures associated with arthrodesis. However, despite many reports describing better results based on mechanistic evaluation, the added value in terms of clinical benefit and patient satisfaction remains to be determined. A critical approach to the evaluation of benefits and complications of these advanced surgical techniques for treatment of cervical spine disorders is required.

Patient-reported outcome measures should become a standard in describing the results of cervical spine surgery.

We conclude that the era of nihilism is long past and that advances in cervical spine surgery now permit full mechanical reconstruction of the cervical spine. Experimental results hold promise that, one day, spinal cord repair and restoration of lost functions can be achieved.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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