Jan Štulík et al.

CERVICAL SPINE TRAUMA







Friedrich Magerl
Petr Šebesta
Jan Kryl
Tomáš Vyskočil
Zdeněk Klézl

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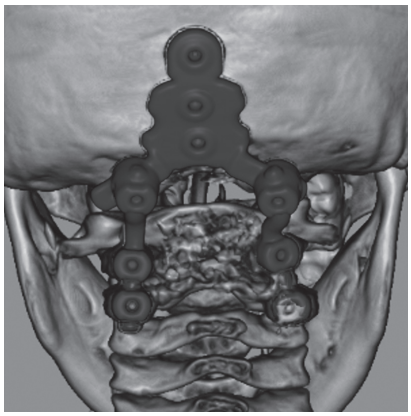

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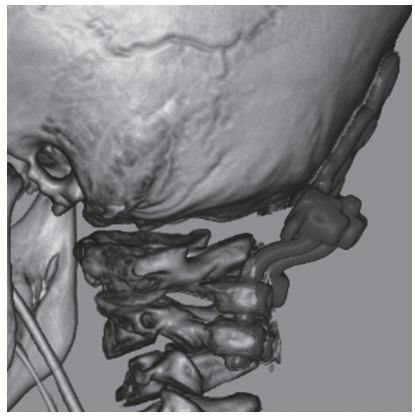
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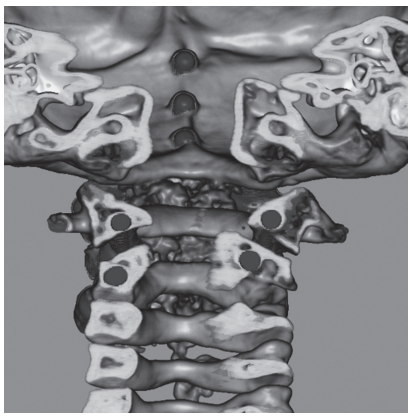
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Foreword

During my long career I had the opportunity to follow and actively support the dynamic development of spinal surgery in our country.

Orthopaedics and especially spinal surgery have recorded a significant upsurge all over the world in a historically short period particularly due to improved diagnostics and development of instrumentation and implants. One of the outcomes of evolution of spinal surgery in the Czech Republic is a unique publication Cervical Spine Trauma.

The Czech specialists have always kept up with the world surgery. One of the first surgeons to perform fusion of the lumbar spine was Eduard Albert (1841–1900) in 1895. His successor in Innsbruck and Vienna, Karel Maydl performed the first laminectomy, that he called resection of the spine, on 22 December 1882. In 1891, Karel Maydl was appointed Head of the Department of Surgery of the Prague University and laid foundations of modern Czech surgery. In 1902, Stanislav Tobiášek began to work at the same Department. Later he opened the first orthopaedic department in Bohemia. He was succeeded by Jan Zahradníček who also dealt in spinal surgery. His activity at the Department marks the beginning of a new era of the Czechoslovak orthopaedic surgery.

After World War II, the efforts in this field focused on development of spinal instrumentation and efficient spine surgery techniques. Harrington in the USA introduced the first comprehensive spinal instrumentation, Roy-Camille in France invented transpedicular implantation of screws and, subsequently, Friedrich Magerl introduced external fixator. It was particularly Magerl who has accelerated the development of spinal surgery as a specialization and who is one of the most prominent personalities in this field. He has based his work on the AO school, founded in 1958, with another outstanding personality M.E. Müller, leading the Department of Orthopaedic Surgery and Traumatology in St. Gallen. This department has hosted most of heads of university clinics from all over Europe over the years. In 1965, I established close cooperation with the Department in St. Gallen.

The seventies of the 20th century witnessed the introduction of CT and later also MRI examination that contributed considerably to further development of diagnostics of spinal injuries and classification systems. Magerl improved and developed new techniques of treatment of spinal injuries, including direct osteosynthesis of the *dens axis*, translaminar and transarticular screws. A revolutionary invention was external fixation, later converted to internal fixation, that has been used in various modifications until today. In cooperation with Bernard Jeanneret, Magerl was also involved in development of instrumentation for posterior cervical stabilization. In 1994, he published together with his colleagues a modern pathomorphological AO classification for fractures of the thoracolumbar spine. He has also introduced AO training courses for spinal surgeons that have undoubtedly conduced to standardization of findings and knowledge in the field of spinal surgery.

I had come to understand the big potential for development of the spinal surgery in our country and its importance during my three-month stay at the Department of Orthopaedic Surgery in Paris, headed by Robert Judet. There I met the Judet's colleagues Letournell and Roy-Camille who introduced me into the mysteries of spinal surgery. Another milestone in the development of the Czech spinal surgery was a long-term stay of Otto Vlach in Twin Cities Scoliosis Center in the USA. After he returned home, he laid foundations of modern surgical treatment of scoliosis and other spinal defects here. In 1986, he published a book on treatment of scoliosis based on an extensive textbook by John H. Moe. For a long time the Department of Orthopaedic Surgery in Brno was actually the only institution in Czechoslovakia that dealt exclusively with surgical treatment of scoliosis. Otto Vlach is a top specialist in this field and was the first to teach us about destabilization effects of laminectomy without fixation, that was at that time performed routinely in spinal fractures with a neurological deficit.

After opening the Orthopaedic Department of 3rd Faculty of Medicine, Charles University in Prague, spinal surgery became one of its three main focuses, together with joint replacement and traumatology of the musculoskeletal apparatus. Our model was the Orthopaedic Department in St. Gallen, with Friedrich Magerl at its head. Thanks to our long-term cooperation a number of our colleagues had the opportunity to gain experience there through short fellowships.

In 1991, the Orthopaedic Department of 3rd Faculty of Medicine, Charles University organized a one-day symposium in Prague on "Spinal surgery – new techniques" with active participation of Professor Magerl and B. Janneret and in the same year the Department started to work on a research task under the grant IGA MZ 1771-3 on "Specification of the technique of stabilization of spine". Under the research program the Department bought modern instruments and implants and at the beginning of 1992 it launched the process of implementation of these new progressive procedures.

The team specialized in spinal surgery at the Department included particularly Martin Krbec, Zdeněk Klézl and Jan Štulík. However, over a certain period spinal surgery was not adequately supported as a specialization and as a result, they left the Department. Zdeněk Klézl left in 1995 for the Orthopaedic Department of the Central Military Hospital in Prague, Martin Krbec was in 1999 appointed Head of the Orthopaedic Department in Brno, where he followed the trend launched by Otto Vlach. In 2009, Martin Krbec became Head of the Orthopaedic Department of 3rd Faculty of Medicine, Charles University in Prague and Zdeněk Klézl a senior spinal surgeon in Derby in United Kingdom. Jan Štulík left in 2001 for the University Hospital Motol in Prague, where he has built in few years an independent Center for Spinal Surgery, together with his colleagues Tomáš Vyskočil, Petr Šebesta and Jan Kryl.

Thanks to high productivity and top quality of the provided medical care, the Center for Spine Surgery University Hospital Motol has won recognition both in the Czech Republic and abroad. The Department is respected also for its activities in the field of research and development and education.

It is with great satisfaction that I follow the development of spinal surgery, the outcomes of these long-term exceptional efforts in such a highly demanding specialization. The present book summarizes the work of authors of several generations. It is the first comprehensive publication dealing with the issue of "Cervical Spine Trauma" in the Czech literature. Fourteen clinical chapters describe in detail individual injuries at different levels of the cervical spine. The monograph was prepared by a team of experienced authors who supplemented it with a wide range of their own high quality radiological material, as well as a number of instructional schemes. The list of references provides an exhaustive overview of the world literature related to this field.

The presented publication has a high scientific and educational value.

I wish to congratulate the authors.

Oldřich Čech
Professor Emeritus, Charles University

Foreword

Spinal trauma surgery has evolved as a separate subspecialty within a wide range of spinal disorders. In this context, this book is a logical step forward, because it brings together all relevant aspects of cervical spine trauma treatment, following systematically the medical aspects and focusing on the surgical treatment. Although the book is primarily intended for trauma surgeons, it may be useful also to those who specialize in non-traumatic disorders, as it will help them get a better picture of the use of instrumentation, biomechanics of trauma and internal fixation and maximize the chance for a successful treatment of cervical spine injuries.

In this relatively circumscribed field the major inherent problems concerning data evaluation due to acuteness of the patients' condition, distribution of cases among multiple Centers and a highly variable mix of spinal injuries, are well known. This has resulted in production of numerous underpowered and often controversial studies. Hence, a vast majority of textbooks, reviews, guidelines and publications that attempt to synthesize the literature usually conclude that further research is needed and no distinct recommendation can be made. However, treating physicians or surgeons must make prompt therapeutic decisions on a daily basis, regardless of the quality of literature. Therefore the experience of surgeons gained over decades of specialisation in this field, is of extraordinary importance. This book offers a unique body of experience of specialists in the field of cervical spine trauma to both the future as well as the already established spine surgeons.

As the authors come from the Central Europe, their readership should be aware that the experience expressed in the book may differ from that in other parts of the world. This, however, should not be perceived as limitation of the applicability of the experience but rather as a contribution of the Central European approach to the world literature.

The recent decades have seen an explosion of innovations, significant progress as well as increasing complexity of cervical spine trauma management. Several new surgical techniques and treatment options have been established, that are included in this book. However, due to the continuous medical progress, obviously further changes are already taking place even during the process of publishing of this book, leaving the reader with a "snapshot" of the development of the body of knowledge.

I wish to congratulate the authors on this excellent book which I am sure will make the decisions of surgeons in the everyday practice much easier. The authors, experts in cervical spine trauma care, have used their long-term clinical experience to formulate recommendations that may be helpful in the efforts to provide the patients with the best possible treatment. I hope that you will enjoy this book and believe that it will bring benefit both to you and to your patients.

Frank Kandziora, M.D., Ph.D.
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1. Introduction

In the past, spinal surgery was only a marginal discipline at many orthopedic and neurosurgical departments, both in the Czech Republic and abroad. Gradually it has won respect as an independent discipline or at least as a sub-specialization singled out from the mentioned disciplines. In the Czech Republic, the Czech Society of Spinal Surgery was founded in 1999. It associates orthopedic surgeons, neurosurgeons and trauma surgeons involved in the treatment of diseases and injuries of the spine and the spinal cord. The Society has soon become a respected member of the Czech Medical Society of Jan Evangelista Purkyně. It has organized eight annual congresses, developed the concept of the discipline, created the database of spinal operations and a register of spinal cord lesions. The database was also used to categorize spinal surgery departments. Currently, there are 20 of them in the Czech Republic of different categories, of which 3–4 top quality departments are fully comparable with the European clinical and scientific standard. Another achievement in this field is development of a network of spinal injury units dealing with the treatment of patients with spinal cord injuries.

Ten years ago, the concept of spinal surgery as an independent discipline was quite unthinkable. Since then the situation has changed and the experience both in the Czech Republic and abroad proves that this idea is feasible and specialized departments call the tune in further development. Therefore, it seems appropriate to explain the respective concepts in historical consequences.

What is spinal surgery? It is a medical discipline that builds on orthopedic surgery, neurosurgery and, taking into account surgical approaches, also on general surgery. It deals particularly with the operative but also with non-operative treatment of spinal diseases. Surgical treatment of spinal diseases has developed along two basic trends, the orthopedic and neurosurgical one. Spinal surgery aims to link the two trends together, make use of their benefits and ensure further advancement. It may be divided according to three basic criteria, namely anatomical location, diagnosis and type of the surgical intervention. In anatomical terms, the spine is divided into the upper cervical spine and craniocervical junction, the lower cervical spine, the thoracic spine, the lumbar spine, sacrum and coccyx. In diagnostic terms, it covers injury, degenerative change, deformity, tumor, inflammation or manifestations of a systemic disease; and in surgical terms, it includes a simple resection, internal fixation, bone fusion of the surrounding spinal segments or mobile stabilization.

The remarkable progress in spinal surgery as a separate discipline would be impossible without a parallel development in the field of asepsis, instrumentation, anesthesiology or imaging methods. The first attempts at treatment of spinal injuries that had to do without achievements which we have at our disposal today, are highly admirable. Today it is hard to imagine for instance an operation without electrocoagulation that has considerably reduced both blood loss and duration of surgery.

The book contains 16 chapters focused on the most important information that is essential for treatment of cervical spine injuries. Knowledge of anatomy of the occipitocervical junction, the lower cervical spine and the cervicothoracic junction is crucial for insertion of fixation components into the occipital bone and individual vertebrae. Biomechanical relations are decisive for the extent of spinal fusion and placement of fixation on the anterior, posterior or, if necessary, on both sides of the spine in markedly unstable injuries.

Indication for surgery should be based on a careful clinical examination and the corresponding radiological, CT or MRI findings. The current CT technology provides a reliable image in a few minutes and subsequently reconstructs any bone injury from the head down to the pelvis, including the complicated occipitocervical, cervicothoracic and lumbosacral regions. In patients with neurological deficit, MRI provides a detailed image of spinal cord injury, posterior ligamentous complex, anterior longitudinal ligament and especially of the intervertebral disc.

Knowledge of surgical approaches is essential for treatment of cervical spine injuries. We recommend to perform anterior approaches to the upper cervical spine and cervicothoracic junction always in cooperation with the respective specialists. Injuries most frequently

involve the lower cervical spine and the most common surgical approach is the Smith-Robinson (anterolateral) approach that is minimally invasive, allows decompression of the spinal canal and fixation, and often also reduction of articular facet dislocation.

Perhaps the biggest progress in spinal surgery can be seen in the development of instrumentation. Currently we have at our disposal a wide range of plate systems with internal stability, titanium cages or posterior stabilization universal systems with polyaxial screws and components fixing the occiput to the upper cervical, lower cervical or in certain cases to the upper thoracic spine. Modern instrumentations are manufactured from titanium which allows subsequent MRI examination.

This publication has been prepared by the team of the Center for Spinal Surgery University Hospital Motol in Prague in cooperation with their colleagues from other departments. The Department was founded in 2002 by separation from 1st Department of Orthopaedics of 1st Faculty of Medicine, Charles University, Prague and the University Hospital Motol. At the beginning it shared premises with the Department of Neurosurgery of the University Hospital Motol. In 2004, these two departments physically split. At present the Center for Spinal Surgery has a total of 25 beds, of which 15 standard and 10 beds in the Intensive Care Unit. One operating theater provides non-stop spinal surgery service where 7 surgeons perform 1200 operations a year, of which approximately one third for spinal injuries. The department cooperates with prominent specialists from all over the world, and is involved in a wide range of scientific and publication activities. The department has based its philosophy on the foundations of the Swiss AO school, the group around Professor Friedrich Magerl and his pupils Professor Bernard Jeanneret, Professor Dieter Grob and others.

2. History

The aim of the publication is to provide a comprehensive overview of diagnostics, classifications and methods of treatment of cervical spine injuries. It is intended for spinal surgeons involved in neurosurgery, traumatology or orthopedics, as well as for general medical public and medical students, as it presents both the basic and detailed information about the possibilities of a highly specialized clinical discipline. The book offers an overview of treatment of often highly complex injuries with all options documented by experience gained by the authors and reports from the world literature. It is the result of work of three generations of spinal surgeons; its conclusions are based on high numbers of treated patients, innumerous hours spent in the operating theatre, departments, examination rooms or specialized conferences.

This chapter offers a general historical overview of contributions of outstanding personalities and their discoveries related to cervical spine surgery, without which our knowledge of this discipline would have not been at the current level. The basic information about breakthrough discoveries and initiatives in this field is vital to gaining a deeper understanding of the discipline as well as its further research and development. Specific details related to individual methods of procedures are presented in the respective chapters.

2.1. Ancient history

Imhotep (2686–2613 BC), vizier of pharaoh Djoser II in 3rd dynasty, was astronomer, magician, high priest, physician. He was also the architect of the first pyramid in Egypt, the famous Step Pyramid at Sakkara. Imhotep was probably the first to write a treatise on surgery, many years later known as the Edwin Smith papyrus. Thanks to it he was more popular than the pharaoh whom he served. The papyrus was found in the caves in Thebes, sold to Edwin Smith in 1862 and later translated by Breasted in 1930. It contains 48 case histories of bone injury, including spine trauma. With amazing accuracy he identified and described sprain, subluxation or dislocation of vertebrae. He was able to distinguish between an injury to the upper spinal cord causing quadriplegia from an injury to the middle spine resulting in paraplegia of lower extremities. Imhotep already knew that paralysis resulted from interruption of the spinal cord but did not understand why. The papyrus is considered to be the first document ever written [16, 95]. Other information sources consider the exact dating of the period when Imhotep lived impossible, based on the current findings (Bareš and Vachala, Czech Institute of Egyptology, personal communication). According to authors, little is known about Imhotep himself and the Djoser pyramid cannot be directly credited to him either. The same applies to authorship of the medical papyrus. The text itself is known from the beginnings of the New Empire, i.e. from the period about 3500 years ago.

Hippocrates (460–375 BC) was born at Kos about 460 BC in the time of Pericles. His father, similarly as his grandfather, was a physician named Heraclides. Early treatises, mainly those dating back to the Greek Period, were influenced by the mythology and written by supporters of the religious cult of Aesculapius, among whom was also Hippocrates. In spite of this fact, when working on his treatises Hippocrates followed the developing trend of a more scientific approach to medicine. He is considered to be one of the first physicians who dissociated medicine from mythology. The period of philosophy based on rational thinking that he advocated in relation to perception of the surrounding environment, is one of the most remarkable epochs of development of the human race. The material, he is credited with, is judged to be a compilation of the work of several people rather than the result of an individual. The works that we call the Hippocratic collection was collected by an Egyptian scholar in the time of King Ptolemy Soterus (323–285 BC). Soterus and his group collected all the written documents that corresponded to the Hippocrates' style, and presented him as the author. One of the most interesting contributions that is most probably authored by Hippocrates is his bench for reduction of fractures (Fig. 2-1). Although

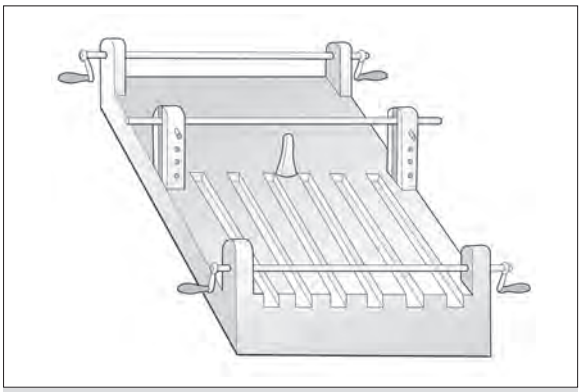


Fig. 2-1. Drawing of the Hippocrates's bench.

we do not know for certain which documents he really wrote, Hippocrates may be considered one of the most outstanding representatives of medicine of all times. No comparable work was created during the following two thousand years [16, 72, 95].

Galen (130–200 AD) was born in Greece, later moved to Rome and became a personal physician to the Roman Emperor Marcus Aurelius. During his stay in Rome he performed exact anatomical dissections. Galen is considered the founder of experimental physiology and embryology. With Hippocrates, Galen was preeminent among the most distinguished physicians of antiquity. He described the muscular system as a complex locomotor unit, demonstrated the relation between the nervous and muscular systems. He was the first to use the terms lordosis, kyphosis and scoliosis to describe spinal deformity and to attempt at their active correction. His work was based on the Hippocrates' writings and for several centuries it was considered as an exceptional medical concept. Galen was also called "the first sports medicine specialist" as he held the official post of physician to the school of gladiators. Due to this post he had ample material for anatomical and physiological studies. He confirmed the Imhotep's and Hippocrates' hypothesis that injuries to the cervical spinal cord cause a different level of loss of mobility and sensitivity than injuries to the spinal cord in the lower segments. He introduced the concept of the central nervous system when he proposed that the spinal cord was an extension of the brain that carried sensation to the limbs and back, and noted that hemisection leads to a contralateral injury to the periphery. Galen made his experiments on makak rhesus monkeys (*Macaca mulatta*), as autopsy was prohibited by law [23, 95].

Oribasius (325–400 AD), a Byzantine physician who went to Rome at the invitation of Emperor Julian. He added a bar to the Hippocratic bench, that was used as a lever for reduction of dislocation of fractures. During traction of the trunk and extremities the lever exerted pressure on the gibbus [63].

Paulus of Aegina (625–690 AD), another Byzantine physician, whose greatest endeavor was to compose an Epitome of medicine in seven books, summarizing the medical knowledge for the last 1000 years. He is considered the author of the idea of using plates after fracture reduction. He was also probably the first to perform laminectomy in fractures where posterior structures of the vertebra dislocated against the spinal cord into the spinal canal. The importance of achievements of Paulus of Aegina is documented by the fact that the next laminectomy was described as late as 12 centuries later [17, 83, 95].

2.2. The Middle Ages

A number of skills developed during the antiquity fell into oblivion during the dark Middle Ages. In the period of the fall of the Roman empire (455 AD) there were no significant contributions to the development of medicine and physicians were merely refining the methods introduced in the Hippocrates' time. In relation to the spine, attention was focused only on fractures while scolioses or deformities caused by tuberculosis were left without treatment. They knew neither the cause of gibbosity, nor the fact that it was the same as in pulmonary tuberculosis. In medicine, science was again replaced by superstition and intellectual stagnation as before the Hippocrates' period. Perhaps the only outstanding person was Roland of Parma who wrote in 1210 his book on "Surgery" where he discarded the use of the Hippocrates' bench and recommended only manual reduction of spinal fractures. Unlike Hippocrates who used turning device rods, he also used traction on the pelvis and extremities with counteraction applied by an assistant, [83].

2.3. Renaissance

Andreas Vesalius (1514–1564) was born in Brussels, but worked in Padua. He is recognized as one of the most significant personalities in the history of medicine. Not only did he develop anatomy as a discipline but he was also the founder of the modern concept of medical science the way we understand it today. In 1543, he published the epical work "De humani Corporis Fabrica Libri Septum" that immediately raised a wave of protests from the opposition. The book gradually won recognition in the medical literature and the original anatomical texts have retained their scientific value until today. The work has laid foundations of anatomical research the principles of which are still followed by the current anatomists. Vesalius supported the idea that a physician must know anatomy and should learn it on anatomical specimens rather than from books only [8].

Ambroise Paré (1510–1590) was born to a poor family in Laval in the north of France. At that time there dominated a rigid system of castes in medicine. By official order, physicians were at the top, followed by surgeons and the last group included barber-surgeons, including Paré. Despite his status he advanced to be the chief army surgeon and consultant to the King. His book "Dix Livres de la Chirurgie" (Ten Books of Surgery) was translated into majority of languages and even today it still is a classical work in medical literature. Paré recommended ligation instead of cauterizing great vessels by boiling oil and supported the idea of careful treatment of wounds. His most famous sentence is "I dressed his wounds , God healed him" [66].

Nicholas Andry (1658–1742) published his first book on the musculoskeletal system called "L'Orthopaedie" where he used for the first time the term orthopedics to refer to a newly emerging medical discipline. He was involved in foundation of an orthopedic hospital, helped organize orthopedic literature and increase its availability. Nicholas Andry was a leading personality and is quite rightly recognized as the father of orthopedics. In his writings he dealt with curvature of the spine with a special focus on postural deformities and their treatment. He pointed out the phenomenon of muscular dysbalance and its relation to deformities. For treatment of deformities he used exercises and supporting devices. The symbol he used in his book, of a crooked young tree which is able to grow straight by applying appropriate forces, has become an international symbol of orthopedic surgery [79].

Percival Pott (1717–1788) explained the nature of a typical gibbosity as a consequence of tuberculosis of the spine in his description of 1769. Although the origin of the deformity was suggested already by Hippocrates and later by Galen, only the Pott's description provided conclusions for practical treatment. Therefore, the deformity was called Pott's disease (triad) [68-70].

2.4. Major discoveries

The history of injuries to the spine and spinal cord is an integral part of the history of treatment of spinal diseases. Most of the texts dealing with spinal diseases in the Edwin Smith's papyrus [16], Hippocrates' writings [3] or works written until 18th century concern primarily treatment of injuries to the spinal cord. The breakthrough discoveries made during 19th century in other fields of medicine significantly contributed to the development of an efficient, mainly surgical, treatment of spinal cord injuries.

Pasteur [65] discovered anesthesia and laid foundations for the discipline of bacteriology. Lister [50] developed a system of aseptic surgery. Semmelweis explained transmission of diseases. Koch [48] discovered and isolated pathogens and ways of their transmission. Schimmelbusch and Terrier [81] discovered sterilization. Halstead [90] introduced rubber gloves in surgery. More sophisticated instruments were developed; the use of electric power improved illumination and in 1896 Roentgen discovered and introduced x-rays into practice.

The most frequently discussed procedure in treatment of spinal cord injuries during 18th century was laminectomy (see 2.5.1.). In 1847, Malgaigne [53] was the first after a failed Hippocrates' attempt, who successfully used hyperextension to treat a spinal dislocation. However, major progress in a focused treatment of spinal injuries was achieved as late as in 20th century. In 1911 Albee [4] and Hibbs [43] described a method of spinal fusion and at the beginning of the thirties Crutchfield [26] introduced its clamp for skull traction that was considered a certain milestone in treatment of injuries to the spine and the spinal cord. Another milestone in the development of treatment of spinal cord injuries was discovery of penicillin by Fleming [32] in 1929. Without antibiotics the treatment of paraplegic patients would be impossible. In 1930 Stryker [85] in Kalamazoo, Michigan designed a turning frame that facilitated care of paraplegic patients. The beginning of the era of internal stabilization of spinal fractures is marked by introduction of the Harrington instrumentation [39, 40], allowing both reduction and stabilization of the spine. Halo-traction and fixation facilitating early mobilization of patients were devised by Nickel [60] and his team in Rancho Los Amigos Hospital in California, which marked further progress in treatment of fractures of the cervical spine. The concept of intermittent catheterization popularized by Sir Ludwick Guttman [61] has changed the long-term survival perspective in paraplegic patients from a few years to an almost normal life expectancy. In 1963, Roy-Camille [77, 78] in France for the first time fixed the spine with transpedicular screws and plates. This system allowed the use of shorter fixations and fusions in spinal injuries. In the seventies of 20th century, Hounsfield developed CT scanning [46]; the first high quality image of the brain was made in 1972. In 1952, Bloch, Stanford and Purcell were awarded the Nobel Prize for development of the principle of nuclear magnetic resonance [10, 71]. In 1977, Friedrich Magerl [51] in St. Galen, Switzerland developed, an external fixation device with transpedicular screws. In 1980, the same author applied the first three simple internal transpedicular fixation devices constructed by Robert Mathys (Magerl, personal communication) (Fig. 2-2). In 1982, Walter Dick in Basel, Switzerland, [27] was the first to use a sophisticated transpedicular internal fixation device in the form which has been with minor modification used until today. Despite the huge amount of different fixation devices developed since then, the Magerl's and Dick's concepts and principles have not been surpassed yet.

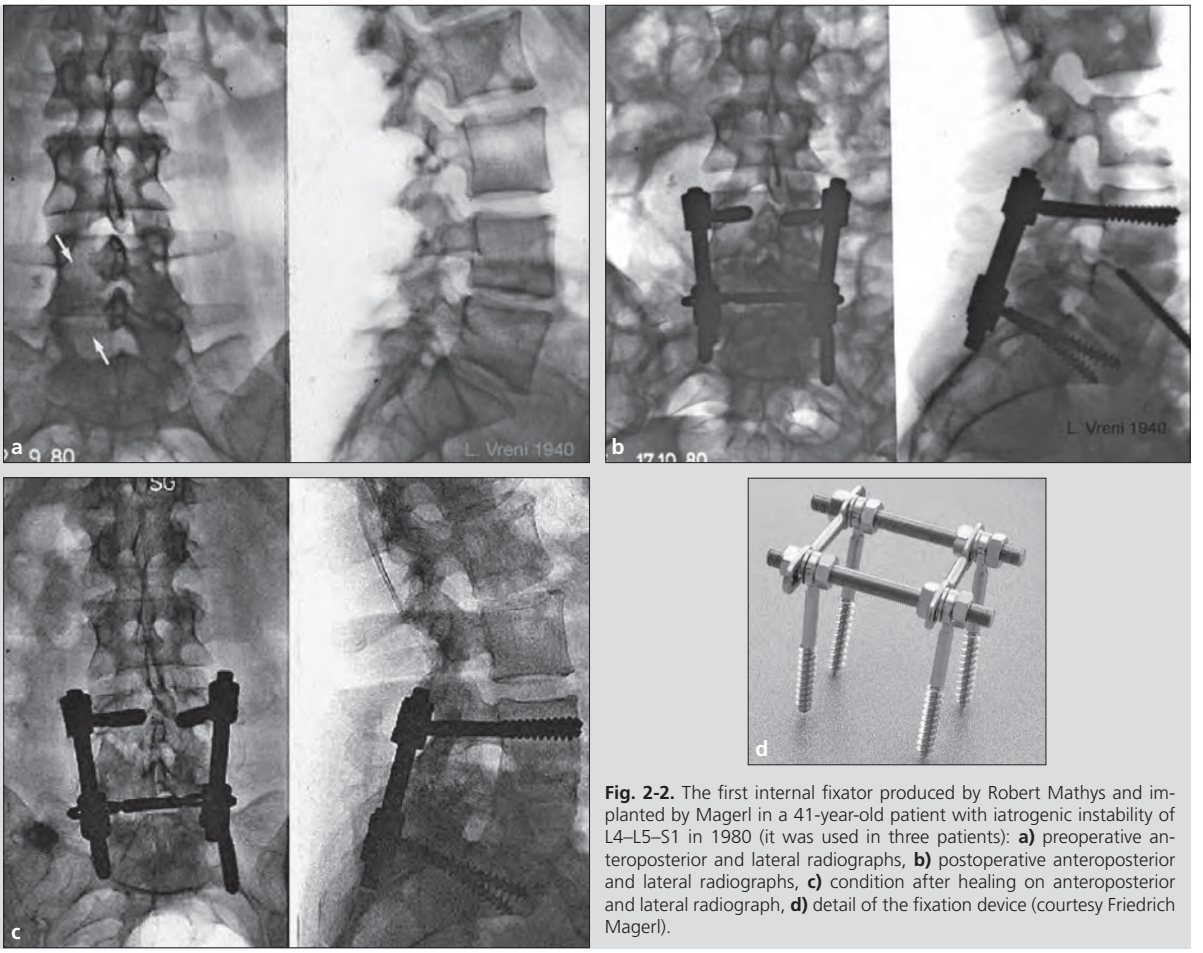


Fig. 2-2. The first internal fixator produced by Robert Mathys and implanted by Magerl in a 41-year-old patient with iatrogenic instability of L4–L5–S1 in 1980 (it was used in three patients): **a)** preoperative anteroposterior and lateral radiographs, **b)** postoperative anteroposterior and lateral radiographs, **c)** condition after healing on anteroposterior and lateral radiograph, **d)** detail of the fixation device (courtesy Friedrich Magerl).

2.4.1. Acute injuries to the central spinal cord

In 1954, Schneider et al. [80] published a description of the syndrome of acute central cervical spinal cord injury which they built primarily on the study presented in 1948 by Taylor and Blackwood [88], dealing with injuries and paraplegia in hyperextension cervical spine injuries with normal radiological appearance of bone structures. Taylor and Blackwood described a syndrome of acute central cervical spinal cord injury characterized by a disproportion, with a more severe affection of the upper as compared to the lower extremities and with a different extent of impairment of the function of the bladder.

2.4.2. Whiplash injury

The term whiplash is still in use, although it is misleading as it assumes a hyperflexion mechanism of the injury. In fact it is an injury caused in hyperextension with a prevailing discoligamentous lesion, fractures are very rare. Typically it is sustained in a rear-end collision by a driver in a standing car without head restraints. Whiplash injury was for the first time probably described by Herold Crowe in 1928 [25].

2.5. Evolution of treatment

The initial works on the cervical spine focused on injuries rather than acquired diseases of non-traumatic etiology. The following text from the Edwin Smith' papyrus was written 4600 years ago. It describes acute injury to the cervical spine:

"If thou examinest a man having a dislocation in a vertebra of his neck, shouldst thou find him unconscious of his two arms (and) his two legs on account of it, while his phallus is erected on account of it, (and) urine drops from his member without his knowing it; his flesh has received wind; his two eyes are bloodshot; it is a dislocation of a vertebra of his neck extending to his backbone which causes him to be unconscious of his two arms (and) his two legs. Diagnosis: Thou shouldst say concerning him: "One having a dislocation in a vertebra of his neck, while he is unconscious of his two legs and his two arms, and his urine dribbles. An ailment not to be treated."

Between the Egyptian and the Greek era, there were not many reports in the literature. In the Odyssey by

Homer we may find description of a man, who had got drunk and tumbled right off the roof and broke his neck, and *"his soul went down to the house of Hades*".

Samuel 4:18 presents the following description of a cervical spine injury*: Eli, falling back off his seat by the side of the doorway into the town, came down on the earth so that his neck was broken and death overtook him, for he was an old man and of great weight. He had been judging Israel for forty years.*

Hippocrates wrote about cervical spine injury in his book *On the Articulations* [15, 30], and his opinion on its treatment was in general pessimistic. He described principles of spine traction behind the head, using bandages and tapes. A more exact use of traction in cervical spine injuries was published by Bontecou as late as in 1887 [14], who placed adhesive tapes on the patient's face and fastened a cord over the top of the bed with a 9 kg weight, to reduce the fracture. In 1929, Taylor [89] introduced traction by a halter; in 1933 he was followed by Crutchfield and his clamp [26]. Gradually, the methods of traction have advanced and improved; the most efficient method is halo traction mentioned in Chapter 11.1.3. Fabricus Hildanus from Padua [44] described, an attempt at reduction of dislocation of fractures by fixing together soft tissues and spinous processes with a special clamp around the year 1646. He also made attempt at an open reduction, however, with limited success.

2.5.1. Laminectomy

In the ancient times Egyptians performed cervical laminectomy as part of the mummification process, but never as a therapeutic procedure. Paulus of Aegina [2] in 7th century AD was the first to remove lamina for stenosis of the spinal canal. In 1762, Antoin Louis used a similar procedure and removed a bullet lodged in the spine. The first real laminectory was performed by a London surgeon Henry Cline in 1814. Although the patient died after 9 days, the use of the method was a great promise for the future. However, majority of the specialists denounced the procedure. Around the year 1800 a lot was written and said about laminectomies, a few of them were performed but all unsuccessfully. As late as in 1829, Alban Smith [83] from Danvil, Kentucky, probably the first after Paulus of Aegina performed a successful laminectomy.

2.6. Posterior cervical spine fixation

In 1891, Berthold Hadra from Galveston in Texas [38] reported internal fixation in a child for dislocation, by wires twisted about the spinous processes of C6–C7. The injury did not heal (absence of fusion), but the result was good, maybe also due to the fact that a healthy child cannot get "destructed". Louis Pilcher from Brooklyn in New York made an attempt at reduction of atlantoaxial dislocation in 1900 [67]. Although there was no fusion either, Pilcher found a big callus there. He later published the finding after ten years and claimed that the patient did very well, also from the viewpoint of functionality. Pilcher in 1910 published in Annals of Surgery an accompanying article on the publication by Mixter and Osgood, who described reduction and fixation of dislocation of C1–C2 by means of silk threads [56]. Neither this case healed with fusion.

2.6.1. Interspinous wiring techniques

William Rogers from Boston introduced modern principles of cervical fusion [75]. He recommended operation with a simultaneous traction, reduction of a fracture and where necessary stabilization by wiring spinous processes followed by fusion. Rogers drilled holes in the spinous processes for wires to pass through them. Posterior wiring techniques were the method of choice for a very long time. The Rogers' technique was further refined by Whitehill et al. [94], Benzel and Kesterson [11], Murphy and Southwick [58], but the principles remained the same. Another modification of the Rogers' method is the Bohlman's "triple-wiring" fixation technique for stabilization of one or more segment instability. Interspinous wiring fixation is similar to the Rogers' method, with wires passed through the holes tightening the corticocancellous grafts on both sides to the decorticated lamina and spinous processes.

2.6.2. Facet wiring techniques

Where spinous processes and lamina cannot be used for fixation, it is possible to choose wiring of facets. Robinson and Southwick [74] in 1960 recommended cervical spinal fusion by wiring rods to the facets. A similar method was described in 1977 by Callahan et al. [21]. The authors removed the articular capsule and drilled holes in articular processes, passed a wire through each hole in a proximal-to-caudal direction, exiting through the joint space. The wires were tightened around the structural grafts and their caudal ends fixed to the spinous process. Alternatively, Steinmann pins or Luque rectangles were used for a multi-segmental fixation, as described by Garfin et al. [35] and Maurer et al. [54]. In 1983, Cahill et al. [20] published an alternative technique, fixing the articular and spinous processes. They used the technique for stabilization of fracture-dislocations of articular processes or subaxial flexion-compression injuries to the

cervical spine. Holes were drilled in the mid-portion of the proximal articular facet. A cable or wire was passed through the hole in the facet and looped beneath the caudal spinous process. This procedure was repeated on the contralateral side. Placement of sublaminar wires was associated with a considerable number of complications, perforation of the dural sac and neurological deficits. A significant improvement was introduction of soft cables that are more flexible and stronger as compared to a standard wire. In 1991, Songer et al. [84] published a cable system consisting of 49 thin wires, which were welded into malleable solid inserting tip. Flexibility of cables allows their simpler and safer insertion beneath the lamina.

2.6.3. Interlaminar clamps

In 1975, Tucker [91] reported the first use of Halifax interlaminar clamps for fixation of C1–C2. Since then, these devices have been applied to stabilize flexion injuries at a single motion segment. The technique required intact laminae at the fusion level and could increase the risk of neurological injury by contributing to canal stenosis due to the sublaminar hooks [62]. Space had to be created between the laminae for insertion of sublaminar hooks. In the next step, screws were inserted and the clamps are tightened together. It was recommended to interpose a structural graft between the spinous processes to prevent hyperextension, and only then to tighten the screws.

2.6.4. Lateral mass screws and plates

At the end of the eighties of 20th century, Roy-Camille et al. [78] introduced the concept of stabilization of the cervical spine by plates and screws inserted into the lateral masses. Initially, the technique was intended for cases of a missing or damaged posterior part of the spine. It provided immediate stability, obviated the need for external halo fixation and promoted bone fusion. The original Roy-Camille technique was modified by Magerl [52], Anderson [6] and An [5]. Each technique differs in the entrance point for screw insertion and screw trajectory in both planes. The screws are generally directed superiorly and laterally to avoid damage to the vertebral artery and the nerve root. Magerl [52] inserts screws slightly cranial and medial to the centre of the facet. The direction of the screw is 25° laterally in the axial plane and parallel to the facet joint in the sagittal plane. In the Anderson's technique [6], the direction of the screw is 10° lateral in the axial plane and 30 to 40° cranial in the sagittal plane. An [5] prefers the direction of the screw 30° lateral in the axial plane and 15° cranial in the sagittal plane.

2.6.5. Lateral mass screws and rods

Lateral mass screws and plates required insertion of screws into the predetermined slots in the plate. In severe injuries or degenerative changes it was difficult to insert the screws properly and the spine had to adapt to the implant. Introduction of a fixation device with placement of screws into the desired entry point resolved the problem and the implant began to be adjusted to the operated on spine. At the end of the eighties and in the nineties of the last century Jeanneret [47] presented the Cervifix system (Synthes, Switzerland), that was a sort of intermediate stage before introduction of the currently used systems. Longitudinal rods had freely-positioned clamps with a hole to accommodate screws inserted according to the Magerl's principles. The disadvantage was a loose connection of the clamp and screw without angular stability, the connection between the clamp and the rod was rigid. At the end of the nineties, the current sophisticated fixation systems with polyaxial screws were developed. The Summit system (DePuy, USA) was designed in cooperation with professor Harms [42]. At present, there is a great number of similar systems based on the above mentioned principles, such as Vertex (Medtronic, USA), Axon, Synapse (Synthes, Switzerland), S4 Cervical (Aesculap, Germany), to name at least some of them.

2.6.6. Transpedicular screws

Abumi et al. [1] were the first to report in 1994 the successful use of transpedicular screws in managing subaxial traumatic instability. In biomechanical studies conducted in animal models and human cadavers they have demonstrated that this technique offers superior stability, fixation, and resistance to screw pullout forces compared with lateral mass screws. The entry hole for screws is placed slightly lateral to the facet center, close to the posterior rim of the superior articular surface. In the transverse plane, the angle of the screw insertion can vary from 25 to 45° medial to the midline, in the sagittal plane screws are inserted parallel to the upper endplate of the vertebral body. The same issue of the journal contained description of transpedicular screws presented by Jeanneret et al.

2.7. Anterior cervical spine fixation

In 1864, Boudof [19] reported anterior approach to the cervical apophysis for drainage of abscesses and Dickson Wright from Toronto [96] in 1930 drained a tubercu-

lous abscess of the pharynx. Around the year 1930, the otolaryngologists were commonly approaching the front of the cervical vertebrae to remove large osteophytes, especially on C5 vertebral body, that interfered with swallowing. Several years before, also the orthopedic surgeons began approaching the given region and cancer surgeons were stripping the lymphatics which lay on the anterior cervical vertebra bodies. However, until the fifties of 20th century orthopedic surgeons and neurosurgeons showed only little interest in this approach [73].

2.7.1. Anterior exposure of the cervical spine

Leroy Abbott was the first to suggest anterior approach to the cervical spine in 1952 when he visited Bailey and Badgley, who subsequently used the approach and described it [7]. In 1958, Robinson and Smith [73] introduced a horseshoe-shaped bone graft and improved bone fusion in anterior reconstruction of the cervical spine. In the same year Cloward [24] reported the technique of a cylindrical bone graft for anterior fusion after discectomy. Another milestone in the development was introduction of anterior cervical instrumentation that has become significantly widespread in the recent 30 years.

2.7.2. Anterior cervical plates

The first anterior cervical plates were devised by Joerg Boehler in 1964 [12, 13]. They were modified plates used for internal fixation of short bones. The first commercially available anterior cervical plates were developed in 1970 by Orozco Declos and Llovet Tapies [64] and used for the first time to fix the cervical spine in an unstable fracture. Later, Caspar et al. [22] devised a trapezoid plate that has been with minor modifications used until now. The AO group advocated the so called *constrained* plate-screw system that provided a rigid connection between the screw and the plate [57]. Morscher introduced a screw with an expandable cross-split head that locked into the plate after insertion of a small central bolt (CSLP – Cervical Spine Locking Plate, Synthes, Switzerland) [45]. Securing the screw in the plate allowed a straighter transmission of forces from the spine to the plate and secured a better stiffness of the construct. Screws were perforated and covered with plasma spray coating for a better bone ingrowth. Another constrained system was the Orion Anterior Cervical Plate (Medtronic, Sofamor Danek, USA), that allowed the use of both mono- and bicortical screws. The plate already came with a lordotic curve. The screw–plate locking mechanism was created by locking screws that threaded into the plate and overlapped the top of the bone screws. *Constrained* plates are suitable for fixation of the injured cervical spine with a marked instability, requiring immediate rigid stabilization. Atlantis (Medtronic, USA) and Codman (Johnson and Johnson, USA) plates allow rotation of screws around the axis passing through the screw head with its simultaneous fixation in the plate and a slight shrinking of the graft. In contrast, DOC (Acromed, USA) plates allow translation but the connection between the screw and the plate is defined and rigid. Excessive pressure on the graft is controlled by a distance transverse component. The disadvantage of some second generation plates is the absence of axial translation and natural pressure on the graft in the course of healing. This may result in a non-union and failure of instrumentation, particularly in multi-segmental fixations [62]. In order to eliminate negative effects and to preserve the principle of screws locked in the plate, so called fully dynamic plate systems have been designed. Dynamic plates allow both rotation and translation of the screw in the plate, the locking mechanism only prevents migration of the screw anteriorly (for details see Chapter 9).

2.8. Atlantoaxial fusion

In 1910, Mixter and Osgood performed the first posterior atlantoaxial spinal fusion for tuberculosis, using a silk loop [87]. In 1939, Gallie [34] described posterior wiring technique, using an H-shaped autologous bone graft from the iliac crest fixed from behind between the posterior atlas arch and the spinous process of the axis. His technique is frequently used even today after 70 years, although almost exclusively as a supplementary procedure to the Magerl transarticular fusion. In 1978, Brooks and Jenkins [18] published a different posterior wiring technique. They placed two rectangular bone graft blocks on each side between arches of C1 and C2 and fixed them separately by wire loops passed beneath the arches of C1 and C2. Also this fixation has been used until today, but as a stand alone procedure only exceptionally and more often as part of the transarticular fixation. These two techniques have been modified by many authors with the aim to increase the primary stability of fixation by changing the position and shape of bone grafts. Quite common is for instance the technique after Sonntag [28]. Another possibility of posterior instrumented spinal fusion is offered by various types of clamps, a typical representative of which is the Halifax clamp. A breakthrough in treatment of atlantoaxial instability was introduction of C1–C2 transarticular screw fixation by Magerl in 1980 [52]. In most cases it was supplemented with the Gallie posterior wiring technique in order to increase stability. The first patient that Magerl operated on with this technique was a 16-year-old patient who first underwent direct screw osteosynthesis of

the dens by a 3.5mm malleolar screw, which Magerl supplemented due to fixation failure and non-union, on 22 September 1980 with transarticular fixation by 3.5mm cortical screws and wiring of arches (Fig. 2-3).

In 2001, Harms and Melcher [42] presented posterior technique of atlantoaxial fixation using a fixation system with polyaxial screws. The principle of the method was described and published in 1994 by Goel [36], who, however, used less sophisticated implants without angular stability of individual components of the fixation system. In 2005, Wright et al. [97] reported a combination of screws inserted into the lateral masses of C1 and translaminar fixation of C2. This procedure is highly suitable mainly in case of an anomalous course of the vertebral artery. Grob et al. [37] presented a possibility of translaminar screw fixation of C1. Another option of atlantoaxial fixation is insertion of screws from the lateral approach after Barbour [9] and DuToit and Simmonds [82]. In this case it is, however, necessary to use approaches from both sides. The Barbour technique has not won much recognition and its use seems to be logical only in releasing atlantoaxial joints in atlantoaxial rotatory dislocation. In 1987, Lesoin et al. [49] described anterior atlantoaxial fusion by two divergently inserted screws from the lateral retropharyngeal approach. In 1999, Vaccaro et al. [92] published a similar technique as Lesoin et al. from the anterior retropharyngeal approach.

2.9. Direct osteosynthesis of the dens

The method of direct internal fixation is one of the options of management of the dens fractures. The method consists of insertion of one or more often two screws from the anterior approach from the C2 vertebral body into the apex of the dens through the fracture line. Lag screw mechanism results in compression of fragments and stabilization of the fracture. The technique was devised and also performed for the first time by Friedrich Magerl in 1979 in a 55-year-old man with an overlooked type III fracture of the dens and Jefferson fracture of the atlas. With a delay, he performed direct screw osteosynthesis with two screws. The patient died on 12th day after operation of myocardial infarction after he returned from a café already being discharged from hospital. Already before, Magerl inserted a screw in the

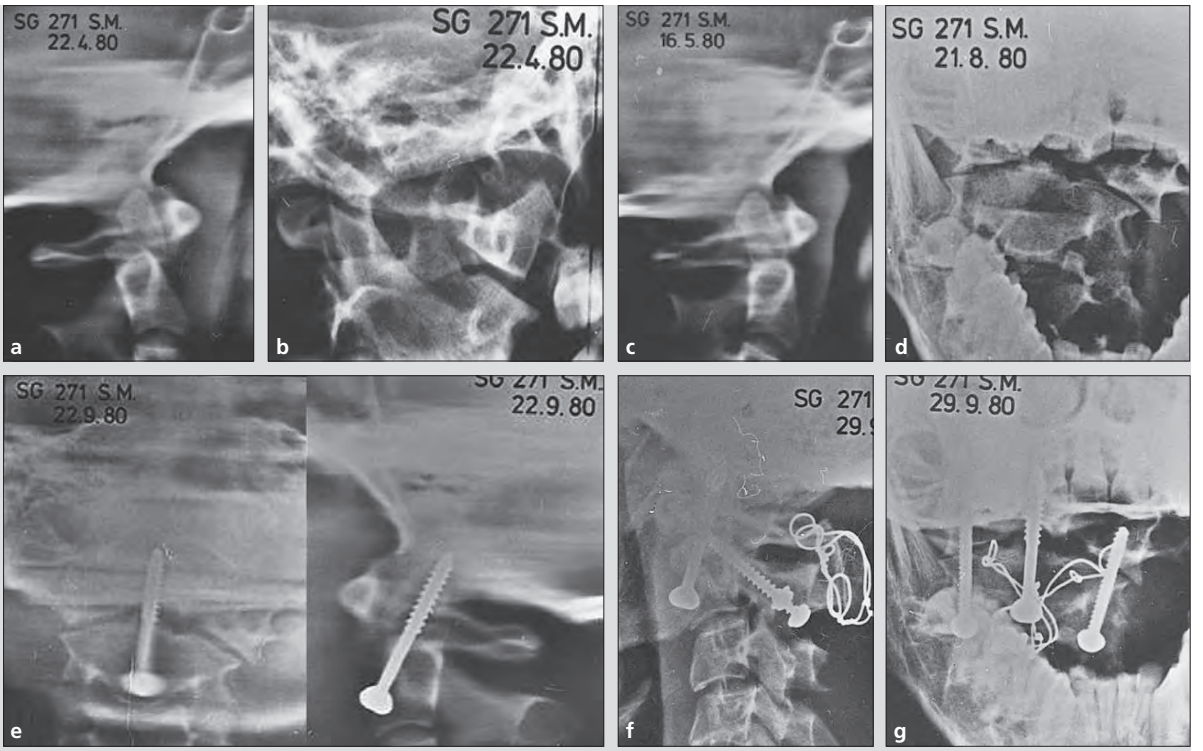


Fig. 2-3. The first transarticular fixation of C1–C2 performed by Magerl in 1980. A 16-year-old man with type II fracture of the dens and polytrauma was treated by a soft collar, the subsequent non-union was later treated by direct screw osteosynthesis of the dens with one 3.5mm malleolar screw; in three weeks the screw pulled out, therefore transarticular fixation of C1–C2 supplemented with fixation by wires posteriorly was performed on 22 September 1980, 10 years following the operation the patient reported only slight pain in the neck, position of C1–C2 was correct and stable: **a)** post-injury lateral radiograph, **b)** post-traumatic transoral radiograph, **c)** lateral radiograph one month after injury, **d)** transoral radiograph 4 months after injury, **e)** condition following direct screw osteosynthesis of the dens on transoral and lateral radiographs 5 months after injury, **f)** C1–C2 lateral view, **g)** C1–C2 fixation on transoral view (courtesy Friedrich Magerl).

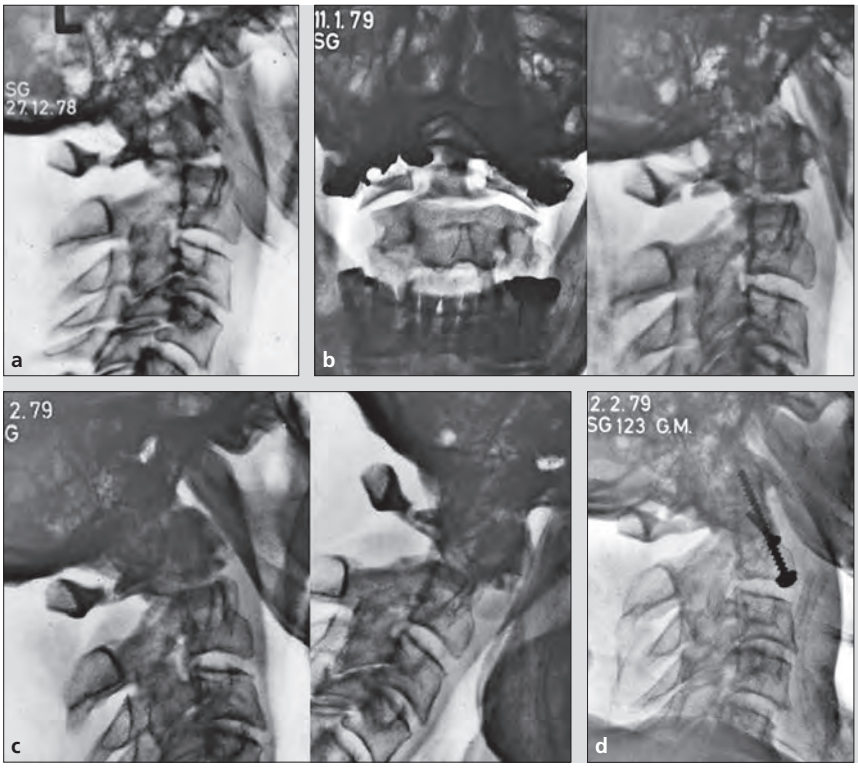


Fig. 2-4. One of the first direct screw osteosynthesis of the dens (the fourth in sequence, the first three fixations of the dens for tumor of C2 were in combination with bone cement) performed by Magerl on 12 February 1979 in a 55-year-old patient with non-union of type III fracture of the dens combined with a Jefferson fracture of the atlas treated initially with Minerva brace; due to rotation during insertion of the tap a short screw was inserted across the fracture line; starting from the second postoperative day, the patient was without complaints, he died after being discharged on 12th day after operation of myocardial infarction while returning home from a restaurant: **a)** post-injury lateral radiograph, **b)** transoral a lateral radiographs 14 days after injury, **c)** functional radiographs in extension and flexion 6 weeks after injury, **d)** the fourth direct internal fixation of the dens with one screw on lateral radiograph (courtesy Friedrich Magerl).

dens in combination with bone cement in tumors of the axis in three patients; the first operation was performed on 9 February 1978. Unfortunately, the records were not preserved as the hospital discards the archived documents after 20 years (Magerl, personal communication) (Fig. 2-4, 2-5). The first published group of 15 operated on patients was presented in 1981 by Joerg Boehler, who confirmed that originally it was Magerl's idea [12, 13]. In the same period, the surgical procedure was independently developed also by Nakanischi in Japan [59].



Fig. 2-5. Professor Friedrich Magerl at the Center for Spinal Surgery University Hospital Motol in Prague in 2007: **a)** in the operating theatre, **b)** discussion with the staff.

References

1. Abumi K, Itoh H, Taneichi H, et al. Transpedicular screw fixation for traumatic lesions of the middle and lower cervical spine: description of the techniques and preliminary report. J Spinal Disord 1994; 7(1): 19–28.
2. Adams F. Paulus Aeginata, vol. 2, London, Syndenham society 1816; 155–156, 193, 197.
3. Adams F. The genuine works of Hippocrates. Baltimore: Williams and Wilkins 1939; 231.
4. Albee FH. Transplantation of a portion of the tibia into the spine for Pott's disease. JAMA 1911; 58: 885.
5. An HS, Coppes MA. Posterior cervical fixation for fracture and degenerative disc disease. Clin Orthop Relat Res 1997; 335: 101–111.
6. Anderson PA, Henley MB, Grady MS, et al. Posterior cervical arthrodesis with AO reconstruction plates and bone graft. Spine 1991; 16(3): 72–79.
7. Bailey RW, Badgley CE. Stabilization of the cervical spine by anterior fusion. Am J Ortop 1960; 42-A: 565–594.
8. Ball JM. Andrea Vesalius. St. Louis: Medical Science Press 1910.
9. Barbour JR. Screw fixation and fractures of odontoid process. South Australian Clin 1971; 5: 20–24.
10. Bloch F. Nuclear induction. Physiol Rev 1946; 70: 460.
11. Benzel EC, Kesterson L. Posterior cervical interspinous compression wiring and fusion for mid to low cervical spinal injuries. J Neurosurg 1989; 70(6): 893–899.
12. Boehler J. Schraubenosteosynthese von Fracturen des Dens Axis. Unfallheilkunde 1981; 84: 221–223.
13. Boehler J. Anterior stabilization for acute fractures and nonunions of the dens. J. Bone Jt Surg 1982; 64-B: 18–27.
14. Bontecou RB. Transactions of the New York Medical Association 1887; vol. 3, 317.
15. Boucher HH. A method of spinal fusion. J Bone Joint Surg Br 1959; 41-B: 248–259.
16. Breasted JH. The Edwin Smith surgical papyrus. Vol 1., Chicago: University of Chicago 1930; 316–342.
17. Brok AJ. Greek medicine. London: JM Dent and Sons 1929.
18. Brooks AL, Jenkins EB. Atlanto-axial arthrodesis by the wedge compression method. J Bone Joint Surg Am 1978; 60(3): 279–284.
19. Boudof BG. Des resections des apopeses transverses des vertebraes. Strausberg 1864.
20. Cahill DW, Bellegarigue R, Ducker TB. Bilateral facet to spinous process fusion: a new technique for posterior spinal fusion after trauma. Neurosurgery 1983; 13(1): 1–4.
21. Callahan RA, Johnson RM, Margolis RN, et al. Cervical facet fusion for control of instability following laminectomy. J Bone Joint Surg Am 1977; 59(8): 991–1002.
22. Caspar W, Barbier DD, Klara PM. Anterior cervical fusion and Caspar plate stabilization for cervical trauma. Neurosurgery 1989; 25(4): 491–502.
23. Clendening L. Source book of medical history. New York: PB. Hoeber, inc 1942.
24. Cloward RB. The anterior approach for removal of ruptured cervical discs. J Neurosurg 1958; 15(6): 602–617.
25. Crowe HE. Injuries to cervical spine. Paper presented at the meeting of the Western Orthopaedic Association, San Francisco 1928.
26. Crutchfield WG.Skeletal traction for dislocation of cervical spine. South Surgeon 1933; 2: 156–159.
27. Dick W. Fixator internae. Paper presented to AO Trauma Course, Davos 1985.
28. Dickman CA, Sonntag VK. Surgical management of atlantoaxial nonunions. J Neurosurg 1995; 83(2): 248–253.
29. Ebraheim NA, De Troye RJ, Rupp RE. Osteosynthesis of the cervical spine with an anterior plate. Orthopedics 1995; 18(2): 141–147.
30. Elsberg CA. Experiences in spinal surgery. Surg Gynecol Obstet 1913; 16: 117–132.
31. Epstein NE. Anterior dynamic plates in complex cervical reconstructive surgeries. J Spinal Disord Tech 2002; (3): 221–227, discussion 227–228.
32. Fleming A. On the bacterial action of cultures of a penicillium, with special reference to their use in the isolation of B. influenzae. The British Journal of Experimental Pathology, Volume X: 1929; No. 3.
33. Floyd T, Grob D. Translaminar screws in the atlas. Spine 2000; 25(22): 2913–2915.
34. Gallie WE. Fractures and dislocations of the cervical spine. Amer J Surg 1939; 46: 495–499.
35. Garfin SR, Moore MR, Marshall LF. A modified technique for cervical facet fusions. Clin Orthop Relat Res 1988; (230): 149–153.
36. Goel A, Laheri V. Plate and screw fixation for atlanto-axial subluxation. Acta Neurochir (Wien) 1994; 129(1–2): 47–53.
37. Grob D, Magerl F. Surgical stabilization of C1 and C2 fractures. Orthopäde 1987; 16(1): 46–54.
38. Hadra BE. Wiring the interspinous processes in Pott's disease. Trans Am Orthop Assoc 1891; 4: 206–210.
39. Harrington PR. Treatment of scoliosis. Correction and internal fixation by spine instrumentation. J Bone Joint Surg Am 1962; 44-A: 591–610.
40. Harrington PR. Technical details in relation to the successful use of instrumentation in scoliosis. Orthop Clin North Am 1972; 3(1): 49–67.
41. Harrington PR. Spinal instrumentation in the treatment of severe progressive spondylolisthesis. Clin Orthop Relat Res 1976; 117: 157–163.
42. Harms J, Melcher PR. Posterior C1–C2 Fusion With Polyaxial Screw and Rod Fixation. Spine 2002; 26: 2467–2471.
43. Hibbs RA. An operation for progressive spinal deformities. NY Med J 1911; 93: 1013.
44. Hildanus F.(1672) In Walker AE. A history of neurological surgery. New York, Hanter Publishing Co 1951; 336.
45. Hollowell JP, Reinartz J, Pintar FA, et al. Failure of synthes anterior cervical fixation device by fracture of Morscher screws: a biomechanical study. J Spinal Disord 1994; 7(2): 120–125.
46. Hounsfield G. Quoted by Oldendorf WH, the quest for an image of the brain. New York, Raven Press 1980.
47. Jeanneret B. Posterior rod system of the cervical spine: a new implant allowing optimal screw insertion. Eur Spine J 1996; 5(5): 350–356.
48. Koch R. Die actiolage Dr. Mitzbrand-Krankheit Klasskerder Medizen. Leipzeig 1912.
49. Lesoin F, Autricque A, Villette E, Franz K, Jokin M. Atlanto-axial arthrodesis by anterior retropharyngeal intermaxillo-hyoidal approach. Neurochirurgie, 1987; 33(3): 239–243.
50. Lister J. On the antiseptic principle in the practice of surgery. Br. Med J 1867; 2: 246.

51. Magerl F. External sceletal fixation of the lower thoracic and upper lumbar spine: current concepts of external fixation of fractures. Berlin: Springer-Verlag 1982.
52. Magerl F, Seemann PS. Stable posterior fusion of the atlas and axis by transarticular screw fixation. In Kehr P, Weidner A. (eds): Cervical spine. Wien: Springer 1987; 322–327.
53. Malgaigne JF. Traité des fractures et des luxations. Vol. 1, Paris 1847; 410–426.
54. Maurer PK, Ellenbogen RG, Ecklund J, et al. Cervical spondylotic myelopathy: treatment with posterior decompression and Luque rectangle bone fusion. Neurosurgery 1991; 28(5): 680–683, 683–684.
55. Mc Cullen GM, Garfin SR. Spine update: cervical spine internal fixation using screw and screw-plate constructs. Spine 2000; 25(5): 643–652.
56. Mixter SJ, Osgood RB. Traumatic lesions of the atlas and axis. Ann Surg 1910; 51: 193–207.
57. Müller M, Allgöver M, Schneider R, et al. Manual of Internal Fixation: Techniques Recommended by the AO-Group. Berlin: Springer-Verlag 1979.
58. Murphy MJ, Southwick WO. Posterior aproaches and fusions. In Cervical Spine Research Society. Philadelphia: Lippincott 1989; 775–795.
59. Nakanishi T, Sasaki T, Tokita N, Hirabayashi K. Internal fixation for the odontoid fracture. Orthop Trans 1982; 6: 176–179.
60. Nickel VL, Perry J, Garret A. The halo. A spinal skeletal traction fixation device. J Bone Joint Surg Am 1968; 50(7): 1400–1409.
61. Ohry A, Ohry-Kossoy K. Spinal cord injuries in the 19th century. Paraplegia 1989; 27: 1–39.
62. Omeis I, De Mattia JA, Hillard VH, Murali R, Das K. History of instrumentation for stabilization of the subaxial cervical spine. Neurosurg Focus 2004; 16(1): E10.
63. Oribasius: Oeuvres d'Oribase, Vol. 4., Paris: Imprimerie nationale 1862.
64. Orozco Declos R, Llovet Tapies J. Osteosynthesis en las fracturas de raquis cervical. Rev Ortop Traumatol 1970; 14: 285–288.
65. Pasteur L. Recherches sur la putréfaction. Comptes Rendus 1863; 56: 734.
66. Pare A. Oeuvres, Paris: Paris, Gabriel Buon 1585.
67. Pilcher LS. Atlo – axoid fracture – dislocation. Ann Surg 1910; 51: 208–211.
68. Pott P. Injuries of the head from external violence. 1st ed. London, C Hitch and L Hawes 1760.
69. Pott P. Remarks on that kind of palsy of the lower limbs, which is frequently found to accompany a curvature of the spine, and is supposed to be caused by it. London: J Johnson 1779.
70. Pott P. In Clendening L. Source book of medical history. New York: Henry Schuman 1942.
71. Purcel EM, et al. Resonance absorption by nuclear magnetic moments in a solid. Physiol Rev 1946; 49: 37–38.
72. Richards DW. Hippocrates of Ostia. JAMA 1968; 204(12): 1049–1956.
73. Robinson RA, Smith GW. Anterolateral cervical disc removal and interbody fusion for cervical disc syndrome. Bull Johns Hopkins Hosp 1955; 96: 223–224.
74. Robinson RA, Southwick WO. Indications and techniques for early stabilization of the neck in some fracture dislocation of the cervical spine. South Med J 1960; 53: 565–579.
75. Rogers WA. Treatment of fracture dislocation of the cervical spine. J Bone Joint Surg 1942; 24: 245–258.
76. Roy-Camille R, Roy-Camille M, Demeulenaere C. Osteosynthesis of dorsal, lumbar, and lumbosacral spine with metallic plates screwed into vertebral pedicles and articular apophyses. Presse Med 1970; 78(32): 1447–1448.
77. Roy-Camille R, Saillant G, Mazel C. Internal fixation of the lumbar spine with pedicle screw plating. Clin Orthop Relat Res 1986; 203: 7–17.
78. Roy-Camille R, Saillant G, Mazel C. Internal fixation of the unstable cervical spine by a posterior osteosynthesis with plates and screws. Philadelphia: Lippincott 1989; 390–403.
79. Ruhrah J. Nicolas Andry: 1658–1742, Am J Dis Child 1932; 44: 1322–1326.
80. Schneider RC, Cherry GR, Pautek H. The syndrome of acute central cervical spinal cord injury; with special reference to the mechanismes involved in hyperextension injuries of cervical spine. J Neurosurg 1954; 11(6): 546–577.
81. Shimmelbusch C. The aseptic treatment of wounds. London: H.K. Lewis 1894.
82. Simmons EH, Du Toit G. Lateral atlantoaxial arthrodesis, Orthop Clin N Amer 1978; 9: 1101–1114.
83. Smith AG. Account of the case in which portion of three dorsal vertebrae were removed for the relief of paralysis from fracture, with partial success. North Am Med Surg J 1829.
84. Songer MN, Spencer DL, Meyer PR, et al. The use of sublaminar cables to replace Luque wires. Spine 1991; 16: 418–421.
85. Stryker H. Quoted. In Frymoer JW, Ducker TB, Hadler NM, et al. The Adult Spine: Principles and Practice. Philadelphia, Lippincott-Raven Publishers 1997; 3–40.
86. Stulik J, Pitzen TR, Chrobok J, Ruffing S, et al. Fusion and failure following anterior cervical plating with dynamic or rigid plates: 6-months results of a multi-centric, prospective, randomized, controlled study. Eur Spine J 2007; 16(10): 1689–1694.
87. Suchomel P, Stulik J, Klezl Z, Chrobok J, Lukas R, Krbec M, Magerl F. Transarticular fixation of C1–C2: a multicenter retrospective study. Acta Chir Orthop Traumatol Cech 2004; 71(1): 6–12.
88. Taylor AR, Blackwood W. Paraplegia in hyperextension cervical injuries with normal radiographic appearances. J Bone Joint Surg 1948; 30b: 245–248.
89. Taylor AR. The mechanism of injury to the spinal cord in the neck without demage to vertebral column. J Bone Joint Surg 1951; 33b: 543–547.
90. Thorwald J. The century of the surgeon. New York: Pantheon Books 1957.
91. Tucker HH. Technical report: method of fixation of subluxed or dislocated cervical spine below C1–C2. Can J Neurol 1975; 2(4): 381–382.
92. Vaccaro AR, Lehman AP, Ahlgren BD, Garfin SR. Anterior C1–C2 screw fixation and bony fusion through an anterior retropharyngeal approach. Orthopedics 1999; 22(12): 1165–1170.
93. White AA, Panjabi MM. Biomechanical considerations in the surgical management of cervical spondylotic myelopathy. Spine 1988; 13(7): 856–860.
94. Whitehill R, Reger SL, Fox E, et al. The use of methylmethacrylate cement as an instantaneous fusion mass in posterior cervical fusions: a canine in vivo experimental model. Spine 1984; 9(3): 246–252.
95. Wiltse LL, Berger PE, Mc Culloch JA. A system for reporting the size and location of lesions in the spine. Spine 1977; 22(13): 1534–1537.
96. Wright D. Quoted. In Fielding JW. Cervical spine surgery. Clin Ortop 1985; 200: 287.
97. Wright NM. Translaminar rigid screw fixation of the axis. J Neurosurg Spine 2005; 3: 409–414.

3. Evolution of the cervical spine

In terms of evolution, the vertebrates (*Vertebrata*) are the most advanced group in the chordates (*Chordata*). They evolved more than a half billion years ago probably from the echinoderms (*Echinodermata*). The most distinctive morphological feature of the vertebrates is the spine composed of vertebrae. The first manifestation of spine are ligament structures in the tail of the hagfish (*Myxini).* However, the oldest living lineage of vertebrates are lampreys (*Cephalaspidomorphi*) with cartilaginous vertebrae along the entire body. The notochord (*chorda dorsalis)* is in lampreys fully preserved. The chondrichthyans (*Chondrichtyes*) also have a cartilaginous spine, but vertebral bodies are already well developed and narrow the notochord that passes through their centers (Fig. 3-1).

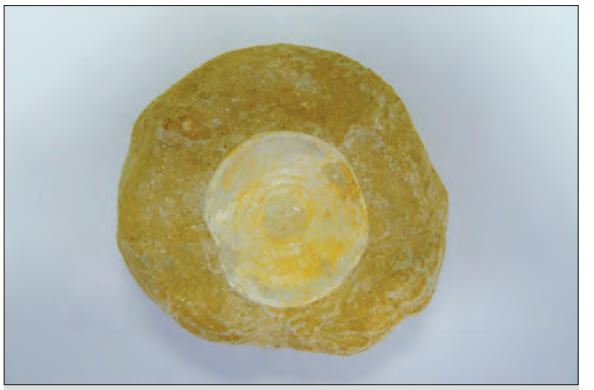


Fig. 3-1. Fossil vertebra of a shark.

Most fishes (*Pisces*) have already an ossified spine with well developed vertebral bodies and arches but the notochord (*chorda dorsalis)* is usually still partially preserved. However, there are exceptions such as the *Latimeria chalumnae* which has no vertebral bodies and the notochord is fully developed. The shape of vertebrae of individual segments of the fish spine does not differ significantly. Diversification of the spine into the cervical, thoracic, lumbar, sacral and coccygeal segments can be seen as late as in the tetrapods (*Tetrapoda*) and is probably associated with their terrestrial adaptation. Typical of the amniotes



Fig. 3-2. Cervical spine of mammals: **a)** giraffe, **b)** dolphin (courtesy Professor Václav Seichert, MD, DSc, collections of the Institute of Anatomy of 1st Faculty of Medicine, Charles University, Prague).



Fig. 3-3. Mammals with atypical number of cervical vertebrae: **a)** cervical spine of dugong (6 vertebrae), **b)** cervical spine of the three-toed sloth (9 vertebrae), **c)** three-toed sloth. Courtesy Professor Václav Seichert, MD, DSc, collections of the Institute of Anatomy of 1st Faculty of Medicine, Charles University, Prague (a, b) and ZOO Prague (c).

(*Amniota*), i.e. reptiles (*Reptilia*), birds (*Aves*) and mammals (*Mammalia*), is differentiation of the atlas – axis complex. Vertebral bodies of mobile segments of the spine are sometimes connected by an intervertebral disc or joint. For instance birds (*Aves*) and turtles (*Testudines*) have saddle joints between vertebral bodies, allowing retraction of the neck. The mammals have a constant number of cervical vertebrae, the same as in humans (Fig. 3-2). The only exception is the sea cow (*Sirenia*) with 6 cervical vertebrae, the Hoffmann's two-toed sloth (*Choloepus Hoffmanni*) also with 6 cervical vertebrae and the three-toed sloth (*Bradypus tridactylus*) with 9 cervical vertebrae [5,9] (Fig. 3-3).

The spine of sloths (*Bradypodidae et Megalonychidae*), and the whole order of the xenarthrans (*Xenarthra* = *Edentata*), is specific for yet another reason. Ossification of ligaments results in the thoracic and lumbar region in so called xenarthral junctions significantly reinforcing the spine. They most probably document adaptation of the prehistoric sloth called *Megatherium* who was of the size of an elephant, who in search for food stood up on two posterior extremities and the xenarthral junctions prevented the spine from damage. In contrast sloths have a highly mobile cervical spine, with a range of rotation of 270°. This range of motion of the cervical spine probably results from the need to facilitate food intake.

Ontogenetic evolution of the spine, similarly as evolution of other organs, follows phylogenesis. Although it is a continuous process, it may be divided according certain milestones in the development into the blastema stage, including the pre-somite and somite stage, the cartilaginous stage and the ossification stage. From the viewpoint of clinical medicine we consider important to divide the whole process also into the prenatal and postnatal stage [2, 3, 13].

3.1. Prenatal development

Prenatal development may be divided according to histological characteristics of the skeletal system into three main phases: the blastema stage, subdivided into the presomite and somite ones, the cartilaginous stage and the ossification stage.

3.1.1. Blastema stage

3.1.1.1. Presomite stage

At the beginning of 3rd week of the embryonic development, a primitive streak is formed at the caudal end of the posterior surface of the embryonic disc, which is continuous at its anterior end with the primitive (Hensen's) node. Mesodermal cells initially deposited between the cells of the ectoderm move to the primitive streak and node and spread peripherally in all directions between the ectoderm and entoderm. Anterior and cranial to the Hensen's node the mesoderm forms so called head (chordomesoderma) process, that projects as far as the prechordal plate (the future bucopharyngeal membrane). Along the axis of the head process, there passes a primitive alimentary canal (Lieberkühn) from the Hensen's node. Medially, the head process ingresses into the roof of the yolk sac and forms the chordal plate. By opening of the Lieberkühn canal, a temporary communication is established between the yolk sac and the amniotic cavity. Later the chordal plate again separates from the yolk sac and forms the definitive notochord. In the meantime, mesoderm gets stronger on the sides of the notochord and forms a plate of paraxial mesoderm that grows thinner through the intermediate mesoderm to form a lateral plate [2, 13]. Parallel to the development of the head process, the medullary plate develops on the posterior surface of the embryonic disc by thickening of the ectoderm and its differentiation into neuroectoderm. Laterally it is bounded by prominent walls which increase in height to form the medullary groove [2, 8, 13].

3.1.1.2. Somite stage

In 3rd week of gestation, the paraxial mesoderm differentiates into primary segments, the somites. First they are formed cranially and then they spread caudally at the speed of three somites a day (Fig. 3-4). By the end of 5th week there are 4 occipital, 8 cervical, 12 thoracic, 4 lumbar, 5 sacral and 8–10 coccygeal somites. At the end of 4th week the somites (except for 1st occipital and 5th–7th coccygeal somites) differentiate into the sclerotome, myotome and dermatome. The sclerotome changes into mesenchyme and encases the notochord and the neural tube. Each somite is divided by the Ebner's fissure into the cranial and caudal part. The caudal part of the sclerotome gets denser and moves cranially to the centre of the corresponding myotome. There differentiates the intervertebral disc and the remainder unites with the cranial part of the more distal sclerotome to form the earliest manifestation of the vertebral body. Extending on both sides of the neural tube are the neural processes as the anlagen of vertebral arches. Anterolaterally, costal processes project between the myotomes.

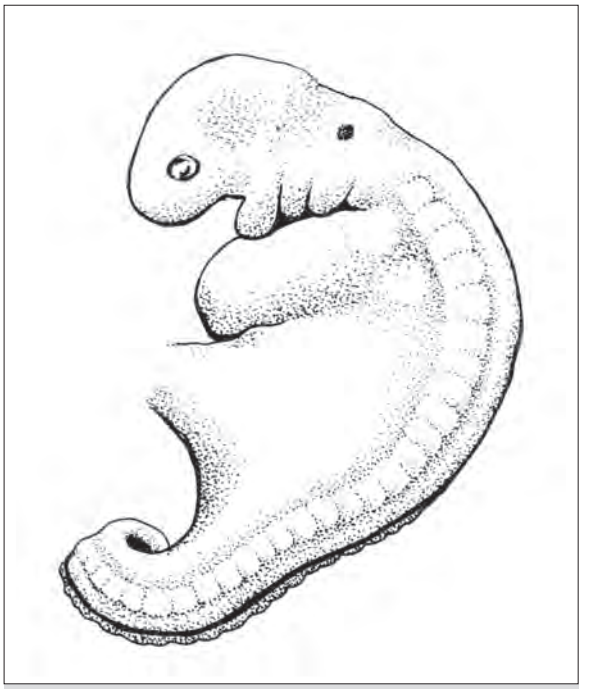


Fig. 3-4. Embryo at the age of 25–27 days with evident 25 somites – according to Vacek.

The occipital somites fuse to form the occipital bone. The material of the fourth occipital somite (proatlas) forms the apex of the dens, apical ligaments of the dens, anterior margin of the foramen occipitale magnum, the anterior two thirds of the occipital condyles, the cruciate ligament, the alar ligaments, lateral atlantal masses and the superior part of the posterior atlas arch.

The first cervical sclerotome forms the posterior and inferior portion of the posterior atlas arch. The anlage of the vertebral body of the atlas fuses with the axis and thus forms the dens.

Anterior to the anlagen of cranial vertebral bodies there develops the hypochordal bow which soon fuses with them. Later there appears an independent chondrification center in it which is the manifestation of the future anterior atlas arch [2, 13].

The medullary groove deepens in the somite stage, until in the stage of 6–7 somites the edges of the medullary plate joint together in the region of 4th–5th somite. Closing of the medullary plate proceeds in both directions until conversion of the original medullary groove into a closed tube is completed. Still before closing of the medullary plate, the neural crest is separated from it which is then located between the neural tube and the superficial ectoderm. The neural crest later differentiates at the medial level into two parts that form the anlage of the spinal neural crest [2, 8, 13].

3.1.2. Cartilaginous stage

In 4th week of gestation, there appear 6 chondrification centers in the mesenchymal cells, two in the vertebral body on either side of the notochord, and one in each neural and costal process. A separate chondrification center develops in the region of the anterior atlas arch. Growing posteriorly and medially from the neural processes are laminar processes that fuse in the midline and close the spinal canal. In cervical vertebrae they continue to grow posteriorly to form the spinous process with the typical bifurcated end. Projecting from the arch are also transverse and articular processes. The neighboring articular facets remain separated by the mesenchyme that gets thinner, with the exception of the intermediate zone. Cavities forming from the periphery of the future joint fuse, the intermediate zone disappears and a joint cavity is formed, with a typical shape of the articular surface. The joint capsule and ligaments differentiate from the surrounding mesenchyme [2, 7, 13].

Costal processes form the anlagen of the ribs. In case of the cervical spine they fuse with the vertebral body and the transverse process to form anterolateral portion of the foramen of the transverse process – anterior tubercle, the lamina intertubercularis and the anterior portion of the posterior tubercle [2, 6, 13].

At the end of 4th week, the neural tube is formed by a paired basal plate located anterolaterally, a paired alar plate located posterolaterally and by the anterior floor and posterior roof plates. Basal and alar plates are separated on both sides by the lateral process of the central canal, *sulcus limitans*. While the lateral walls of the neural tube expand by proliferation of cells and growth of processes of cells from the spinal cord, brain and spinal ganglia, the anterior plate grows slowly and transforms into anterior median fissure (*fissura mediana anterior)*. In the region of the posterior plate, the proliferating cells fuse in the midline to form the anlage of the posterior median sulcus (*sulcus medianus posterior)*. Axons of the basal plate neuroblasts join with processes of spinal ganglia neuroblasts to form the spinal nerve. The mesenchyme surrounding the neural tube condenses to form the spinal meninges. Intumescences appear in the 2nd month [2, 8, 13].

3.1.3. Ossification stage

Ossification of the spine begins at 9th week of gestation when paired ossification centers appear in the arches of the cervical spine, followed by ossification centers in the bodies of the lower thoracic and upper lumbar vertebrae and in the arches of thoracic and lumbar vertebrae. Only then ossification centers appear in the bodies of cervical and lower lumbar vertebrae. In 5th month, ossification centers are developed in all the vertebrae, except for coccyx. In the cartilaginous anlage of the atlas, ossification centers form in the lateral masses and sometimes also in the anterior arch. A paired ossification center is found in the prenatal period also in the axis (*dens epistrophei*) [2, 6, 7, 11–13]. By 3rd month, the cartilaginous anlage of the occipital bone contains an initially paired ossification center in the basilar part (*pars basilaris),* one center in each lateral part (*pars lateralis)* and one center in the occipital squama (*squama occipitalis)*. The centers are separated by growth zones– *synchondrosis intraoccipitalis anterior et posterior*. The upper part of the occipital squama begins to ossify in the form of intermembranous ossification from 3rd month. The membranous and chondral part of the squama is separated by the *sutura mendosa*.

Starting from 3rd month, the vertebral column grows faster than the spinal cord which in 10th month reaches the level of 3rd lumbar vertebra [2, 8, 13].

3.2. Postnatal development

At birth, three ossification centers are present in all the vertebrae of the lower cervical spine – one in the vertebral body and one in each half of the arch. Growth cartilage separating the ossification center in the vertebral body from those in the arch is located anterior to the pedicles and is called the neurocentral synchondrosis. Ossification centers in the vertebral arch unite at the age of 1–4 years, neurocentral synchondroses disappear between 3rd and 8th year of age. At the age of 7–10 years ossification proceeds in the vertebral body as far as unci. In puberty, there may variably occur secondary ossification centers in the transverse (costal) and spinous processes and endplates of vertebral bodies. Ossification centers in endplates are of annular shape (ring of apophysis) and are separated from the rest of the vertebral body by a growth cartilage, although they themselves do not contribute to the growth of the vertebra. The ring of apophysis fuses with the rest of the vertebral body approximately at the age of 18, sometimes even later. Articular processes do not have their own ossification centre and ossify as part of the arch. Unequal growth in the postnatal development changes orientation of articular facets. In C2–C4 segments the angle of the joint line of the intervertebral joint relative to the horizontal plane changes from 30° to 60–70°, in C4–C7 segments from 55° to 70° [2, 6, 7, 13].

The atlas has at birth two developed ossification centers in the lateral masses. In 20% of newborns the center is present in the anterior atlas arch, which may be of irregular shape or split, sometimes also asymmetrically. It appears by 1st year of the child, at the latest. The posterior arch ossifies usually by extension of ossification centers from the lateral masses, although an independ-

ent ossification center in this location was also described. After the age of 4 years, the atlas almost ceases to grow, growth cartilages disappear between 4th and 6th year of age [2, 6, 7, 13].

In the axis, there are at birth, in addition to the ossification centers similar to those in the C3–C7 segment, also centers in the dens. Two longitudinal centers of the dens fuse usually prior to birth, but sometimes as late as in 4th month of age. In the caudal part, below the level of intervertebral joints of C1–C2, they are separated from the ossification center in the body of the axis by a bipolar physis, so called dentocentral cartilage, responsible for the longitudinal growth of the upper portion of the vertebral body and the lower portion of the dens. Anatomically, the growth cartilage is not separated from the neurocentral synchrondrosis. It is a barrier between the blood supply to the dens and the body of the axis. It disappears at the age of 3–7 years. The bone scar after union of ossification centers can be visible for another several years. At the age of 6–7 years, there appears an ossification center in the apex of the dens, called *ossiculum terminale Bergmanni*, which fuses with the main centers of the dens at about 12 years of age. The ring apophysis occurs only on the lower endplate of the axis [2, 6, 7, 11–13].

On the occipital bone, there are at birth intraoccipital synchondroses separating the above described ossification centers that survive until 4th–7th year of age. *Sutura mendosa* is evident until 4th year of age.

The spinal cord gets shorter relative to the vertebral column in the postnatal development and from 6th year of age the *conus medullaris* extends to the level of the disc of L1–L2 [2, 8, 12].

3.3. Congenital anomalies and developmental defects

Congenital anomalies and developmental defects are present already at birth. In cervical spine traumatology, they are important particularly in differential diagnostics.

- Manifestation of the occipital vertebra [1, 4]
- Basilar impression [1, 4]
- *Proc. paratransversarius C1* [4]
- *Foramen arcuale C1* [4]
- Aplasia of the dens [4]
- *Os odontoideum* [3, 7, 11, 12]
- *Rhachischisis posterior, spina bifida cystica, spina bifida occulta* [1, 3, 4, 6, 10]
- *Spina bifida ventralis (rhachischisis anterior)*, butterfly vertebra [1, 4]
- Hemivertebra (semivertebra), hemisomia, asomia [1, 3, 4, 10]
- Congenital block, assimilation (occipitalization) of the atlas, non-segmented neural crest [1, 3, 4, 6, 10]
- Cervical rib [2, 4]
- Klippel-Feil syndrome [1, 3, 4, 10]
- Spondylolysis (*spina bifida lateralis*) [1, 4, 10]
- Aplasia of half of the arch [4]
- Baastrup syndrome [3, 4]
- Diastematomyelia [1, 3, 10]
- Amyelia [1]
- Arnold-Chiari malformation [1]
- *Os interparietale Incae* [2]
- *Ossa praeinterparietalia* [2]
- *Condylus tertius ossis occipitalis* [2]
- *Proc. paramastoideus* [2]

References

1. Bednář B. Patologie. Svazek 3. Praha: Avicenum 1984.
2. Čihák R, Grim M. Anatomie 1. Praha: Grada 2001.
3. Dungl P. Ortopedie. Praha: Grada Publishing 2005.
4. Grashey R, Birkner R. Atlas typischer Röntgenbilder vom normalen Menschen. München-Berlin, Urban & Schwarzenberg 1964.
5. Hanzák J, Veselovský Z. Světem zvířat. I. díl. Savci. Praha: Albatros 1965.
6. McMinn RMH, Hutchings RT. Barevný atlas anatomie člověka. Bratislava: Slovart 1992.
7. Ogden JA, Hensinger RN, McColoug NC. Skeletal injury in the child. New York: Springer 2000.
8. Petrovický P. Malá neuroanatomie. Praha: Karolinum 1993.
9. Prokop R. Zkamenělý svět. Praha: Práce 1989.
10. Sosna A, Vavřík P, Krbec M, Pokorný D. Základy ortopedie. Praha: Triton 2001.
11. Štulík J, Krbec M. Injuries of the atlas. Acta Chir orthop Traumatol Čech 2003; 70: 274–278.
12. Štulík J, Krbec M. Os Odontoideum – Post-traumatic Instability of C1–2. Acta Chir orthop Traumatol Čech 1999; 66: 356–361.
13. Vacek Z. Embryologie pro pediatry. Praha: Univerzita Karlova 1992.

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