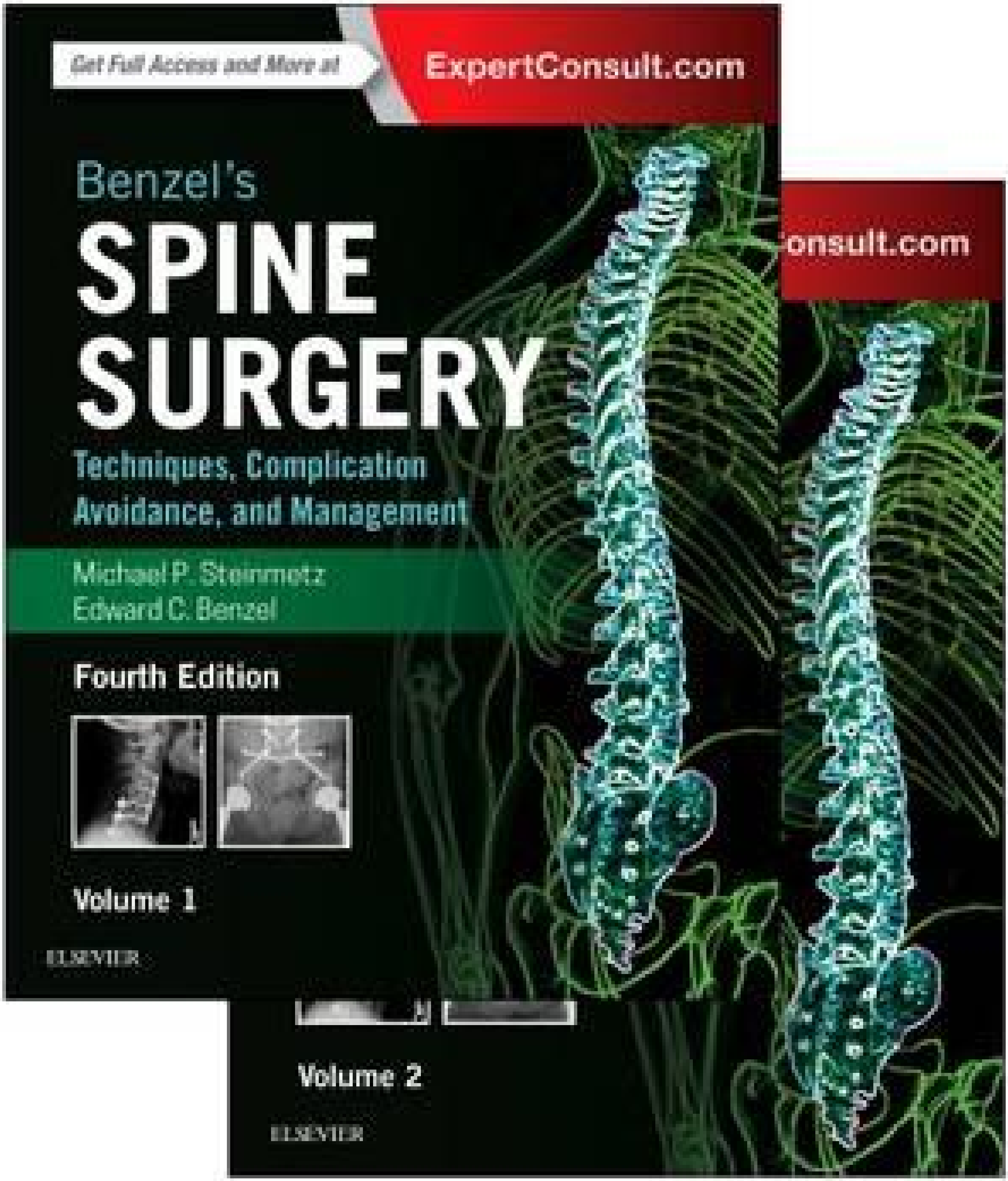
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Dedication

This book is dedicated, in part, to our wives, Bettina and Mary; children; and to those whose shoulders upon which we stood while assimilating the wherewithal to complete this book.
They include present and past partners, collaborators, fellows, residents, and assistants.

We, as well, dedicate this book to Charles (Charlie) Kuntz IV, who was to partner with us as co-editor until his untimely death, which deprived all of us of his collegiality and wisdom.
His insight and creativity helped form the infrastructure for this edition. If this edition is seen as the best one yet, it is in large part related to Charlie's out-of-the-box creative thinking.

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Preface

It was stated in the front matter of the second edition of this book that it "was bigger and better than the first." The same was true for the third edition. Now this fourth edition is without question much bigger and better than the third. The fourth edition is unique in that the name has changed, with "Benzel's" being added to the title. Two co-editors began this project, Charles D. Kuntz IV and Michael P. Steinmetz. Dr. Kuntz was not destined to see this project through; hence, two editors (Steinmetz and Edward C. Benzel) "took it across the finish line."

The purpose of this book (to assist the spine surgeon with the avoidance, identification, and management of complications) has not changed throughout all its renditions. However, its presentation has, with the fourth edition even more colorful than the third edition. In addition, the contributors are even more seasoned. They have refined the information transmission process, as well as the dialogue employed. This fourth edition is even easier to read than the third. The fourth edition has been reorganized and is much more user friendly than prior editions.

This edition remains a *techniques* book but provides much, much more. In addition to the "*how* tos," it provides significant discussion regarding the "*when* tos," the "when *not* tos," and the "*whys*" associated with the decision-making process.

Decision-making is, indeed, the central focus of this text. Decision-making is facilitated by understanding both the triumphs and the mistakes made by our predecessors. This book provides both. In addition to technique, it focuses on ethics, logic, nonoperative management, and controversies. The fundamentals, however, are emphasized. The fundamental disciplines of anatomy, physics and its progeny of biomechanics, and physiology provide the foundation for all we do as spine surgeons. We focus on this foundation in our practices and have striven to do so in the pages that follow.

RISK TAKING

Surgeons are risk takers and surgery is a risk-taking endeavor. The patient places himself or herself in the hands of the surgeon, and the ensuing decision-making process involves the resolution (or the attempts at such) of many technical and quality-of-life–related issues and dilemmas. A surgical procedure may be warranted if the sum of the costs (both financial and personal) and risks is less than the sum of the benefits. This risk/benefit analysis should be of paramount concern and should be emphasized by the surgeon and realized by the patient. This book is designed to help surgeons achieve these goals, by minimizing the *risk-taking* component and by maximizing the *benefit* component of this "equation."

REPETITION

We learn most effectively by having data presented in a repetitive manner, often from different perspectives, using differing techniques (e.g., written, mathematical, or visual).

The true understanding of a concept or body of knowledge involves the *spiral of learning*, which often involves multiple exposures to information so that a solid database (foundation of knowledge) is acquired. New (raw) data are then added and assimilated. This "expanded" knowledge base can then be applied to, and enhanced by, additional basic science, clinical input, and applications. This entire process is perpetually refined and reshaped by new experiences, such as clinical encounters or through reading and other sources of learning (Fig. 1). Repetition is the mother of learning. Repetition is, indeed, good—very good.

WHAT IS A COMPLICATION?

The definition of what constitutes a complication is usually unclear and often the subject of debate. In a way, it's like pornography: "I cannot define it, but I know it when I see it."

> *I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description ["hard-core pornography"]; and perhaps I could never succeed in intelligibly doing so. But I know it when I see it, and the motion picture involved in this case is not that.*
>
> **—Justice Potter Stewart, concurring opinion in Jacobellis v. Ohio 378 U.S. 184 (1964), regarding possible obscenity in The Lovers.**

Perhaps complications and pornography alike do not require strict definition, which may be too confining and, in the case of complications, detract from the purpose of focusing on its mitigation—i.e., *doing what's right*!

In the prefaces to the prior editions of this book, reference was made to the Canadian Thistle as both a weed and a flower. To some it is a weed and to others it is considered a flower. To the spine surgeon, the patient, and the attorney, a complication has different meanings, and often different consequences. Postoperative pain (as subjective as it may be) may not be considered a complication by the surgeon. It may be perceived as annoying or even as a source of substantial distress to the patient. Conversely, it may be viewed as a source of revenue, and, therefore, joy by a plaintiff attorney. Beauty is clearly in the eye of the beholder, and without question, *ugly* is indeed a matter of perception and perspective.

Thus, the definition of a complication is not as clear as *outsiders* (e.g., the lay public and the legal system) often believe, or want to believe, is the case (as is the case with the definition of pornography). With all this in mind, and in the best interest of our patients, we should attain and maintain objectivity. We should not be swayed by uneducated or undeserved accolades from the medically naive, or by threats from entrepreneurs or the devious. Complications must be defined to the best of our ability, avoided when possible, and aggressively managed when they occur. Their avoidance, identification, and management should not be charged with emotion and anger but attacked with an armamentarium of logic, thoughtfulness, science, and objectivity.

The avoidance, identification, and management of the complications of spine surgery are addressed in the pages that follow by experts in the field. These experts themselves are not infallible. They address complications with which they have had first-hand experience. We must seize the opportunity to benefit from their wisdom and experience. A wise person can learn from the observations and mistakes of others.

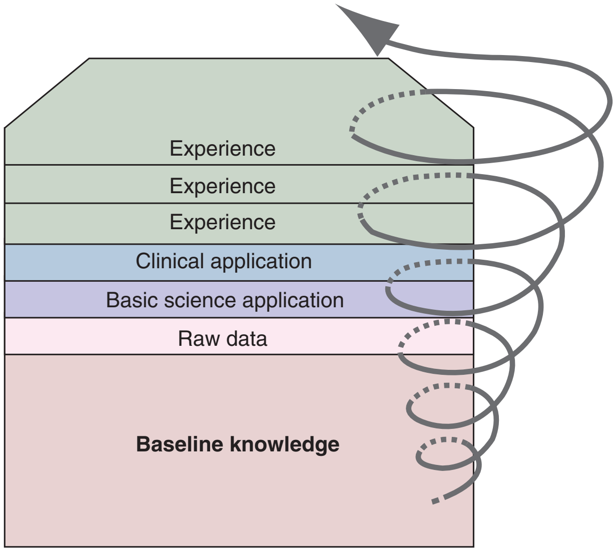


Figure 1. The spiral of learning.

The Components and Factors Involved with the Definition of a Complication of Spinal Surgery: A Survey

1. Does your service have an explicit written (or "understood") definition of what constitutes a surgical complication? If so, could you append it to this questionnaire? If not, would you briefly describe your own concept of a complication under comments below?
   Yes 9% No 88% No response 3%
2. How do you decide what will be presented at a Morbidity and Mortality conference?
   Residents decide 31% Faculty decides 24%
   Faculty/residents decide 35% Other 10%
3. Do you consider a complication as an adverse event occurring (check all that apply):
   a. *Within 48 hours of surgery 45%*
   b. *Within a week of surgery 46%*
   c. *Within a month of surgery 75%*
   d. *While the patient was in the hospital 43%*
   e. *With reasonable assurance as a result of the surgical manipulation 75%*
   f. *None 23%*
4. Do you consider recurrent sciatica that is identical to the preoperative lumbar laminotomy pain pattern to be a complication if it occurs (check all that apply):
   a. *Within 48 hours of surgery 35%*
   b. *Within a week of surgery 36%*
   c. *Within a month of surgery 41%*
   d. *Within 2 months of surgery 25%*
   e. *Within 6 months of surgery 35%*
   f. *None 1%*
5. Do you consider the occurrence of pneumonia to be a complication if it occurs (check all that apply):
   a. *In a 25-year-old postoperative ventilated cervical quadriplegic patient 57%*
   b. *In a 65-year-old postoperative lumbar fusion patient with chronic obstructive pulmonary disease 13%*
   c. *In a 25-year-old nonoperated ventilated cervical quadriplegic patient 45%*
   d. *In a 40-year-old healthy nonsmoker on day 2 following a routine lumbar discectomy 96%*

6a. Do you consider a dural tear that is successfully repaired during surgery and that has no adverse sequelae to be a complication of surgery?
   Yes 43% No 57%

6b. Do you consider this same dural tear to be a complication of surgery if (check all that apply):
   a. *It is associated with 2 days of severe positional headaches 74%*
   b. *It is associated with CSF leakage through the wound and requires lumbar drainage to manage successfully 96%*
   c. *It requires reoperation to manage 96%*

7. Do you consider pedicle screw fracture at 6 months following surgery to be a complication if (check all that apply):
   a. *It is asymptomatic and associated with a solid fusion 24%*
   b. *It is asymptomatic and associated with a pseudarthrosis 65%*
   c. *It is associated with persistent back pain and a solid fusion 38%*
   d. *It is associated with persistent back pain and a pseudarthrosis 86%*
   e. *None of the above 13%*
8. In a patient who has undergone an anterior cervical discectomy with fusion, do you consider a pseudarthrosis (without excessive movement on flexion/extension x-rays) to be a complication if (check all that apply):
   a. *It is asymptomatic 24%*
   b. *It is associated with neck pain 80%*
   c. *It is associated with radicular pain 80%*
   d. *None 15%*
9. One year following a fusion and the placement of a hook-rod system for an unstable LI fracture in a patient without neurologic deficit, the patient complains of back pain at the rostral implant insertion site. Do you consider this a complication if (check all that apply):
   a. *You successfully manage the pain with an exercise program 12%*
   b. *Narcotic analgesics are required to manage the pain 30%*
   c. *The pain is managed successfully by surgical removal of the spinal implant 40%*
   d. *None 52%*
10. If we as surgeons could more accurately define what constitutes a complication (check all that apply):
   a. *Would the quality of our practices be improved?*
      Yes 63% No 28% No response 9%
   b. *Would medical reporting in the literature be enhanced?*
      Yes 92% No 6% No response 2%
   c. *Would quality assurance be enhanced?*
      Yes 76% No 14% No response 10%
   d. *Would the medico-legal climate be:*
      Worsened 29% Improved 38% No effect 29% No response 4%
   e. *And if we could simultaneously standardize which complications were the result of negligence, would the medico-legal climate be:*
      Worsened 20% Improved 50% No effect 23% No response 7%

Figure 2. Bias and conflict of interest survey.

Like a Canadian Thistle, a complication (and, yes, pornography) implies different things to different people. We must put complications in their appropriate perspective by clarifying their definition as they pertain to the situation at hand. We should then actively avoid them and aggressively identify and manage them when they do occur.

BIAS AND CONFLICT OF INTEREST

Bias and conflicts of interest can skew and pervert objectivity. Please remember as you read the pages that follow that all of us (including the contributors to this book) are biased and conflicted. It is literally impossible not to harbor such biases. Some are more obvious than others. Nevertheless, as with the definition of complications and pornography, the definition of bias and conflict of interest is often unclear. We, in an attempt to inform our readership regarding the more obvious biases and conflicts of interests, have had each contributor disclose such conflicts as they pertain to the subject matter presented herein. They were asked to fill out the form depicted in Figure 2. Please remember that we all have bias and conflicts of interest. Those listed here represent but a scratching of the surface. Like so many other aspects of interpersonal communications—it's a start.

Finally, the fourth edition begins a new era for this book. It involves reorganization related improvements, reorganized editorship, and improvements that come with an evolving maturation of the medical writing and editorial process. Please read, enjoy, and employ the messages and information imparted.

Michael P. Steinmetz
Edward C. Benzel

In Memoriam

Photograph courtesy of Mayfield Clinic, Cincinnati, Ohio.

Charles D. Kuntz IV (1964-2015)

The spine surgery and neurosurgery communities suffered a great loss in 2015. Charles D. (Charlie) Kuntz IV left us very prematurely. His vitality, creativity, dry sense of humor, compassion, empathy, and love for the game (spine surgery) have left a lasting impression on our profession. Charlie was part of a three-editor team during the initial development phase of this edition. So, in part, this book embodies and is marked by Charlie's stamp—a stamp of approval, if you will.

Charlie left us during the early phases of this book, but his contributions were substantial. Several of his chapters are included as they existed at the time of his death. They are perhaps a little unrefined, but we felt compelled to leave them as is.

We all will miss Charlie, but will never forget him. Please understand that there is a little of Charlie in every word in this edition.

Michael P. Steinmetz
Edward C. Benzel

Video Contents

SECTION 1 History

1 History of Spine Surgery

Sait Naderi, Edward C. Benzel

SUMMARY OF KEY POINTS

- Although most advances in spine surgery occurred in the 19th and 20th centuries, their roots date back several thousand years. During the antique period, some special spine disorders were described and treated using drugs and orthotics.
- The Greco-Roman age was associated with a better understanding of spinal disorders and their treatment. Hippocrates and Galen were the most known figures of this period.
- There was a limited advancement during the Middle Ages.
- Further advancements were made during the Renaissance. Many scientists contributed to the body of knowledge in the fields of anatomy, neuroscience, and biomechanics during and after the Renaissance.
- Many technologic advancements occurring since the 1800s have also contributed to the spine-related sciences.
- Finally, an understanding of spine biomechanics and metallurgy as well as the use of imaging and the microscope in spine care have improved the surgeon's ability to perform spine surgery more safely and effectively.

The evolution of spine surgery has revolved around three basic surgical goals: decompression, surgical stabilization, and deformity correction. To emphasize their importance, these surgical goals form the framework for this chapter. However, other related fundamental arenas—such as anatomy, biomechanics, and nonsurgical treatment modalities—have contributed to the development of surgical concepts as well.

Although most advances in spine surgery occurred in the 19th and 20th centuries, their roots date back several thousand years. Without understanding and appreciating the past, it is not possible to understand and appreciate the advancements of the past two centuries. Therefore, before touching on the history of the spine over the past two centuries, this chapter presents a short examination of spine medicine from the antique period, medieval period, and Renaissance.

ANTIQUE PERIOD AND SPINE SURGERY

There is no evidence of surgical decompression and stabilization, or the surgical correction of deformity, during the antique period except for laminectomy in a trauma case reported by Paulus of Aegina. However, it is known that physicians of the antique period were, to some extent, able to evaluate patients with spinal disorders. They in fact used frames for reduction of dislocation and gibbus (i.e., kyphosis) and applied some of the knowledge gained from human and animal dissections.

Srimad Bhagwat Mahapuranam, an ancient Indian epic (3500–1800 BCE), depicts the oldest documentation of spinal traction. A passage from this document describes how Lord Krishna applied axial traction to correct a hunchback in one of his devotees.[1]

The Edwin Smith Papyrus (2600–2200 BCE) is the most well known document on Egyptian medicine. This document reports 48 cases. Imhotep (2686–2613 BCE), a late second-dynasty surgeon, authored this papyrus, which reported six cases of spinal trauma. Hence, nearly 4600 years ago, vertebral subluxation and dislocation and traumatic quadriplegia and paraplegia were described.[2] In the early 21st century, it was reported that Egyptian physicians described the "spinal djet column concept."[3]

Antique medicine was also influenced by the Greco-Roman period physicians.[4] *Hippocrates* (460–375 BCE) addressed the anatomy and pathology of the spine, describing the normal curvatures of the spine, its structure, and the tendons attached to it. He defined tuberculous spondylitis, posttraumatic kyphosis, scoliosis, spinal dislocation, and spinous process fracture. He addressed the relationship between spinal tuberculosis and gibbus. According to Hippocrates, spinous process fracture was not dangerous. However, fractures of the vertebral body were more important. He described two frames for reduction of the dislocated spine, including the Hippocratic ladder and the Hippocratic board.[5] The details of Hippocratic treatment were recorded by Aulus Cornelius Celsus (25 BCE–50 CE).

Aristotle (384–322 BCE) focused on kinesiology. His treatises—"parts of animals, movement of animals, and progression of animals—described the actions of the muscles." He analyzed and described walking, in which rotatory motion is transformed into translational motion. Although his studies were not directly related to the spine, they were the first to address human kinesiology and, in fact, biomechanics.[6]

Galen of Pergamon (130–200 CE), another physician of the antique era, worked as a surgeon and anatomist. He studied the anatomy of animals and extrapolated his findings to human anatomy. His anatomic doctrines became the basis for medical education for more than 1200 years. He used the terms *kyphosis*, *scoliosis*, and *lordosis*, and he attempted to correct these deformities. He also worked as the official surgeon of gladiators in amphitheaters. Because of this position, he was accepted as "the father of sports medicine." He confirmed the observations of Imhotep and Hippocrates regarding the neurologic sequences of cervical spine trauma. Nevertheless, to the best of our knowledge, he did not operate for spinal trauma.[6,7]

Oribasius (325–400 CE), another physician of the antique period, added a bar to the Hippocratic reduction device and used it to treat both spinal trauma and spinal deformity.[8,9]

One of the most important figures dealing with spinal disorders during the end of this period was *Paulus of Aegina* (625–690 CE). He collected what was known from the previous 1000 years in a seven-volume encyclopedia. Paulus of Aegina not only used the Hippocratic bed, but also worked with a red-hot iron. He is credited with performing the first known laminectomy. This was performed for a case of spinal fracture resulting in spinal cord compression. He emphasized the use of orthoses in spinal trauma cases.[6,10]

MEDIEVAL PERIOD AND SPINE SURGERY

The studies and reports of Paulus of Aegina are the most important sources of information regarding this period of medicine.[11] This age was followed by the Dark Ages (ca. 500–1000 CE) in Europe. Although Western medicine showed no progress during the Dark Ages, the Eastern world developed the science. The early Islamic civilizations realized the importance of science and scientific investigation. The most important books of the antique age were translated into Syrian, Arabic, and Persian. Therefore, using the Western doctrines, the Islamic civilizations discovered new information and were able to contribute further. In terms of spine medicine, several important contributors, including Avicenna and Abulcasis, added to this movement.

Avicenna (981–1037 CE), a famous physician from present-day Uzbekistan, worked in all areas of medicine (Fig. 1-1). His famous book, the *Canon of Medicine*, was a seminal textbook until the 17th century in Europe. He described the biomechanics-related anatomy of the spine, as well as flexion, extension, lateral bending, and axial rotation of the spine.[12] Avicenna also used a traction system similar to the system described by Hippocrates.[13]

Abulcasis (936–1013 CE), a famous Arabian surgeon of the 11th century, wrote a surgery treatise, "At-Tasnif." He described several surgical disorders, including low back pain, sciatica, scoliosis, and spinal trauma. He recommended the use of chemical or thermal cauterization for several spinal disorders. He also developed a device to reduce the dislocated spine.[14]

Figure 1-1. Avicenna.

Serefeddin Sabuncuoglu (1385–1468 CE), a Turkish physician of the 15th century, wrote an illustrated atlas of surgery,[15] in which he described scoliosis, sciatica, low back pain, and spinal dislocations. He delineated a technique for reduction of spinal dislocations using a frame similar to that designed by Abulcasis.

RENAISSANCE AND SPINE SURGERY

Gradually, the intellectual doldrums of the Dark Ages in Europe evolved into the Renaissance. Academic centers were established in Europe, as well as centers for the translation of documents, similar to centers established in Islamic regions. Thus, the classics from the antique age were translated into Latin from Arabic, making their scientific information available to the scholars and physicians of the Renaissance. During this time, the Western world spawned disciplines, including art, medicine, physics, and mathematics.

The works of *Leonardo da Vinci* (1452–1519 CE) are of importance in this regard. Da Vinci worked on the philosophy of mechanics and on anatomy in *De Figura Humana*. He described spine anatomy, the number of vertebrae, and the joints in detail. By studying anatomy in the context of mechanics, da Vinci gained some insight into biomechanics. He considered the importance of the muscles for stability in the cervical spine. However, his work was unpublished for centuries, and his brilliant daydreaming had a limited scientific influence on biomechanics.[16,17]

Andreas Vesalius (1514–1564 CE), an anatomist and physician, wrote his famous anatomy book, *De Humani Corporis Fabrica Liberi Septum*, which changed several doctrines described by Galen. Actually, it took several centuries for the world to accept that Galen had made errors that Vesalius corrected. Because he described and defined modern anatomy, he is commonly accepted as the "father of anatomy." He described the spine, intervertebral disc, and intervertebral foramina. His biomechanical point of view regarding the flexion extension of the head was similar to that of Avicenna.[18]

The early anatomic studies and observations were followed by biomechanical advancements. Prominent among the contributors to those advancements was *Giovanni Alfonso Borelli* (1608–1679 CE), who described the biomechanical aspects of living tissue. He is the founder of the "iatrophysics" concept—a term that subsequently became known as biomechanics. He is accepted as the "father of spinal biomechanics." His book, *De Motu Animalium*, describes the movements of animals. He wrote that the intervertebral disc is a viscoelastic material that carries loads. This is so because he observed that muscles could not bear the loads alone. He concluded that the intervertebral discs should have function during load bearing. He was the first scientist to describe the human weight center (center of gravity).[19,20]

The studies and accomplishments of the Renaissance period were not limited to the aforementioned. Many scientists contributed to the body of the literature in this period. The advancements from this period resulted in the formation of early modern surgery, beginning in the 19th century.

EARLY MODERN PERIOD AND SPINE SURGERY

Many developments and inventions contributed to the progress and evolution of spine surgery (Table 1-1). Each of these steps had an important impact on the improvement of spine health care and inspired other developments. Advances in nursing care, in anesthesiology, in asepsis and antisepsis, and the development of antibiotics increased the braveness of

TABLE 1-1 Developments and Inventions Contributing to the Spine Surgery

Developments in anesthesiology
Developments in nursing care
Developments in asepsis and antisepsis
Developments in radiodiagnostics
Development of metallurgy
Invention of spine instruments
Invention of biomaterials
Understanding of spine biomechanics

surgeons to do surgery. The improvement of spine imaging assisted with the diagnosis of spinal disorders. Developments in surgical techniques and instrumentation improved surgical techniques of spinal disorders.[21-23] The early modern period continued with many more developments and inventions—particularly in the fields of metallurgy, biomaterials, biomechanics and imaging—after the 1960s. This period continued with the progression of minimally invasive techniques.[24]

Spinal Decompression and the Early Modern Period

Although an open decompression of the spinal canal for spinal cord compression was recommended by some surgeons as early as the 16th and 18th centuries (e.g., Pare, Hildanus), there is no evidence of successful intervention except for a case reported by Paulus of Aegina prior to the 19th century.

Spinal decompression in the early modern period was primarily via laminectomy. Throughout most of the 19th century, laminectomy was developed and its utility debated as the only surgical approach to all spinal pathologies, including tumor, trauma, and infection. At the dawn of the 20th century, the indications for laminectomy were extended to the decompression of spinal degenerative disease, an understanding of which had eluded 19th-century surgeons because they failed to appreciate the connection between its clinical and pathologic manifestations.

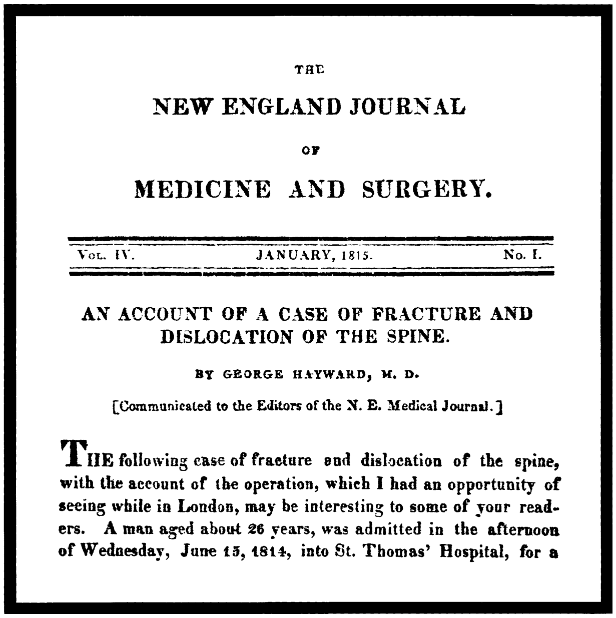
During the 19th century, spine surgery was performed almost exclusively for neural element decompression. Numerous nonoperative approaches to deformity correction were attempted over the centuries, but the surgical approach to deformity correction was a 20th-century development. The techniques of spinal stabilization were also a product of the 20th century—both spinal fusion and internal fixation appearing around the turn of the 20th century. Moreover, a failure to recognize the implications for treatment of degenerative spinal disease, including spondylosis and degenerative disc disease, meant that the solution to these problems had to wait for the new century.

Thus, during the 19th century, the indications for spine surgery were limited to the treatment of tumor, trauma, and infection.[25] Although each of these conditions posed unique clinical and surgical problems, they shared the need for surgical decompression. Throughout the early modern period, surgical decompression of the spine was the single most common reason to undertake the risks of spine surgery, and laminectomy was the most commonly used technique to achieve it.

Birth and Development of the Laminectomy

H. J. Cline, Jr., and the Argument against Spine Surgery

At the beginning of the 19th century, the prospects for spine surgery appeared grim. The dismal results of a well-publicized



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AN ACCOUNT OF A CASE OF FRACTURE AND DISLOCATION OF THE SPINE.

BY GEORGE HAYWARD, M. D.

[Communicated to the Editors of the N. E. Medical Journal.]

THE following case of fracture and dislocation of the spine, with the account of the operation, which I had an opportunity of seeing while in London, may be interesting to some of your readers. A man aged about 26 years, was admitted in the afternoon of Wednesday, June 15, 1814, into St. Thomas' Hospital, for a

Figure 1-2. First page of H. J. Cline Jr.'s historic laminectomy, as reported by G. Hayward. *(From Cline HJ Jr [cited by Hayward G]: An account of a case of fracture and dislocation of the spine.* N Engl J Med Surg *4:13, 1815.)*

operation for a traumatic spinal injury stimulated a heated debate over the "possibility" of spine surgery that persisted for nearly a century. At the center of this debate was H. J. Cline, Jr., a little-known British surgeon.

In 1814, Cline performed a multilevel laminectomy for a thoracic fracture-dislocation associated with signs of a complete paraplegia (Fig. 1-2).[26] The patient was a 26-year-old man who fell from the top of a house. "He was bled previous to his admission" to the St. Thomas's Hospital in London, "and some imprudent attempts were made to relieve him by pressing the knees against the injured part, which only increased the pain and inflammation."[26] Upon admission to the hospital the patient was examined by Cline, who "ascertained that some of the spinous processes . . . were broken off and were pressing upon the spinal marrow . . . [and] who resolved to cut down and remove the pressure from the spinal marrow."[26]

The patient was observed overnight in the hospital, and on the day following admission, Cline performed his proposed operation. Although the operation was performed within 24 hours of injury, Cline was unable to reduce the dislocation or to achieve a complete decompression of the neural elements. The patient survived for 3 days after surgery, with increasing pain and a steadily increasing pulse. Following the patients death "on an examination of the body by Mr. Cline, it was found that the spinal marrow was entirely divided."[26] Despite the severity of the neural injury and the complexity of the fracture-dislocation, the untoward outcome of this unfortunate case would remain a topic of conversation for almost a century, providing ample ammunition for the opponents of spine surgery.

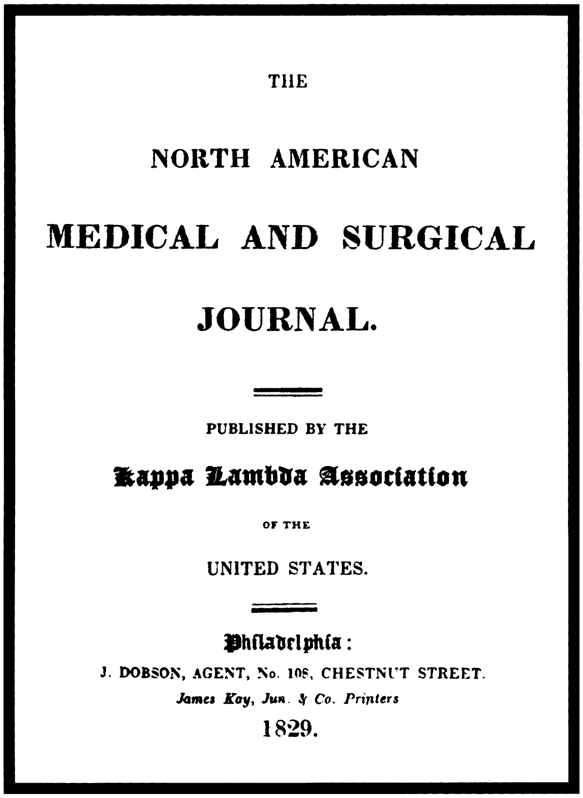
Cline's case was not an isolated mortality. In 1827, for example, Tyrell[27] reported a 100% mortality for a small series of patients with surgically treated spinal dislocation and neurologic injury. Other reports (e.g., Rogers[28] in 1835) were often equally discouraging. Looking back on these early years of the debate about spine surgery, the early 20th century British surgeon Donald Armour[29] described the controversy this way:

This [Cline's operation] precipitated and gave rise to widespread and vehement discussion as to its justification. This discussion, often degenerating into bitter and virulent personalities, went on many years. Astley Cooper, Benjamin Bell, Tyrell, South, and others favored it, while Charles Bell, John Bell, Benjamin Brodie, and others opposed it. The effect of so eminent a neurologist as Sir Charles Bell against the procedure retarded spinal surgery many years—the operation was described with such extravagant terms as "formidable," "well-nigh impossible," "appalling," "desparate [sic] and blind," "unjustifiable," and "bloody and dangerous."

Of course, surgical fatalities in this period were due as much to septic complications and anesthetic inadequacies as they were to surgical technique. The lack of an effective means of pain control during surgery intensified the problem of intraoperative shock and made speed essential. Furthermore, the problems of wound infection and septicemia were both predictable and frequently fatal. These hindrances to surgery were not ameliorated until the introduction of general anesthetic agents (i.e., nitrous oxide, ether, and chloroform) in the mid-1840s and the adoption of Listerian techniques (using carbolic acid) in the 1870s.[30]

A. G. Smith and the First Successful Laminectomy

Despite these risks, a little-known surgeon named Alban G. Smith from Danville, Kentucky, performed a laminectomy in 1828 on a patient who had fallen from a horse and sustained a traumatic paraplegia. To Smith's credit, his patient not only survived the operation but achieved a partial neurologic recovery. The operative technique and surgical results were reported in the *North American Journal of Medicine and Surgery* in 1829 (Fig. 1-3).[31] Smith's procedure comprised a multilevel laminectomy through a midline incision, involving removal of the depressed laminae and spinous processes, exploration of the dura mater, and closure of the soft tissue incision. Although the report of this landmark case appears to have attracted little attention at the time, it is a significant technical achievement and places Smith among the pioneers of the early modern period in spine surgery.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1829.

Figure 1-3. Title page of journal that contains the first successful report of a laminectomy. The surgeon and the author of the report was Alban G. Smith of Danville, Kentucky. *(From Smith AG: Account of a case in which portions of three dorsal vertebrae were removed for the relief of paralysis from fracture, with partial success.* North Am Med Surg J *8:94–97, 1829.)*

Laminectomy for Extramedullary Spinal Tumor

During the half century after Smith's historic operation, the primary indication for laminectomy was spinal trauma. In the latter part of the 19th century, the indications for laminectomy were extended to tumor and infection.[32] The first and most celebrated surgical case for spinal tumor in the 19th century, that of Captain Gilbey, was also the first successful one, and it played an important role in the rehabilitation of the laminectomy as a safe and effective procedure.

Captain Gilbey was an English army officer who suffered the misfortune of losing his wife in a carriage accident in which he also was involved. Although Gilbey himself escaped serious injury, he soon began to experience progressive dull back pain, which he attributed to the accident. As the pain became relentless, Gilbey sought the advice of a series of physicians, all of whom were unable to identify the source of his pain. Eventually, Gilbey was referred to the eminent London neurologist William Gowers, who elicited from the patient a history of back pain, urinary retention, paraplegia, and loss of sensation below the thoracic level (Fig. 1-4).[33]

The neurologist's diagnosis was immediate and unequivocal: the cause of Gilbey's symptoms was located in his spine, where a tumor was causing compression of the thoracic spinal cord. Although no intraspinal tumor had ever been resected successfully, Gowers referred the patient to his London surgical colleague, Victor Horsley (Fig. 1-5). After all, Gowers had himself asserted, in his authoritative textbook, *Manual of Diseases of the Nervous System*, that removal of an intradural spinal cord tumor was "not only practicable, but actually a less formidable operation than the removal of intracranial tumors."[34]

Horsley acted quickly. Within 2 hours of the initial consultation, a skin incision was made at 1 PM, June 9, 1887, at the National Hospital, Queens Square, London. Despite his precipitous decision to undertake this dangerous operation, Horsley did not approach the operation unprepared. Although the Act of 1876 made it a criminal offense to experiment on a vertebrate animal for the purpose of attaining manual skill, Horsley had repeatedly practiced the proposed procedure in the course of his surgical experimentation. Despite some initial difficulty in locating the tumor, an intradural neoplasm in the upper thoracic spine causing compression of the spinal cord was identified and safely resected. The pathologic diagnosis was "fibromyxoma of the theca."

Follow-up 1 year later revealed almost complete neurologic recovery. The patient was walking without assistance and had returned to his premorbid work schedule. He remained well, with no evidence of tumor recurrence, up to the time of his death from an unrelated cause 20 years later.

Laminectomy for Intramedullary Spinal Tumor

In 1890, Fenger attempted to remove an intramedullary spinal tumor in an operation that resulted in the patient's death.[35] In 1905, Cushing[36,37] also attempted to remove an intramedullary spinal cord tumor but decided to abort the procedure after performing a myelotomy in the dorsal

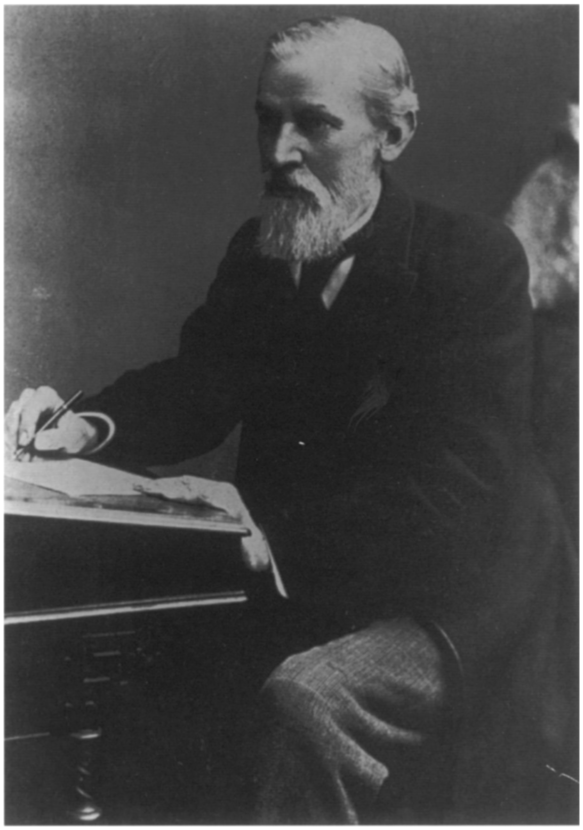

Figure 1-4. William R. Gowers.

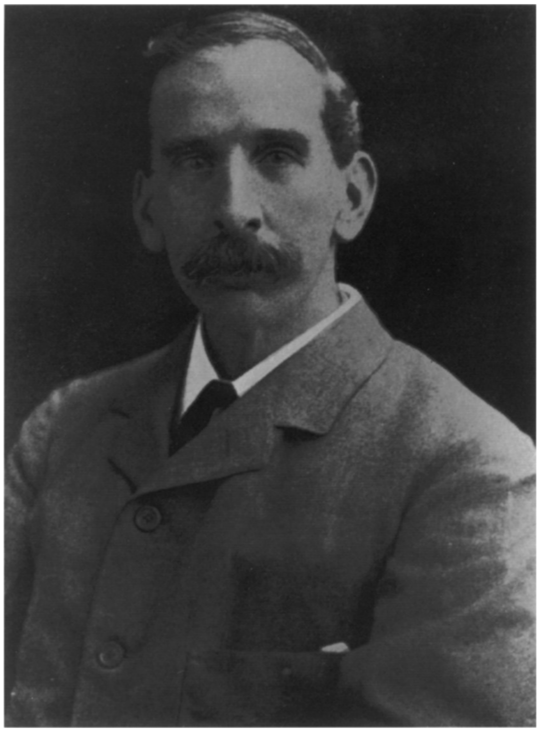

Figure 1-5. Sir Victor Horsley.

column. To Cushing's surprise, the patient improved after surgery. In 1907, von Eiselsberg[38] successfully resected an intramedullary tumor.

The unexpected improvement that was observed in the patient reported by Cushing attracted the attention of New York surgeon Charles Elsberg. Elsberg[39] described Cushing's technique, which he aptly named the "method of extrusion." The technique was intended to remove an intramedullary tumor by spontaneous extrusion of the tumor through a myelotomy made in the dorsal column. The rationale for this method was predicated on the theory that an intramedullary tumor was associated with an increase in intramedullary pressure. Release of this pressure by a myelotomy that extended from the surface of the spinal cord to the substance of the tumor was expected to provide sufficient force to spontaneously extrude the tumor. According to Elsberg, the advantage of this procedure over a standard tumor resection was that it required minimal manipulation of the spinal cord and therefore minimal spinal cord tissue injury.

Because the spontaneous extrusion of an intramedullary tumor occurred slowly, Elsberg performed these procedures in two stages. In the first stage, a myelotomy was fashioned in the dorsal column, extending from the surface of the spinal cord to the tumor (Fig. 1-6A).

When the tumor was identified and observed to begin to bulge through the myelotomy incision, the operation was concluded, the dura mater was left opened, and the wound closed. In the second stage of the procedure, which was performed approximately 1 week after the first stage, Elsberg reopened the wound and inspected the tumor (Fig. 1-6B). Typically, the tumor was found outside the spinal cord, and the few adhesions that remained between the spinal cord and the tumor were sharply divided. After the tumor was removed, the wound, including the dura mater, was closed.

Variations in Laminectomy Technique

By the last decade of the 19th century, after the case of Captain Gilbey, the possibility of safely performing a spinal operation was established in the collective surgical consciousness. Furthermore, new anesthetic techniques and aseptic methods had become available to most practicing surgeons.[40] All of these factors increased the appeal of the laminectomy to surgeons and widened its range of application. For example, after Horsley's widely publicized success for resecting a spinal tumor, many similar operations were soon described in the literature,[41-46] and in 1896, Makins and Abbott[47] reported 24 cases of laminectomy for vertebral osteomyelitis.

Although the safety and efficacy of the laminectomy had convinced many proponents of the utility of the procedure, toward the end of the century surgeons began to worry about postoperative instability. Advances in operative technique and perioperative management meant that more and more patients survived the operation and ultimately became ambulatory, which further heightened concern about stability.

In 1889, Dawbarn[48] described an osteoplastic method of laminectomy that addressed this concern. Instead of a midline incision, Dawbarn described two lateral incisions that were carried down to the transverse processes. The lateral incisions were connected in an H-like fashion, and a superior and inferior flap—including skin, muscle, fascia, and bone—was then turned. In closing the wound, the intact flaps were reflected back and reapproximated in their normal anatomic positions.

Although not all surgeons subscribed to the osteoplastic method, many turn-of-the-century surgeons were largely preoccupied with modifications of this procedure.[49] At the same time, however, a more important innovation in laminectomy

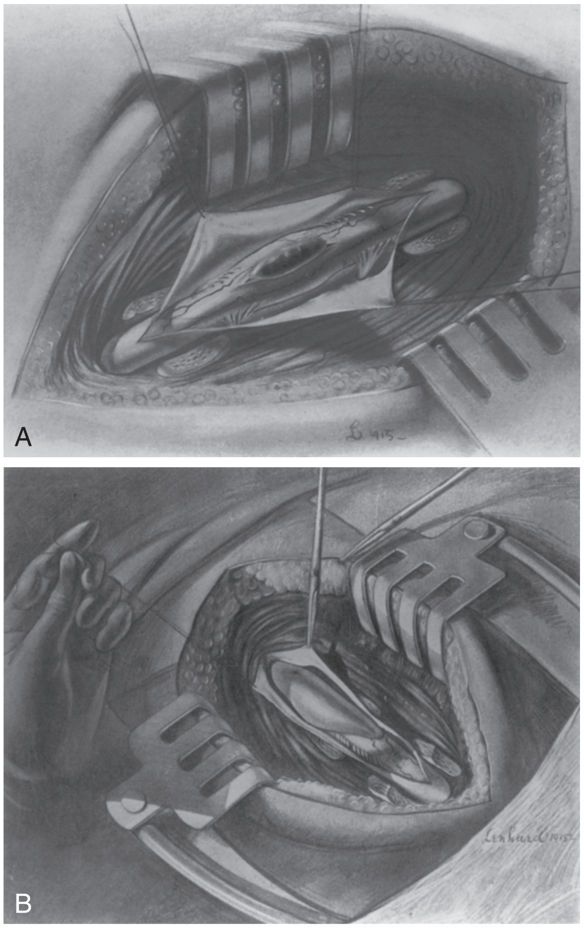

Figure 1-6. A, The first stage in an intramedullary spinal cord tumor resection by the extrusion method. Note that the tumor is bulging through the myelotomy incision. The wound was subsequently closed. **B,** The second stage in an intramedullary spinal cord tumor resection by the extrusion method, 1 week after the first stage. Note that the tumor has spontaneously extruded since the first operation and now may be removed easily. *(From Elsberg CA, Beer E: The operability of intramedullary tumors of the spinal cord: a report of two operations with remarks upon the extrusion of intraspinal tumors.* Am J Med Sci *142:636–647, 1911.)*

Figure 1-7. Charles A. Elsberg.

technique, the hemilaminectomy, was developed independently in both Italy[50,51] and the United States.[51]

In 1910, A. S. Taylor of New York described the hemilaminectomy: a midline incision, a subperiosteal paravertebral muscle takedown, and the removal of a hemilamina with a Doyen saw.[51] The advantages of the hemilaminectomy over the cumbersome osteoplastic method were obvious, and Taylor argued that compared with the laminectomy, the hemilaminectomy interfered less with the mechanics of the spine. Despite such detractors as Charles Elsberg, who responded that the field of view was narrow and the effect of laminectomy on spinal mechanics negligible, Taylor successfully championed its use.

Charles A. Elsberg: The Laminectomy in Stride

Charles A. Elsberg was one of the most influential writers on spinal decompression (Fig. 1-7). Working at the Neurological Institute of New York, which he had helped to found, Elsberg[52] published his first series of laminectomies in 1913. In 1916, he published his classic text, *Diagnosis and Treatment of Surgical Diseases of the Spinal Cord and Its Membranes.*[53] Although these publications represent landmarks in the history of spine surgery, they constitute more of a culmination than an innovation in spine surgery. Elsberg's work on spine surgery, coming as it did at the end of a century of evolution of the decompressive laminectomy, effectively codified 19th and early 20th century developments.

In his textbook, Elsberg outlined the surgical indications and contraindications for laminectomy. He noted the beneficial effects in his own large series of laminectomies and puzzled over the benefits that may occur in the absence of evident increased intradural pressure, such as in patients with multiple sclerosis. He argued that the primary indications for operation were cases of tumor, trauma, and infection that were associated with symptoms localized to a spinal level. Patients with progressive symptoms should be operated on quickly, in the absence of contraindications such as metastatic cancer or advanced Pott disease.

Given the exhaustive scope of these early Elsberg publications—which, in addition to tumor, trauma, and infection, also review the management of congenital spine disease—conspicuously little is said about the most common late 20th-century indication for laminectomy: degenerative spine disease. The tardy development of a treatment for degenerative spine disease should be understood in the larger context of 19th and early 20th century knowledge of spinal pathology.

Unlike degenerative disease, tumor, trauma, and infection were already well known in antiquity. Although the concept of localization of function in the nervous system was undeveloped during the 19th century, the diagnosis and localization of tumor, trauma, and infection, particularly in their late stages, were not especially difficult. Degenerative disease, on the other hand, possessed a more subtle pathophysiology that was not as easily characterized, especially without the help of

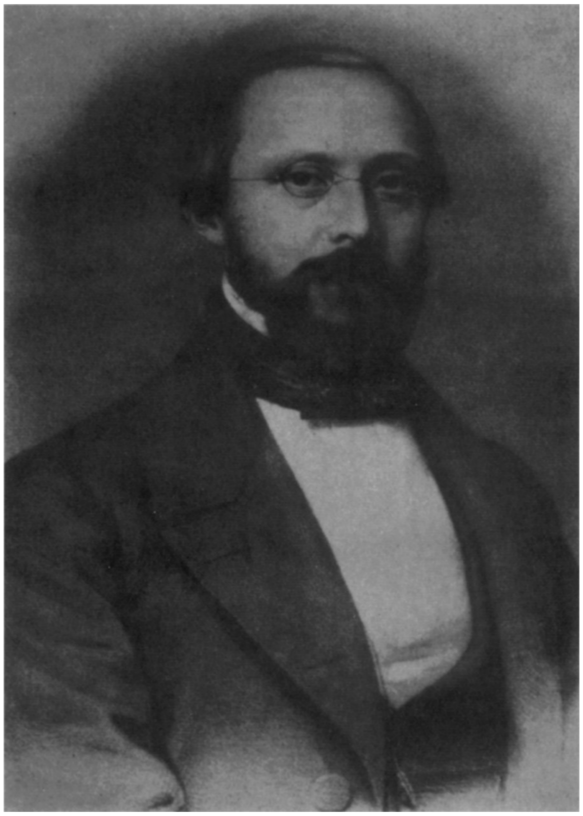

Figure 1-8. Rudolph Virchow.

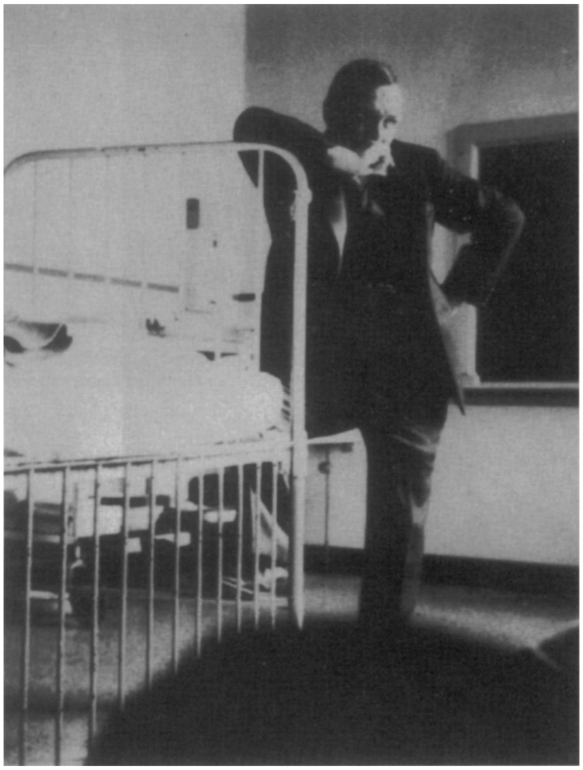

Figure 1-9. Walter E. Dandy.

radiography. Thus, recognition of degenerative spine disease eluded the 19th-century surgeon. This tardy appreciation for the clinical, surgical, and pathologic importance of degenerative spine disease deserves further mention.

Laminectomy for Intervertebral Disc Herniation. Intervertebral disc pathology was first described by Rudolph Virchow[54] in 1857 (Fig. 1-8). Virchow's description of a fractured disc was made at autopsy on a patient who had suffered a traumatic injury.

In 1896, the Swiss surgeon T. Kocher[55,56] identified and described a traumatic disc rupture at autopsy of a patient who had fallen 100 feet and landed on her feet. Although Kocher recognized that the L1-2 disc was displaced dorsally, no clinical correlation was suggested.

The first transdural intervertebral discectomy was reported by Oppenheim and Krause[57] in 1908. However, they reported the disc as "enchondroma."

In 1911, George Middleton,[58] a practicing physician, and John Teacher, a Glasgow University pathologist, described two cases of ruptured intervertebral disc observed at autopsy. Like Virchow and Kocher before them, however, Middleton and Teacher, although they described the pathology, failed to postulate its connection with radiculopathy or back pain.

In 1911, Joel Goldthwaite[59] made this connection. In an article on the lumbosacral articulation, Goldthwaite described and illustrated how weakening of the annulus fibrosus could result in dorsal displacement of the nucleus pulposus. The nucleus pulposus, he argued, could in turn result in low back pain and paraparesis. What eluded Goldthwaite and the surgeons before him, however, was the connection between a herniated disc and radiculopathy.

In a 1929 issue of the *Archives of Surgery*, Walter E. Dandy[60] published a description of two cases of herniated lumbar discs causing a cauda equina syndrome (Fig. 1-9). Dandy correctly described how "loose cartilage from the intervertebral disc" produced the symptoms of cauda equina compression that were relieved alter surgical decompression. He considered that in the second decade of the 20th century, more than 20 years after the first spinal fusion operations, intervertebral disc disease could be added to the list of indications for decompressive laminectomy.

Despite the several aforementioned publications on intervertebral disc herniation, the concept of disc herniation and its relationship to radiculopathy was defined by Mixter and Barr.

Several studies were performed in North America, but an anatomic, radiologic, and microscopic study was performed on 5000 human spines in the Dresden Pathology Institute by Schmorl and Junghanns. The results of this study were published in a book titled *The Human Spine in Health and Disease.* In 1932, Barr, an orthopedic surgeon from Massachusetts General Hospital, was assigned to write a critique of this study.

In June of 1932, Barr attempted to treat a patient with an extruded disc herniation. Following a 2-week unsuccessful course of nonoperational treatment, Barr consulted with Mixter. Mixter recommended a myelogram. The myelogram revealed a filling defect. Mixter subsequently operated on the patient and removed the "tumor." Barr studied the "tumor" specimens. Because he contributed to Schmorl's study published in German, Barr remembered the microscopic appearances in Schmorl's study and realized that the specimen from this index patient was the nucleus pulposus. After this finding, Mixter, Barr, and Mallory (pathologist) reevaluated all the cases that were diagnosed (or misdiagnosed) as chondroma in recent years at Massachusetts General Hospital. They retrospectively diagnosed most of these cases as ruptured intervertebral discs. Mixter and Wilson operated on the first ruptured disc herniation diagnosed preoperatively on December 31,

1932. Mixter and Barr reported the case in *New England Surgical Society* in September 30, 1933.[61,62]

In the late 1930s, Love[63] from the Mayo Clinic reported on an extradural laminectomy technique. In 1967, Yasargil[64] used the microscope for discectomy. Yasargil[64] and Caspar reported the first results of the lumbar microdiscectomy.[65]

Laminectomy for Cervical Disc Herniation. In 1905 Watson and Paul[66] performed a negative exploration for cervical spinal cord tumor. They found an anterior extradural mass in the intervertebral disc at autopsy. This may be the first reported case of cervical disc herniation. The first dorsal approach was performed by Elsberg[67] in 1925. He found a "chondroma" in a quadriparetic patient.

Laminectomy for Spinal Stenosis. Unlike the herniated intervertebral disc, the stenotic spinal canal was described comparatively early in the 19th century. Portal,[68] in 1803, observed that a small spinal canal may be causally related to spinal cord compression, leading to paraplegia. No clinical reports of this entity were published, however, until 1893 when William A. Lane[69] described the case of a 35-year-old woman with a progressive paraplegia and a degenerative spondylolisthesis. The patient improved after a decompressive laminectomy.

Further demonstration of the efficacy of decompressive laminectomy for spinal stenosis came from Sachs and Frankel[70] in 1900. They published an account of a 48-year-old man with neurogenic claudication and spinal stenosis whose symptoms improved after a two-level laminectomy. Recognition of the degenerative nature of the clinical entity of spinal stenosis was established by Bailey and Casamajor[71,72] in 1911 in a report on a patient who was successfully decompressed by Charles Elsberg. In his 1916 textbook, Elsberg[53] later wrote, "a spinal operation may finally be required in some cases of arthritis or spondylitis on account of compression of the nerve roots or the cord by new-formed bone."

In 1945, Dr. Sarpyener, a Turkish orthopedic surgeon, described congenital lumbar spinal stenosis.[73] This report was followed by a report on adult spinal stenosis from Dr. Verbiest.[74] In 1973, Hattori[75] described the technique of laminoplasty.

APPROACHES TO THE SPINE

Dorsolateral Approaches to the Spine

In 1779, Percival Pott described a condition involving spinal kyphosis and progressive paraplegia in a now-classic monograph titled "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; together with its method of cure; etc." (Fig. 1-10). For the management of this condition, which now bears his name, Pott recommended the use of a paraspinal incision to drain pus from the invariably present paraspinal abscess. For almost a century, this simple surgical procedure became a standard part of the treatment of Pott's paraplegia.

By the late 19th century, however, the laminectomy had received widespread acceptance as a safe and effective method of spinal decompression.[76] This was in part related to the decrease in surgical mortality associated with the adoption of the Listerian methods beginning in the 1870s, and it was only natural then that the laminectomy would play a role in the management of Pott disease. As in many of its applications, however, disenchantment arose with the results of laminectomy, and alternative approaches were therefore sought.[77] The most promising of these approaches was Ménard's so-called costotransversectomy.

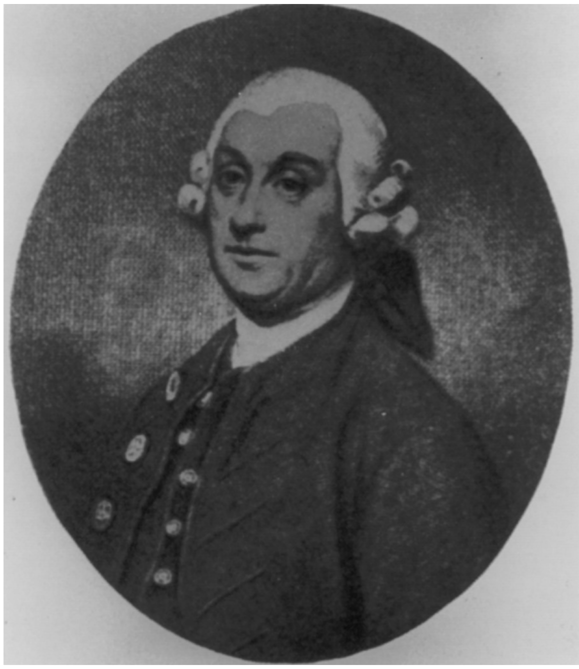

Figure 1-10. Percival Pott.

Ménard's Costotransversectomy

Like many surgeons at the beginning of the 20th century, Ménard[78] was disappointed by the surgical results from the laminectomy. In 1894, he described the costotransversectomy as an alternative method for achieving Pott's goal, namely, drainage of the paraspinal abscess. The advantage of the costotransversectomy over the laminectomy lay in the improved exposure it provided of the lateral aspect of the vertebral column. The procedure was also known as the "drainage latéral," emphasizing that the goal of the procedure was to drain the lateral, paravertebral tubercular abscess.

As described by Ménard, the costotransversectomy involved an incision overlying the rib that was located at the apex of the kyphos. The rib was then skeletonized and divided about 4 cm distal to the articulation with its corresponding vertebra, from which it was disarticulated and removed. These maneuvers provided access to the tuberculous focus, which was exposed and then decompressed directly (Fig. 1-11). Ménard did not intend to totally remove the lesion, but rather to simply decompress the abscess.

The surgical results of Ménard's costotransversectomy far surpassed the results obtained with the laminectomy. Ménard experienced several successes among his first 23 cases, including significant motor improvement.[79] Regrettably, these promising initial surgical results began to sour with time, as it became increasingly clear that two major complications were occurring with increasing frequency: postoperative development of secondary infection and the postoperative formation of draining sinus tracts. Both problems resulted from the opening up of the abscess. Because no antitubercular chemotherapeutic agents were available at the time, the consequences of the infections that ensued after surgery were frequently disastrous, resulting in significant surgical mortality. As Calot[80] grimly put it in 1930, "The surgeon who, so far as tuberculosis is concerned, swears to remove the evil from the very root, will only find one result waiting him: the death of his patient." The operation of Ménard thus fell into disrepute, and in time even Ménard abandoned it.

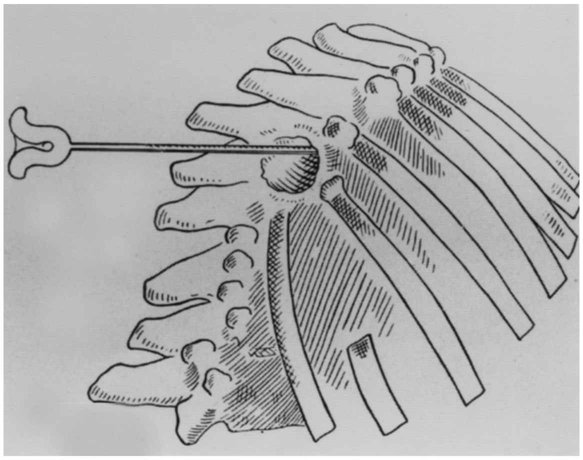

Figure 1-11. Drainage of a tubercular abscess via the costotransversectomy of Ménard. *(From Ménard V: Causes de la paraplegia dans le mal de Pott. Son traitement chirurgical par l'ouverture direct du foyer tuberculeux des vertebras.* Rev Orthop *5:47–64, 1894.)*

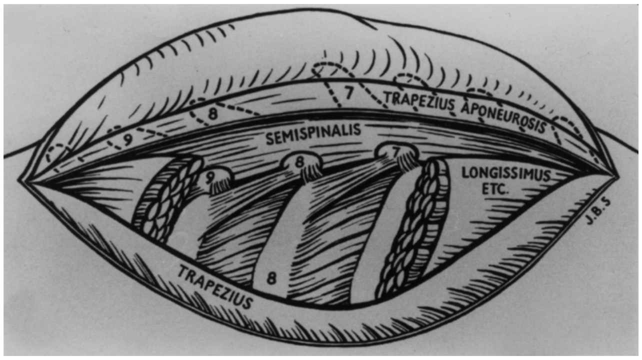

Figure 1-12. Dorsolateral exposure via Capener's lateral rhachotomy. Note that the exposure requires a transverse division of the paraspinal muscles. *(From Capener N: The evolution of lateral rhachotomy.* J Bone Joint Surg [Br] *36:173–179, 1954.)*

Capener's Lateral Rhachotomy

Like Ménard, the English surgeon Norman Capener attempted to find a surgical solution to the problem of Pott's paraplegia. Capener modified Ménard's costotransversectomy in a procedure that he developed and began using in 1933, which was first reported by H. J. Seddon[81] in 1935. Departing from the emphasis of Pott and Ménard, who simply decompressed the tubercular abscess, Capener attempted to directly remove the lesion, which typically consisted of a ventral mass of hardened material. To achieve his more radical goal of spinal decompression, Capener required a more lateral or ventral view of the vertebrae than was afforded by Ménard's approach.

Capener's solution was to adopt Ménard's costotransversectomy but with this difference: whereas Ménard approached the spine via a trajectory that was medial to the erector spinae muscles, Capener[82] transversely divided the muscles and retracted them rostrally and caudally (Fig. 1-12). He named his new approach the *lateral rhachotomy* to distinguish it from Ménard's *costotransversectomy.* The simple change in dissection planes distinguishes these two techniques by producing a significantly different trajectory and surgical exposure. Although the operation was designed for the surgical treatment of Pott's paraplegia, Capener later drew attention to the versatility of the approach and its appropriateness for a variety of pathologic processes, including "the exploration of spinal tumors, the relief of certain types of traumatic paraplegia, and the drainage of suppurative osteitis of the vertebral bodies."[82]

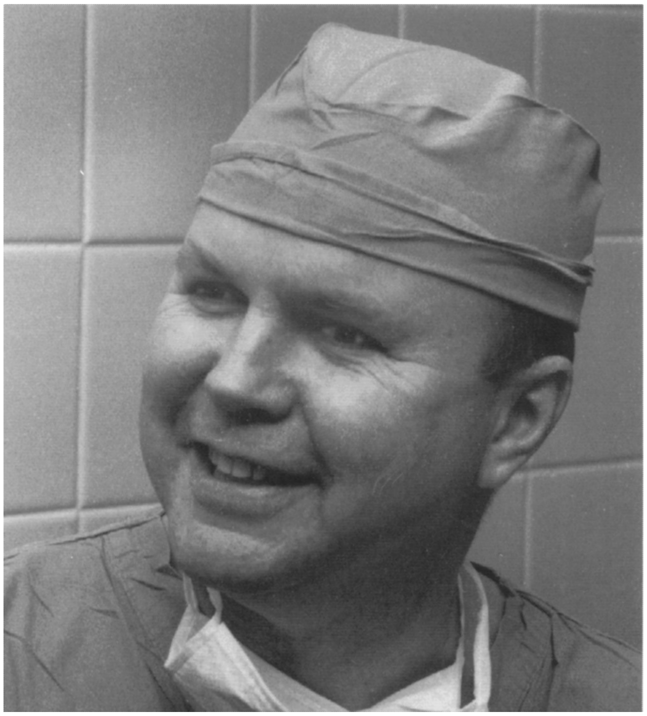

Figure 1-13. Sanford J. Larson.

It was perhaps unfortunate that for 19 years the only description of Capener's lateral rhachotomy was in a single case report published by another surgeon.[81] Not until 1954 did Capener himself describe the procedure, and even then he still chose not to publish the results of his 23 cases.[82]

In the interval between Seddon's 1935 description of the lateral rhachotomy and Capener's 1954 report of the same operation, the emergence of a new treatment, antitubercular chemotherapy, was to transform the history of the treatment of Pott's paraplegia. In 1947, streptomycin first became available for clinical use. This was followed by the introduction of *para*-aminosalicylic acid (PAS) in 1949 and isoniazid (INH) in 1952. The effect of the introduction of these new chemotherapeutic agents on the treatment of tuberculosis was spectacular. With the addition of streptomycin alone, the average relapse rate of tuberculosis was decreased by 30% to 35%. Although the effect of antitubercular chemotherapy was not as substantial for the treatment of spinal tuberculosis as for the pulmonary form, its mere availability raised new questions about the optimal management of Pott's paraplegia and, in particular, about the indications for surgical intervention.

Larson's Lateral Extracavitary Approach

In 1976, Sanford J. Larson and colleagues[83] at the Medical College of Wisconsin published an influential article that helped to popularize Capener's lateral rhachotomy, which they modified and renamed the *lateral extracavitary approach* (Fig. 1-13). This approach has been used more for trauma and tumor than for tuberculosis. The technical difference that distinguishes the lateral rhachotomy from the lateral extracavitary approach lies primarily in the treatment of the paraspinous muscles.

Whereas Capener's procedure involves transversely dividing these muscles and reflecting them rostrally and caudally, Larson's procedure uses a surgical exposure with a trajectory ventral to the paraspinous muscles, which are then reflected medially to expose the ventrolateral aspect of the spine. Later in the procedure these muscles are redirected laterally to provide access for instrumentation of the dorsal aspect of the spine using the same surgical exposure as that for the ventrolateral approach. Although neurosurgeons, as spine surgeons, had traditionally emphasized spinal decompression over spinal stabilization, an essential aspect of the significance of Larson's overall contribution to the discipline of spine surgery lies in the fact that, as a neurosurgeon, he dedicated his career to the advancement of reconstructive spine surgery.

SPINAL STABILIZATION AND DEFORMITY CORRECTION

The history of surgical stabilization and deformity correction must include a description of the birth and evolution of spinal fusion and spinal instrumentation. Special emphasis must be given to the role of spinal biomechanics and its influence on the development of internal fixation. Many factors hindered the development of surgical approaches to the decompression, stabilization, and deformity correction of the ventral spine. The development and mastery of the special techniques that were required to safely manage ventral spinal pathologies did not appear until after the beginning of the 20th century, in part because they depended on advances in anesthetic techniques and a more sophisticated approach to perioperative management.

Except for degenerative disease, the technique and indications for the decompressive laminectomy were well established by the turn of the 20th century. The idea of spinal decompression, previously the exclusive province of surgical pioneers, had demonstrated its clinical utility with results that fully justified its acceptance into standard surgical practice. However, the idea of decompression, which had dominated spine surgery during the 19th century, did not exist alone. Indeed, before the dawn of the 20th century, attention had already turned to another surgical idea: spinal stabilization. Of course, many attempts at surgical stabilization of the unstable spine had been made during the 19th century and before. However, the ancient admonition that vertebral fractures constituted an "ailment not to be treated" was reinforced by the surgeon's singular lack of success. And, thus, despite early attempts at spinal stabilization in the latter part of the 19th century, spinal decompression remained the primary indication for surgery of the spine, until World War II.

Recognition of the idea that compression of the neural elements, in cases of tumor, trauma, and infection, could be responsible for neurologic compromise was the crucial first step needed to develop the idea that spinal decompression could improve neurologic outcome. The invention of a technical means to achieve decompression, namely by laminectomy, represented the next necessary step in bringing this concept into clinical practice. Similarly, the idea of spinal stabilization arose from the observation that the unstable spine was at risk for the development of progressive deformity and that surgical intervention might prevent such deformities. Of course, bringing this concept into practice depended on achieving an adequate technical means. Indeed, two technical advances were developed around the beginning of the 20th century that provided a means for spinal stabilization that would revolutionize the practice of modern spine surgery.[84]

BIRTH AND DEVELOPMENT OF SPINAL FUSION AND SPINAL INSTRUMENTATION

Both spinal fusion and spinal instrumentation were born around the turn of the 20th century as methods of stabilizing the unstable spine. For many years, these two technical advances were developed and applied essentially independently, with results that were often complicated by pseudarthrosis. Early attempts at spinal instrumentation in particular failed to gain popularity because of their inability to maintain more than immediate spinal alignment. Spinal fusions were often used to achieve stabilization, but these also frequently suffered a similar fate: pseudarthrosis.[85]

By the 1960s, however, a half century of experience with spinal fusion and instrumentation suggested the concept of the "race between bony fusion and instrumentation failure." The improved surgical results that arose from the application of this important surgical concept provided support for the successful strategy of combining spinal instrumentation with meticulous fusion.

Spinal Fusion

The idea of using spinal fusion for stabilization is attributed to Albee[86] and Hibbs,[87] who, in 1911, independently reported its use (Fig. 1-14). Although these early operations were performed to prevent progressive spinal deformation in patients with Pott disease, the procedure was later adopted in the management of scoliosis and traumatic fracture. The method described by Hibbs, which was most frequently used, involved harvesting an autologous bone graft from the laminae and overlaying the bone dorsally. Despite later improvements in this technique, however, such as the use of autologous iliac crest graft, the rate of pseudarthrosis, particularly in scoliosis, remained unacceptably high.[88]

In the 1920s, Campbell[89] described trisacral fusion and iliac crest grafting. In 1922, Kleinberg[90] used xenograft for spinal fusion. Anterior lumbar interbody fusion (ALIF) was described by Burns[91] in 1933, and posterior lumbar interbody fusion (PLIF) was performed by Cloward[92] in 1940. In the late 1990s, transforaminal lumbar interbody fusion (TLIF) was described. In 1959, Boucher described a different spine fusion method.[93] In 1977, Callahan and colleagues[94] used bone for lateral cervical facet fusion.

Several ventral cervical fusion techniques were described in the 1950s. Robinson and Smith[95] described their technique in 1955, and Cloward[96] described his cervical fusion technique in 1958.

Spinal Instrumentation and Clinical Biomechanics

Like spinal fusion, internal fixation was first applied around 1900. These early constructs used tension-band fixators that were applied dorsally, primarily in cases of trauma. The limitation of the constructs, however, soon became apparent because the metals they contained were subject to the corrosive effects of electrolysis.

With the introduction of vitallium by Venable and Stuck[97] in the 1930s, a metal was found that was previously used successfully as a dental filling material and that had proven resistant to electrolysis (Fig. 1-15).[98] Further attempts at internal fixation during the 1930s and 1940s included fixed-moment arm cantilever constructs. These also failed to maintain alignment.[49,99,100]

F. W. Holdsworth

In the 1950s, the British orthopedic surgeon Sir Frank W. Holdsworth[101] performed perhaps the first large systematic study of the problem of internal fixation for the treatment of posttraumatic fracture. Although the constructs he used, which employed cantilever beams attached to the spinous processes, were traditional, Holdsworth's emphasis on patient selection