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Dr. Kathryn Ko completed her neurosurgery training at Mount Sinai Medical Center in New York City and earned an MFA from the Academy of Art University in representational painting. Dr. Ko is the host of Art on Call, a series that deals with the intersection of art and medicine. Dr. Ko regards art as a necessary continuation of her surgical practice. The operating theater is her studio; the treatment of the subject begins with the scalpel and ends with the brush.

Youmans & Winn Neurological Surgery

SEVENTH EDITION

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John A. Jane, Sr., MD, PhD, 1931-2015
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"Pigmaei gigantum humeris impositi plusquam ipsi gigantes vident."
(If I have seen further it is by standing on the shoulders of giants.) Issac Newton 1676[1]

"Though lives die, the life is not dead, and the memory of lives such as these will be reverently and forever shared not by a profession alone, not by a nation alone, but by the universal brotherhood of man." Andreas Vesalius 1543[2]

Dr. Jane was a giant whose shoulders were the foundation for advances in neurological surgery and for many generations of neurosurgeons. The department he fashioned at the University of Virginia was a fountainhead of originality, research, and advances in clinical care. Even more distinctively, he combined these efforts with a unique, compelling, and dominating focus on education. Dr. Jane united this scholarly emphasis with a warm and welcoming personality, an immense and eclectic intellect, and an ironic and unlimited sense of humor. Like Thomas Jefferson,[3] the founder of the University of Virginia, Dr. Jane sought to create an "academic village" that fostered curiosity, innovation, and intellectual rigor in a supportive milieu. With his personal involvement and encouragement, his students and trainees pursued careers and leadership positions in academic institutions throughout America and the world. These trainees and their descendants will affirm the validity of Vesalius's observation[2]: memories of John Jane's life and his "message"[4] will be shared with future generations of neurosurgeons.[5]

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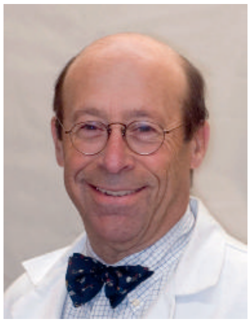

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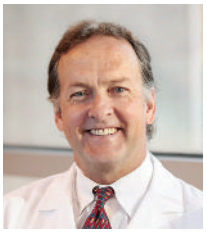

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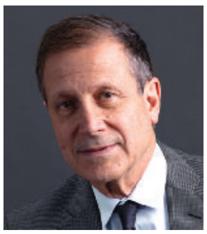

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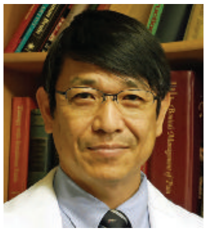

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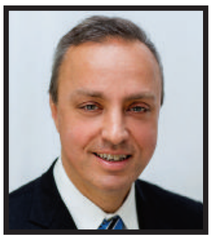

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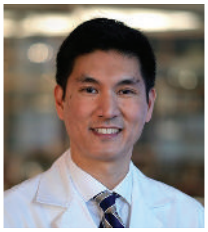

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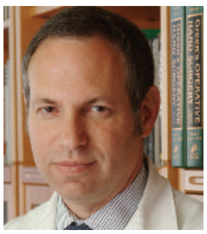

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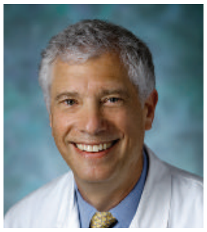

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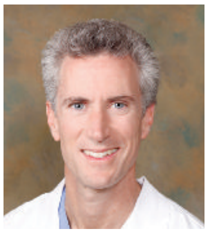

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382: Endovascular Management of Cerebral Vasospasm

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235: Surgical Management of the Pediatric Subaxial Cervical Spine

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99: Surgery for Tourette's Syndrome

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21: Positioning for Spinal Surgery

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239: Pediatric Vertebral Column and Spinal Cord Injuries

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361: Acute Surgical and Endovascular Management of Ischemic and Hemorrhagic Stroke

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93: Neurophysiologic Monitoring for Movement Disorders Surgery
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352: Traumatic and Penetrating Head Injuries

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305: Evaluation and Treatment of C2 (Axis) Fractures

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24: Brain Retraction
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260: Neuroelectronic Systems

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18: Surgical Planning: An Overview

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201: Ventricular Shunting Procedures

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307: Treatment of Cervicothoracic Junction Injuries

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66: Magnetoencephalography (MEG)/ Magnetic Source Imaging (MSI)

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169: Pharmacologic Treatment of Pain

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347: Mild Traumatic Brain Injury in Adults and Concussion in Sports

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393: Endovascular Flow Diversion for Intracranial Aneurysms

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16: Principles of Neurocritical Care

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71: Intracranial Monitoring: Subdural Strip and Grid Recording

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59: Animal Models of Epilepsy

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376: Genetics of Intracranial Aneurysms

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265: Fractionated Radiotherapy for Brain Tumors

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323: Nucleoplasty and Posterior Dynamic Stabilization Systems

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78: Radiosurgical Treatment for Epilepsy

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36: Postoperative Infections of the Head and Brain
57: Neurosurgical Epidemiology and Outcomes Assessment
126: Brain Tumor Outcome Studies: Design and Interpretation

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132: Surgical Navigation for Brain Tumors

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195: Endoscopic Treatment of Craniosynostosis

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388: Surgical Management of Middle Cerebral Artery Aneurysms

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204: Management and Prevention of Shunt Infections

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145: Primary Central Nervous System Lymphomas

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293: Assessment and Treatment of Primary Malignant Tumors of the Axial Skeleton

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390: Microsurgery of Basilar Apex Aneurysms

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388: Surgical Management of Middle Cerebral Artery Aneurysms

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339: Animal Models of Traumatic Brain Injury

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52: Physiology of the Cerebrospinal Fluid and Intracranial Pressure

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122: Endovascular Techniques for Tumor Embolization

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19: Surgical Simulation and Robotic Surgery
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27: Thorascopic Spine Surgery

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359: Cerebral Blood Flow and Metabolism and Cerebral Ischemia

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221: Vein of Galen Aneurysmal Malformation

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3: Surgical Anatomy of the Skull Base
4: Improving Patient Safety
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31: Shunting

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153: Ventricular Tumors

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358: Rehabilitation of Patients with Traumatic Brain Injury

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150: Pituitary Tumors: Functioning and Nonfunctioning
202: Neuroendoscopy

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124: Genetic Syndromes of Brain Tumors

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87: Surgical Management of Tremor

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308: Transient Quadriparesis and Athletic Injuries of the Cervical Spine

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133: Endoscopic Approaches to Brain Tumors

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105: Treatment of Intractable Vertigo

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211: Pediatric Supratentorial Hemispheric Tumors

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34: Medical and Surgical Management of Chronic Subdural Hematomas

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297: Assessment and Treatment of Rheumatoid Arthritis and Inflammatory Spinal Diseases

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280: Differential Diagnosis of Spinal Disease

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13: Physiologic Evaluation of the Brain with Magnetic Resonance Imaging

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230: Lipomyelomeningocele

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339: Animal Models of Traumatic Brain Injury

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182: Dorsal Root Entry Zone Lesions for Pain

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235: Surgical Management of the Pediatric Subaxial Cervical Spine

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191: Craniopagus Twins

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359: Cerebral Blood Flow and Metabolism and Cerebral Ischemia

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262: Radiobiology of Radiotherapy and Radiosurgery

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25: Visualization and Optics in Neurosurgery

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401: Epidemiology and Natural History of Intracranial Vascular Malformations

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141: Pineal Tumors

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241: Clinical Features and Management of Cerebral Palsy

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217: Neurocutaneous Tumor Syndromes

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374: Cerebral Venous and Sinus Thrombosis

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343: Therapeutic Strategies for Repair and Regeneration following Traumatic Brain Injury

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359: Cerebral Blood Flow and Metabolism and Cerebral Ischemia
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123: Brain Tumors during Pregnancy
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73: Surgical Techniques for Non–Temporal Lobe Epilepsy: Corpus Callosotomy, Multiple Subpial Transection, and Topectomy

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330: Posterior, Transforaminal, and Anterior Lumbar Interbody Fusion: Techniques and Instrumentation

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59: Animal Models of Epilepsy

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386: Microsurgery of Anterior Communicating Artery Aneurysms

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67: Single-Photon Emission Computed Tomography in Epilepsy Surgery Evaluation

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268: Radiosurgery for Benign Intracranial Tumors

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408: Treatment of Other Intracranial Dural Arteriovenous Fistulas

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353: Blast-Induced Neurotrauma

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323: Nucleoplasty and Posterior Dynamic Stabilization Systems

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263: Radiation Therapy Technique

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291: Evaluation and Treatment of Fungal and Tubercular Infections of the Spine

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74: Surgery for Extratemporal Lobe Epilepsy

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272: Radiosurgery for Benign Spine Tumors and Vascular Malformations
406: Surgical and Radiosurgical Management of Grade IV and V Arteriovenous Malformations

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364: Neurovascular Imaging
370: Extracranial Vertebral Artery Diseases

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72: Intracranial Monitoring: Stereo-Electroencephalography Recording

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246: Peripheral Neuropathies
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275: Spinal Biomechanics and Basics of Spinal Instrumentation

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376: Genetics of Intracranial Aneurysms

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327: Anterior Thoracic Instrumentation

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85: Patient Selection Criteria for Deep Brain Stimulation in Movement Disorders

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315: Evaluation and Treatment of Scheuermann's Kyphosis

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225: Inflicted Trauma (Child Abuse)

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163: Scalp Tumors

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166: Anatomy and Physiology of Pain

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365: The Natural History and Medical Management of Carotid Occlusive Disease

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26: Advantages and Limitations of Cranial Endoscopy

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104: Management of Spasticity by Central Nervous System Infusion Techniques

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330: Posterior, Transforaminal, and Anterior Lumbar Interbody Fusion: Techniques and Instrumentation

Erwin M.J. Cornips, MD
Pediatric Neurosurgeon
Department of Neurosurgery
Maastricht University Medical Center
Maastricht, The Netherlands
135: Intraoperative Magnetic Resonance Imaging

G. Rees Cosgrove, MD, FRCS(C)
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Brigham and Women's Hospital
Boston, Massachusetts
98: A History of Psychosurgery

William T. Couldwell, MD, PhD
Professor and Chair
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University of Utah School of Medicine
Salt Lake City, Utah
Overview and Controversies (General)
26: Advantages and Limitations of Cranial Endoscopy

Peter B. Crino, MD, PhD
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University of Maryland School of Medicine
Baltimore, Maryland
60: Malformations of Cortical Development

Andrew Crofton, BA
Department of Pathology and Human Anatomy
Neurosurgery Center for Research, Training, and Education
Loma Linda University School of Medicine
Loma Linda, California
7: Coagulation for the Neurosurgeon

D. Kacy Cullen, PhD
Assistant Professor of Neurosurgery
Perelman School of Medicine at the University of Pennsylvania
Philadelphia, Pennsylvania
337: Biomechanical Basis of Traumatic Brain Injury

Brian P. Curry, MD
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Walter Reed National Military Medical Center
Bethesda, Maryland
286: Evaluation and Treatment of Lumbar Disk Disease

Erasmo Barros da Silva, Jr., MD, MSc
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Instituto de Neurologia de Curitiba
Curitiba, Brazil
320: Bone Graft Options, Graft Substitutes, and Harvest Techniques

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Salt Lake City, Utah
37: Postoperative Infections of the Spine

Robert F. Dallapiazza, MD, PhD
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University of Virginia Medical Center
Charlottesville, Virginia
95: Transcranial Magnetic Resonance Imaging–Guided Focused Ultrasound Thalamotomy for Tremor

Richard Tyler Dalyai, MD
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Philadelphia, Pennsylvania
17: The Neurosurgical Intensive Care Unit and the Unique Role of the Neurosurgeon

Deepa Danan, MD, MBA
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University of Virginia School of Medicine
Charlottesville, Virginia
181: Diagnosis and Management of Painful Neuromas

David J. Daniels, MD, PhD
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Assistant Professor of Pharmacology
Mayo Clinic
Rochester, Minnesota
211: Pediatric Supratentorial Hemispheric Tumors

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Edmonton, Alberta, Canada
381: Medical Management of Cerebral Vasospasm

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University of Minnesota Medical Center
St. Paul, Minnesota
160: Juvenile Nasopharyngeal Angiofibromas

Matthew L. Dashnaw, MD, PharmD
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Rochester, New York
347: Mild Traumatic Brain Injury in Adults and Concussion in Sports

Carlos A. David, MD
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Tufts University School of Medicine
Boston, Massachusetts;
Director, Cerebrovascular and Skull Base Surgery
Department of Neurosurgery
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Burlington, Massachusetts
371: Microsurgical Management of Intracranial Occlusion Disease

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Macquarie University
New South Wales, Australia;
Faculty of Health Science
University of Adelaide
Adelaide, South Australia, Australia
355: Craniofacial Injuries

Arthur L. Day, MD
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University of Texas Medical School at Houston
Houston, Texas
384: Microsurgery of Paraclinoid Aneurysms

Rafael De la Garza-Ramos, MD
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Baltimore, Maryland
292: Assessment and Treatment of Benign Tumors of the Axial Skeleton

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David Geffen School of Medicine at UCLA
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Hospital do Coração
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14: Molecular Imaging of the Brain with Positron Emission Tomography

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293: Assessment and Treatment of Primary Malignant Tumors of the Axial Skeleton

Matthew Decker, MD, MPH
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Gainesville, Florida
279: Bone Metabolism and Osteoporosis

Oscar H. Del Brutto, MD
Director, The Atahualpa Project
Universidad Espiritu Santo School of Medicine
Guayaquil, Ecuador
42: Parasitic Infections

Bradley N. Delman, MD
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New York, New York
13: Physiologic Evaluation of the Brain with Magnetic Resonance Imaging

Mahlon R. DeLong, MD
W. P. Timmie Professor of Neurology
Emory University School of Medicine
Atlanta, Georgia
82: Rationale for Surgical Interventions in Movement Disorders

Franco DeMonte, MD, FRCSC, FACS
Mary Beth Pawelek Chair in Neurosurgery
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University of Texas MD Anderson Cancer Center
Houston, Texas
157: Neoplasms of the Paranasal Sinuses

Milind Deogaonkar, MBBS, MS, MCh
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Wexner Medical Center
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100: Surgery for Obsessive-Compulsive Disorder

Arati Desai, MD
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116: Angiogenesis and Brain Tumors: Scientific Principles, Current Therapy, and Future Directions

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383: Surgical Approaches to Intracranial Aneurysms

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194: Syndromic Craniosynostosis

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311: Classification of Spinal Deformity

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139: Unusual Gliomas

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112: Brain Tumor Stem Cells

Peter Dirks, MD, PhD, FRCSC
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Toronto, Ontario, Canada
208: Thalamic Tumors

Brian J. Dlouhy, MD
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University of Iowa Hospitals and Clinics
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233: Developmental Anomalies of the Craniovertebral Junction and Surgical Management
243: Selective Dorsal Rhizotomy for Spastic Cerebral Palsy

Amish H. Doshi, MD
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13: Physiologic Evaluation of the Brain with Magnetic Resonance Imaging

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Harold Hoffman Shoppers Drug Mart Chair, Pediatric Neurosurgery
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32: The Role of Third Ventriculostomy in Adults and Children: A Critical Review
203: Cerebrospinal Fluid Devices

Alexander Drofa, MD, FRCSC
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Sanford Medical Center Fargo;
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Fargo, North Dakota
393: Endovascular Flow Diversion for Intracranial Aneurysms

Andrew F. Ducruet, MD
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361: Acute Surgical and Endovascular Management of Ischemic and Hemorrhagic Stroke

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134: Awake Craniotomy and Intraoperative Mapping

Ann-Christine Duhaime, MD
Nicholas T. Zervas Professor of Neurosurgery
Harvard Medical School
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Boston, Massachusetts
225: Inflicted Trauma (Child Abuse)

Aaron S. Dumont, MD
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414: Microsurgical Treatment of Spinal Vascular Malformations

Gavin P. Dunn, MD, PhD
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Departments of Neurological Surgery and Pathology and Immunology
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Washington University School of Medicine in St. Louis
St. Louis, Missouri
143: Intracranial Ependymomas in Adults

Ian F. Dunn, MD
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Brigham and Women's Hospital
Boston, Massachusetts
143: Intracranial Ependymomas in Adults
150: Pituitary Tumors: Functioning and Nonfunctioning
202: Neuroendoscopy

Joshua R. Dusick, MD
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397: Revascularization Techniques for Complex Aneurysms and Skull Base Tumors

James H. Eberwine, PhD
Elmer Holmes Professor
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Philadelphia, Pennsylvania
44: Molecular Biology and Genomics: A Primer for Neurosurgeons

Paula Eboli, MD
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Los Angeles, California
369: Nonatherosclerotic Carotid Lesions

Gerald W. Eckardt, MD
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326: Posterior Subaxial and Cervicothoracic Instrumentation

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Lucile Packard Endowed Professor of Neurosurgery and Pediatrics
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212: Ependymomas

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203: Cerebrospinal Fluid Devices

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119: Local Therapies for Gliomas

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405: Microsurgery of Arteriovenous Malformations

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95: Transcranial Magnetic Resonance Imaging–Guided Focused Ultrasound Thalamotomy for Tremor

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Columbia University Medical Center
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21: Positioning for Spinal Surgery
Overview and Controversies (Vascular)
387: Microsurgery of Distal Anterior Cerebral Artery Aneurysms
403: Adjuvant Endovascular Management of Brain Arteriovenous Malformations

Tarek M.I. Elmadhoun, MD, PhD, FICS
Clinical Fellow
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245: Peripheral Nerve Examination, Evaluation, and Biopsy

Todd M. Emch, MD
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12: Radiology of the Spine

Samuel Emerson, MD, PhD
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47: Stem Cell Biology in the Central Nervous System

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113: Molecular Genetics and the Development of Targets for Glioma Therapy

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340: Genetics of Traumatic Brain Injury

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200: Experimental Hydrocephalus

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Van L. Weatherspoon, Jr., Eminent Distinguished Professor and Chair
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148: Meningeal Sarcomas and Hemangiopericytomas

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318: Assessment and Treatment of Proximal Junctional Kyphosis

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Dean, Medical School
University of Caxias do Sul
Caxias do Sul, Brazil
289: Treatment of Discitis and Epidural Abscess

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116: Angiogenesis and Brain Tumors: Scientific Principles, Current Therapy, and Future Directions

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Bernstein Focus Neurotechnology
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260: Neuroelectronic Systems

Christopher J. Farrell, MD
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36: Postoperative Infections of the Head and Brain

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Gerald and Tootsie Halbert Chair in Neural Repair and Regeneration, University Health Network;
Senior Scientist, Toronto Western Research Institute, University Health Network
Toronto, Ontario, Canada
Overview and Controversies (Spine)
277: Pathophysiology and Treatment of Spinal Cord Injury
295: Assessment and Treatment of Metastatic Spinal Lesions
303: Medical Management of Spinal Cord Injury

Valery Feigin, MD, PhD, FAAN
Professor of Epidemiology and Neurology
Auckland University of Technology;
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336: Epidemiology of Traumatic Brain Injury

Eva L. Feldman, MD, PhD
Russell N. DeJong Professor of Neurology
University of Michigan School of Medicine
Ann Arbor, Michigan
246: Peripheral Neuropathies

Neil Feldstein, MD, FACS
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229: Myelomeningocele and Myelocystocele

James E. Feng, BA
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311: Classification of Spinal Deformity

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Stanford, California
45: Optogenetics and CLARITY

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40: Meningitis and Encephalitis

Matheus Fernandes de Oliveira, MD, MSci
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Department of Neurosurgery
DFV Neuro
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280: Differential Diagnosis of Spinal Disease

Javier M. Figueroa, MD, PhD
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136: Low-Grade Gliomas: Astrocytomas, Oligodendrogliomas, and Mixed Gliomas

Juan J. Figueroa, MD
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Milwaukee, Wisconsin
42: Parasitic Infections

Aaron G. Filler, MD, PhD, JD, FRCS
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Overview and Controversies (PNS)
248: Imaging for Peripheral Nerve Disorders
250: Brachial Plexus Nerve Entrapments and Thoracic Outlet Syndromes
251: Piriformis Syndrome, Obturator Internus Syndrome, Pudendal Nerve Entrapment, and Other Pelvic Entrapments
257: Nerve Injuries of the Lower Extremity
259: Pain, Complications, and Iatrogenic Injury in Nerve Surgery

J. Max Findlay, MD, PhD
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University of Alberta
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381: Medical Management of Cerebral Vasospasm

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37: Postoperative Infections of the Spine

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186: Neuroembryology and Molecular Genetics of the Brain

Charles G. Fisher, MD, MHSc, FRCSC
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Vancouver Spine and Spinal Cord Institute
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293: Assessment and Treatment of Primary Malignant Tumors of the Axial Skeleton

Eugene S. Flamm, MD
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Leo Davidoff Department of Neurosurgery
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1: Historical Overview of Neurosurgery

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401: Epidemiology and Natural History of Intracranial Vascular Malformations

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and Alberta Children's Hospital Research Institute
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46: Neuroembryology

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Omaha, Nebraska
175: Neurosurgical Management of Intractable Pain

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Birmingham, Alabama
368: Blunt Cerebrovascular Injury

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216: Intracranial Germ Cell Tumors

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340: Genetics of Traumatic Brain Injury

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Overview and Controversies (Epilepsy)

Robert M. Friedlander, MD, MA
Walter E. Dandy Professor and Chairman
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Overview and Future Opportunities (Basic Science)

Donald E. Fry, MD
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43: Surgical Risk of Transmittable Disease

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273: Spinal Anatomy

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239: Pediatric Vertebral Column and Spinal Cord Injuries

Gregory N. Fuller, MD, PhD
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110: Brain Tumors: An Overview of Current Histopathologic and Genetic Classifications

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389: Microsurgery of Vertebral Artery and Posterior Inferior Cerebellar Artery Aneurysms

Adriana Galvan, PhD
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Emory University
Atlanta, Georgia
81: Anatomy and Synaptic Connectivity of the Basal Ganglia

Gurpreet S. Gandhoke, MD
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308: Transient Quadriparesis and Athletic Injuries of the Cervical Spine
332: Sacropelvic Fixation: Anterior and Posterior Options

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42: Parasitic Infections

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161: Tumors of the Orbit

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57: Neurosurgical Epidemiology and Outcomes Assessment

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400: Pathobiology of True Arteriovenous Malformations

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405: Microsurgery of Arteriovenous Malformations

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186: Neuroembryology and Molecular Genetics of the Brain

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103: Lesioning Surgery for Spasticity

Carter S. Gerard, MD
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73: Surgical Techniques for Non–Temporal Lobe Epilepsy: Corpus Callosotomy, Multiple Subpial Transection, and Topectomy

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13: Physiologic Evaluation of the Brain with Magnetic Resonance Imaging

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156: Glomus Tumors

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271: Radiosurgery for Malignant Spine Tumors

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271: Radiosurgery for Malignant Spine Tumors

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160: Juvenile Nasopharyngeal Angiofibromas
189: Arachnoid Cysts in Childhood
240: Pediatric Epilepsy Surgery

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309: Evaluation, Classification, and Treatment of Thoracolumbar Spine Injuries

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51: The Blood-Brain Barrier

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101: Surgery for Major Depressive Disorder

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78: Radiosurgical Treatment for Epilepsy

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120: Clinical Features: Neurology of Brain Tumor and Paraneoplastic Disorders

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6: Complication Avoidance in Neurosurgery

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49: Cellular Mechanisms of Brain Energy Metabolism

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176: Evidence-Based Neurostimulation for Pain
180: Dorsal Rhizotomy and Dorsal Root Ganglionectomy

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257: Nerve Injuries of the Lower Extremity

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324: Occiput, C1, and C2 Instrumentation

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188: Dandy-Walker Syndrome

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292: Assessment and Treatment of Benign Tumors of the Axial Skeleton

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229: Myelomeningocele and Myelocystocele
235: Surgical Management of the Pediatric Subaxial Cervical Spine

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20: Positioning for Cranial Surgery

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413: Endovascular Treatment of Spinal Vascular Malformations

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399: Traumatic Cerebral Aneurysms Secondary to Penetrating Intracranial Injuries

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397: Revascularization Techniques for Complex Aneurysms and Skull Base Tumors

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72: Intracranial Monitoring: Stereo-Electroencephalography Recording

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207: Optic Pathway Hypothalamic Gliomas

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338: Neuropathology of Traumatic Brain Injury

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1: Historical Overview of Neurosurgery Overview and Controversies (Pediatrics)
187: Encephaloceles, Meningoceles, and Cranial Dermal Sinus Tracts
191: Craniopagus Twins

C. Rory Goodwin, MD, PhD
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123: Brain Tumors during Pregnancy
155: Chordomas and Chondrosarcomas

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396: Infectious Aneurysms

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14: Molecular Imaging of the Brain with Positron Emission Tomography

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215: Brainstem Gliomas

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258: Benign and Malignant Tumors of the Peripheral Nerve

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28: Cranioplasty
348: Initial Resuscitation, Prehospital Care, and Emergency Room Care in Traumatic Brain Injury
357: Traumatic Cerebrospinal Fluid Fistulas

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56: Neuropsychological Testing

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177: Peripheral Nerve Stimulation for Neuropathic Pain

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25: Visualization and Optics in Neurosurgery
382: Endovascular Management of Cerebral Vasospasm

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7: Coagulation for the Neurosurgeon
51: The Blood-Brain Barrier
Overview and Controversies (Pediatrics)
206: General Approaches and Considerations for Pediatric Brain Tumors
214: Cerebellar Astrocytomas
224: Management of Head Injury: Special Considerations in Children

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139: Unusual Gliomas

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368: Blunt Cerebrovascular Injury

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296: Assessment and Treatment of Malignant Primary Spinal Tumors

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79: Electrical Stimulation for Epilepsy (VNS, DBS, and RNS)
88: Ablative Procedures for Parkinson's Disease

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408: Treatment of Other Intracranial Dural Arteriovenous Fistulas

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382: Endovascular Management of Cerebral Vasospasm

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Overview and Controversies (Oncology)
127: Neurocognition in Brain Tumor Patients

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234: Achondroplasia and Other Dwarfisms

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290: Treatment of Pyogenic Vertebral Spondylodiscitis

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139: Unusual Gliomas

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376: Genetics of Intracranial Aneurysms
410: Genetics of Cerebral Cavernous Malformations

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209: Choroid Plexus Tumors

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147: Meningiomas

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7: Coagulation for the Neurosurgeon
Overview and Future Opportunities (Basic Science)
69: Motor, Sensory, and Language Mapping and Monitoring for Cortical Resections

Stephen J. Haines, MD
Lyle A. French Chair
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38: The Use and Misuse of Antibiotics in Neurosurgery
57: Neurosurgical Epidemiology and Outcomes Assessment

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307: Treatment of Cervicothoracic Junction Injuries

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214: Cerebellar Astrocytomas

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68: Wada Testing

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84: Clinical Overview of Movement Disorders

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236: Intraspinal Tumors in Children

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365: The Natural History and Medical Management of Carotid Occlusive Disease

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87: Surgical Management of Tremor

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368: Blunt Cerebrovascular Injury

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309: Evaluation, Classification, and Treatment of Thoracolumbar Spine Injuries

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329: Posterior Thoracic and Lumbar Instrumentation with Historical Overview
335: Minimally Invasive Techniques for Degenerative Disease

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131: Risks of Intrinsic Brain Tumor Surgery and Avoidance of Complications

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377: The Natural History of Cerebral Aneurysms

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99: Surgery for Tourette's Syndrome

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152: Epidermoid, Dermoid, and Neurenteric Cysts

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277: Pathophysiology and Treatment of Spinal Cord Injury
341: Neurochemical Pathomechanisms in Traumatic Brain Injury

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Overview and Controversies (Pediatrics)

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232: Tethered Spinal Cord: Fatty Filum Terminale, Meningocele Manqué, and Dermal Sinus Tracts

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117: Delivery of Therapy to Brain Tumors: Problems and Potentials

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334: Evaluation, Indications, and Techniques of Revision Spine Surgery

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111: Brain Tumor Immunology and Immunotherapy

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310: Evaluation and Treatment of Osteoporotic Fractures (Cement Augmentation)

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166: Anatomy and Physiology of Pain

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276: Disk Degeneration and Regeneration

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405: Microsurgery of Arteriovenous Malformations

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48: Neurons and Neuroglia

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140: Primitive Neuroectodermal Tumors

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60: Malformations of Cortical Development
71: Intracranial Monitoring: Subdural Strip and Grid Recording

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267: Radiosurgery for Malignant Intracranial Tumors

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251: Piriformis Syndrome, Obturator Internus Syndrome, Pudendal Nerve Entrapment, and Other Pelvic Entrapments

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61: Diagnosis and Classification of Seizures and Epilepsy

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362: Intraoperative Cerebral Protection

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113: Molecular Genetics and the Development of Targets for Glioma Therapy

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24: Brain Retraction

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Overview and Controversies (Vascular)

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97: Thalamotomy for Focal Hand Dystonia

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47: Stem Cell Biology in the Central Nervous System

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275: Spinal Biomechanics and Basics of Spinal Instrumentation

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70: Investigation of Human Cognition in Epilepsy Surgery Patients

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45: Optogenetics and CLARITY

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386: Microsurgery of Anterior Communicating Artery Aneurysms

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15: Intracranial Pressure Monitoring
Overview and Controversies (Trauma)
351: Surgical Management of Traumatic Brain Injury

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121: Radiologic Features of Central Nervous System Tumors

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348: Initial Resuscitation, Prehospital Care, and Emergency Room Care in Traumatic Brain Injury

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38: The Use and Misuse of Antibiotics in Neurosurgery

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281: Nonsurgical and Postsurgical Management of Low Back Pain

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34: Medical and Surgical Management of Chronic Subdural Hematomas
Overview and Controversies (Trauma)

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139: Unusual Gliomas

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237: Introduction to Spinal Deformities in Children
300: Adult Tethered Cord Syndrome
301: Adult Syringomyelia

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54: Extracellular Fluid Movement and Clearance in the Brain: The Glymphatic Pathway

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167: Molecular Basis of Nociception

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85: Patient Selection Criteria for Deep Brain Stimulation in Movement Disorders

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230: Lipomyelomeningocele

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272: Radiosurgery for Benign Spine Tumors and Vascular Malformations

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279: Bone Metabolism and Osteoporosis

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236: Intraspinal Tumors in Children

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361: Acute Surgical and Endovascular Management of Ischemic and Hemorrhagic Stroke

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199: Cerebrospinal Fluid Disorders and Transitional Neurosurgery

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216: Intracranial Germ Cell Tumors

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234: Achondroplasia and Other Dwarfisms

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17: The Neurosurgical Intensive Care Unit and the Unique Role of the Neurosurgeon

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197: Hydrocephalus in Children: Etiology and Overall Management

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193: Nonsyndromic Craniosynostosis: Introduction and Single-Suture Synostosis

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193: Nonsyndromic Craniosynostosis: Introduction and Single-Suture Synostosis

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51: The Blood-Brain Barrier
58: Electrophysiologic Properties of the Mammalian Central Nervous System

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361: Acute Surgical and Endovascular Management of Ischemic and Hemorrhagic Stroke

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208: Thalamic Tumors

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80: Epilepsy Surgery: Outcome and Complications

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83: Neuropathology of Movement Disorders

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107: Deep Brain Stimulation for Obesity

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195: Endoscopic Treatment of Craniosynostosis

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125: Principles of Chemotherapy

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29: Production and Flow of Cerebrospinal Fluid

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91: Deep Brain Stimulation: Mechanisms of Action

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297: Assessment and Treatment of Rheumatoid Arthritis and Inflammatory Spinal Diseases

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288: Evaluation and Treatment of Degenerative Lumbar Spondylolisthesis
313: Evaluation and Treatment of Cervical Deformity

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222: Pediatric Cerebral Aneurysms
409: Natural History of Cavernous Malformations

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331: Image-Guided Spinal Navigation: Principles and Clinical Applications

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11: Computed Tomography and Magnetic Resonance Imaging of the Brain

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314: Evaluation and Treatment of Adolescent Idiopathic Scoliosis

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276: Disk Degeneration and Regeneration

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308: Transient Quadriparesis and Athletic Injuries of the Cervical Spine
332: Sacropelvic Fixation: Anterior and Posterior Options

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94: Emerging and Experimental Neurosurgical Treatments for Parkinson's Disease

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334: Evaluation, Indications, and Techniques of Revision Spine Surgery

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319: Treatment of High-Grade Spondylolisthesis

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70: Investigation of Human Cognition in Epilepsy Surgery Patients

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238: Thoracolumbar Spinal Disorders in Pediatric Patients
317: Evaluation and Treatment of Adult Scoliosis and Sagittal Plane Deformity

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394: Endovascular Hunterian Ligation
404: Endovascular Management of Arteriovenous Malformations for Cure

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269: Radiosurgery of Intracranial Vascular Malformations

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373: Adult Moyamoya Disease

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270: Radiosurgery for Functional Disorders

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378: Pathobiology of Intracranial Aneurysms

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151: Craniopharyngiomas in Adults
210: Pediatric Craniopharyngiomas

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412: Classification of Spinal Arteriovenous Lesions

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330: Posterior, Transforaminal, and Anterior Lumbar Interbody Fusion: Techniques and Instrumentation

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400: Pathobiology of True Arteriovenous Malformations

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359: Cerebral Blood Flow and Metabolism and Cerebral Ischemia

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165: Sarcoidosis, Tuberculosis, and Demyelinating Disease

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Director, Peripheral Nerve Center
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3: Surgical Anatomy of the Skull Base
Overview and Future Opportunities (Basic Science)
50: Cellular and Molecular Responses in the Peripheral and Central Nervous Systems: Similarities and Differences

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283: Evaluation and Treatment of Cervical Disk Herniations

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366: Carotid Endarterectomy

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172: Percutaneous Procedures for Trigeminal Neuralgia

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306: Evaluation, Classification, and Treatment of Cervical (C3-C7) Injuries

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240: Pediatric Epilepsy Surgery

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34: Medical and Surgical Management of Chronic Subdural Hematomas
Overview and Controversies (Trauma)

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402: Therapeutic Decision Making in the Management of Arteriovenous Malformations of the Brain

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123: Brain Tumors during Pregnancy

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Overview and Controversies (Functional)
96: Selective Peripheral Denervation for Cervical Dystonia

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367: Carotid Artery Angioplasty and Stenting

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108: Deep Brain Stimulation for Alzheimer's Disease

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12: Radiology of the Spine

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135: Intraoperative Magnetic Resonance Imaging

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99: Surgery for Tourette's Syndrome

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201: Ventricular Shunting Procedures

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291: Evaluation and Treatment of Fungal and Tubercular Infections of the Spine

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Overview and Controversies (Spine)
280: Differential Diagnosis of Spinal Disease
312: Evaluation of Spinal Alignment

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261: General and Historical Considerations of Radiotherapy and Radiosurgery

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327: Anterior Thoracic Instrumentation

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313: Evaluation and Treatment of Cervical Deformity

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266: Fractionated Radiotherapy for Spine Tumors

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148: Meningeal Sarcomas and Hemangiopericytomas

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311: Classification of Spinal Deformity

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5: Neuroanesthesia: Preoperative Evaluation

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154: Overview of Skull Base Tumors

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146: Metastatic Brain Tumors

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398: Multimodality Treatments of Cerebrovascular Disorders
407: Carotid-Cavernous Fistulas

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89: Deep Brain Stimulation for Parkinson's Disease

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4: Improving Patient Safety

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315: Evaluation and Treatment of Scheuermann's Kyphosis

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394: Endovascular Hunterian Ligation

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115: Malignant Glioma Microenvironment

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150: Pituitary Tumors: Functioning and Nonfunctioning

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395: Microsurgical Management of Giant Intracranial Aneurysms

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79: Electrical Stimulation for Epilepsy (VNS, DBS, and RNS)

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88: Ablative Procedures for Parkinson's Disease

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350: Physiologic Monitoring for Traumatic Brain Injury
379: Surgical Decision Making for the Treatment of Intracranial Aneurysms

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264: Radiosurgery Technique

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339: Animal Models of Traumatic Brain Injury

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360: Acute Medical Management of Ischemic and Hemorrhagic Stroke
372: Endovascular Management of Intracranial Occlusion Disease

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Director, Clinical Spine Research
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314: Evaluation and Treatment of Adolescent Idiopathic Scoliosis

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109: Neuroprosthetics

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178: Spinal Cord Stimulation

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Department of Radiology
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Adjunct Assistant Professor
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392: Endovascular Approaches to Wide-Necked Intracranial Aneurysms

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282: Complication Avoidance in Spine Surgery

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102: Surgery for Anorexia Nervosa

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155: Chordomas and Chondrosarcomas

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128: Frame and Frameless Stereotactic Brain Biopsy

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364: Neurovascular Imaging

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200: Experimental Hydrocephalus
227: Neonatal Brain Injury

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193: Nonsyndromic Craniosynostosis: Introduction and Single-Suture Synostosis

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356: Prognosis after Traumatic Brain Injury

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171: Trigeminal Neuralgia: Diagnosis and Nonoperative Management
261: General and Historical Considerations of Radiotherapy and Radiosurgery

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101: Surgery for Major Depressive Disorder
108: Deep Brain Stimulation for Alzheimer's Disease

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231: Split Spinal Cord

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26: Advantages and Limitations of Cranial Endoscopy

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374: Cerebral Venous and Sinus Thrombosis

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102: Surgery for Anorexia Nervosa

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14: Molecular Imaging of the Brain with Positron Emission Tomography

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214: Cerebellar Astrocytomas

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365: The Natural History and Medical Management of Carotid Occlusive Disease

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Overview and Controversies (Oncology)
119: Local Therapies for Gliomas
144: Hemangioblastomas

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410: Genetics of Cerebral Cavernous Malformations

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Overview and Controversies (Functional)
101: Surgery for Major Depressive Disorder
108: Deep Brain Stimulation for Alzheimer's Disease

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199: Cerebrospinal Fluid Disorders and Transitional Neurosurgery

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41: Acquired Immunodeficiency Syndrome

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287: Cervical, Thoracic, and Lumbar Stenosis

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262: Radiobiology of Radiotherapy and Radiosurgery

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357: Traumatic Cerebrospinal Fluid Fistulas

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Overview and Controversies (Trauma)
336: Epidemiology of Traumatic Brain Injury
356: Prognosis after Traumatic Brain Injury

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33: Pathophysiology of Chronic Subdural Hematomas
380: Perioperative Management of Subarachnoid Hemorrhage

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205: Genetics of Pediatric Brain Tumors

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372: Endovascular Management of Intracranial Occlusion Disease

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317: Evaluation and Treatment of Adult Scoliosis and Sagittal Plane Deformity

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Overview and Future Opportunities (Basic Science)
49: Cellular Mechanisms of Brain Energy Metabolism

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142: Medulloblastomas in Adults
213: Medulloblastomas

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223: Pediatric Arteriovenous Malformations

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153: Ventricular Tumors

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79: Electrical Stimulation for Epilepsy (VNS, DBS, and RNS)

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Overview and Controversies (PNS)
252: Techniques in Nerve Reconstruction and Repair
253: Nerve Transfers
255: Early Management of Brachial Plexus Injuries

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207: Optic Pathway Hypothalamic Gliomas

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188: Dandy-Walker Syndrome

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22: Positioning for Peripheral Nerve Surgery
259: Pain, Complications, and Iatrogenic Injury in Nerve Surgery

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340: Genetics of Traumatic Brain Injury

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161: Tumors of the Orbit

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162: Skull Tumors

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76: Selective Approaches to the Mesial Temporal Lobe

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58: Electrophysiologic Properties of the Mammalian Central Nervous System
76: Selective Approaches to the Mesial Temporal Lobe

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233: Developmental Anomalies of the Craniovertebral Junction and Surgical Management

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398: Multimodality Treatments of Cerebrovascular Disorders

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396: Infectious Aneurysms

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63: Continuous Electroencephalography in Neurological-Neurosurgical Intensive Care: Applications and Value

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404: Endovascular Management of Arteriovenous Malformations for Cure

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245: Peripheral Nerve Examination, Evaluation, and Biopsy

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320: Bone Graft Options, Graft Substitutes, and Harvest Techniques

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57: Neurosurgical Epidemiology and Outcomes Assessment

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298: Assessment and Treatment of Ankylosing Spondylitis and Diffuse Idiopathic Skeletal Hyperostosis

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174: Microvascular Decompression for Trigeminal Neuralgia

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164: Pseudotumor Cerebri

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226: Growing Skull Fractures

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65: Neuroradiologic Evaluation for Epilepsy Surgery: Magnetic Resonance Imaging

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Overview and Controversies (General)

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132: Surgical Navigation for Brain Tumors

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44: Molecular Biology and Genomics: A Primer for Neurosurgeons

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284: Evaluation and Treatment of Ossification of the Posterior Longitudinal Ligament

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360: Acute Medical Management of Ischemic and Hemorrhagic Stroke
372: Endovascular Management of Intracranial Occlusion Disease

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12: Radiology of the Spine

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61: Diagnosis and Classification of Seizures and Epilepsy

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367: Carotid Artery Angioplasty and Stenting

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363: Diagnostic and Therapeutic Neurosonology

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392: Endovascular Approaches to Wide-Necked Intracranial Aneurysms

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407: Carotid-Cavernous Fistulas

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375: Nonlesional Spontaneous Intracerebral Hemorrhage

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402: Therapeutic Decision Making in the Management of Arteriovenous Malformations of the Brain

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215: Brainstem Gliomas

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196: Nonsynostotic Plagiocephaly

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273: Spinal Anatomy

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346: Clinical Pathophysiology of Traumatic Brain Injury

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340: Genetics of Traumatic Brain Injury
345: Advanced Structural and Functional Imaging of Traumatic Brain Injury

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121: Radiologic Features of Central Nervous System Tumors

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140: Primitive Neuroectodermal Tumors

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328: Anterior and Lateral Lumbar Instrumentation

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2: Surgical Anatomy of the Brain

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199: Cerebrospinal Fluid Disorders and Transitional Neurosurgery

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269: Radiosurgery of Intracranial Vascular Malformations

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64: Evaluation of Patients for Epilepsy Surgery

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222: Pediatric Cerebral Aneurysms

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97: Thalamotomy for Focal Hand Dystonia

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277: Pathophysiology and Treatment of Spinal Cord Injury

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295: Assessment and Treatment of Metastatic Spinal Lesions

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335: Minimally Invasive Techniques for Degenerative Disease

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111: Brain Tumor Immunology and Immunotherapy

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181: Diagnosis and Management of Painful Neuromas

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412: Classification of Spinal Arteriovenous Lesions

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150: Pituitary Tumors: Functioning and Nonfunctioning

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363: Diagnostic and Therapeutic Neurosonology

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177: Peripheral Nerve Stimulation for Neuropathic Pain

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41: Acquired Immunodeficiency Syndrome

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221: Vein of Galen Aneurysmal Malformation

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7: Coagulation for the Neurosurgeon
51: The Blood-Brain Barrier

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175: Neurosurgical Management of Intractable Pain

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170: Evidence-Based Approach to the Treatment of Facial Pain

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247: Monitoring of Neural Function: Electromyography, Nerve Conduction, and Evoked Potentials

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190: Chiari Malformations

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97: Thalamotomy for Focal Hand Dystonia

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389: Microsurgery of Vertebral Artery and Posterior Inferior Cerebellar Artery Aneurysms

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107: Deep Brain Stimulation for Obesity

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302: Assessment and Classification of Spinal Instability
332: Sacropelvic Fixation: Anterior and Posterior Options
342: Traumatic Brain Injury: Proteomic Biomarkers

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84: Clinical Overview of Movement Disorders

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53: Cerebral Edema
144: Hemangioblastomas
414: Microsurgical Treatment of Spinal Vascular Malformations

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123: Brain Tumors during Pregnancy
128: Frame and Frameless Stereotactic Brain Biopsy

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170: Evidence-Based Approach to the Treatment of Facial Pain

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163: Scalp Tumors

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412: Classification of Spinal Arteriovenous Lesions

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159: Trigeminal Schwannomas

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Overview and Controversies (Epilepsy)
62: Antiepileptic Medications: Principles of Clinical Use

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383: Surgical Approaches to Intracranial Aneurysms

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160: Juvenile Nasopharyngeal Angiofibromas
189: Arachnoid Cysts in Childhood

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345: Advanced Structural and Functional Imaging of Traumatic Brain Injury

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357: Traumatic Cerebrospinal Fluid Fistulas

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159: Trigeminal Schwannomas

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116: Angiogenesis and Brain Tumors: Scientific Principles, Current Therapy, and Future Directions

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342: Traumatic Brain Injury: Proteomic Biomarkers

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89: Deep Brain Stimulation for Parkinson's Disease

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329: Posterior Thoracic and Lumbar Instrumentation with Historical Overview

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221: Vein of Galen Aneurysmal Malformation

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219: Skull Lesions in Children: Dermoids, Langerhans Cell Histiocytosis, Fibrous Dysplasia, and Lipomas

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391: Endovascular Approaches to Narrow-Necked Intracranial Aneurysms

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288: Evaluation and Treatment of Degenerative Lumbar Spondylolisthesis
313: Evaluation and Treatment of Cervical Deformity

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228: Birth Brachial Plexus Injury
243: Selective Dorsal Rhizotomy for Spastic Cerebral Palsy

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130: Basic Principles of Skull Base Surgery
149: Vestibular Schwannomas

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242: Intrathecal Baclofen Therapy for Cerebral Palsy

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146: Metastatic Brain Tumors

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413: Endovascular Treatment of Spinal Vascular Malformations

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347: Mild Traumatic Brain Injury in Adults and Concussion in Sports

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105: Treatment of Intractable Vertigo

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158: Esthesioneuroblastomas

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54: Extracellular Fluid Movement and Clearance in the Brain: The Glymphatic Pathway
104: Management of Spasticity by Central Nervous System Infusion Techniques

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218: Pediatric Intraventricular and Periventricular Tumors

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86: Functional Imaging in Movement Disorders

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23: Incisions and Closures
163: Scalp Tumors
193: Nonsyndromic Craniosynostosis: Introduction and Single-Suture Synostosis

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139: Unusual Gliomas

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80: Epilepsy Surgery: Outcome and Complications

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269: Radiosurgery of Intracranial Vascular Malformations
398: Multimodality Treatments of Cerebrovascular Disorders

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6: Complication Avoidance in Neurosurgery
149: Vestibular Schwannomas

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192: Molecular Genetics and Priniciples of Craniosynostosis

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212: Ependymomas

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137: Malignant Gliomas: Anaplastic Astrocytoma, Glioblastoma, Gliosarcoma, and Anaplastic Oligodendroglioma

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374: Cerebral Venous and Sinus Thrombosis

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231: Split Spinal Cord

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183: Percutaneous Cordotomy and Trigeminal Tractotomy-Nucleotomy

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109: Neuroprosthetics
257: Nerve Injuries of the Lower Extremity

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122: Endovascular Techniques for Tumor Embolization

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128: Frame and Frameless Stereotactic Brain Biopsy
157: Neoplasms of the Paranasal Sinuses

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78: Radiosurgical Treatment for Epilepsy
Overview and Controversies (Radiation)
268: Radiosurgery for Benign Intracranial Tumors

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Adelaide, Australia
355: Craniofacial Injuries

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Edegem, Belgium
336: Epidemiology of Traumatic Brain Injury

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194: Syndromic Craniosynostosis

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Madison, Wisconsin
Overview and Controversies (Spine)
307: Treatment of Cervicothoracic Junction Injuries

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State University of New York University at Buffalo
Women and Children's Hospital of Buffalo
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206: General Approaches and Considerations for Pediatric Brain Tumors

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100: Surgery for Obsessive-Compulsive Disorder

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294: Assessment and Treatment of Benign Intradural Extramedullary Tumors

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2: Surgical Anatomy of the Brain

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Professor of Pathology
Department of Fonaments Clínics
Faculty of Medicine, University of Barcelona;
Chief of Section
Department of Pathology: Neuropathology
Hospital Clinic of Barcelona
Barcelona, Spain
110: Brain Tumors: An Overview of Current Histopathologic and Genetic Classifications

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163: Scalp Tumors

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343: Therapeutic Strategies for Repair and Regeneration following Traumatic Brain Injury

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114: Genetic Origins of Brain Tumors

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114: Genetic Origins of Brain Tumors

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122: Endovascular Techniques for Tumor Embolization

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137: Malignant Gliomas: Anaplastic Astrocytoma, Glioblastoma, Gliosarcoma, and Anaplastic Oligodendroglioma

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382: Endovascular Management of Cerebral Vasospasm

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32: The Role of Third Ventriculostomy in Adults and Children: A Critical Review
204: Management and Prevention of Shunt Infections

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415: Pregnancy and the Vascular Lesion

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74: Surgery for Extratemporal Lobe Epilepsy

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349: Critical Care Management of Traumatic Brain Injury

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25: Visualization and Optics in Neurosurgery

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Overview and Controversies (Pediatrics)
198: Infantile Posthemorrhagic Hydrocephalus

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260: Neuroelectronic Systems

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268: Radiosurgery for Benign Intracranial Tumors

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395: Microsurgical Management of Giant Intracranial Aneurysms

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300: Adult Tethered Cord Syndrome
301: Adult Syringomyelia

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109: Neuroprosthetics

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4: Improving Patient Safety

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16: Principles of Neurocritical Care

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175: Neurosurgical Management of Intractable Pain

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168: Approach to the Patient with Chronic Pain

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Overview and Controversies (Trauma)
350: Physiologic Monitoring for Traumatic Brain Injury

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17: The Neurosurgical Intensive Care Unit and the Unique Role of the Neurosurgeon

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286: Evaluation and Treatment of Lumbar Disk Disease
298: Assessment and Treatment of Ankylosing Spondylitis and Diffuse Idiopathic Skeletal Hyperostosis

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10: Neurourology

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8: Neuro-ophthalmology

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259: Pain, Complications, and Iatrogenic Injury in Nerve Surgery

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411: Microsurgery for Cerebral Cavernous Malformations

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142: Medulloblastomas in Adults
Overview and Controversies (Pediatrics)
213: Medulloblastomas

Mina G. Safain, MD
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237: Introduction to Spinal Deformities in Children

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178: Spinal Cord Stimulation

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262: Radiobiology of Radiotherapy and Radiosurgery

Rajiv Saigal, MD, PhD
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50: Cellular and Molecular Responses in the Peripheral and Central Nervous Systems: Similarities and Differences
315: Evaluation and Treatment of Scheuermann's Kyphosis

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267: Radiosurgery for Malignant Intracranial Tumors

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238: Thoracolumbar Spinal Disorders in Pediatric Patients
300: Adult Tethered Cord Syndrome
301: Adult Syringomyelia

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108: Deep Brain Stimulation for Alzheimer's Disease

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136: Low-Grade Gliomas: Astrocytomas, Oligodendrogliomas, and Mixed Gliomas

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391: Endovascular Approaches to Narrow-Necked Intracranial Aneurysms

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187: Encephaloceles, Meningoceles, and Cranial Dermal Sinus Tracts

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282: Complication Avoidance in Spine Surgery

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34: Medical and Surgical Management of Chronic Subdural Hematomas

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Overview and Controversies (Spine)
299: Adult Congenital Malformations of the Thoracic and Lumbar Spine

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378: Pathobiology of Intracranial Aneurysms

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Overview and Controversies (Spine)
285: Evaluation and Treatment of Thoracic Disk Herniation
287: Cervical, Thoracic, and Lumbar Stenosis
289: Treatment of Discitis and Epidural Abscess
320: Bone Graft Options, Graft Substitutes, and Harvest Techniques
322: Lumbar Arthroplasty

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19: Surgical Simulation and Robotic Surgery

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46: Neuroembryology

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24: Brain Retraction

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Overview and Controversies (Oncology)
146: Metastatic Brain Tumors
152: Epidermoid, Dermoid, and Neurenteric Cysts

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318: Assessment and Treatment of Proximal Junctional Kyphosis

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35: Basic Science of Central Nervous System Infections
39: Brain Abscess

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55: Altered Consciousness

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264: Radiosurgery Technique

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27: Thorascopic Spine Surgery
37: Postoperative Infections of the Spine
274: Assessment of Spinal Imaging

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374: Cerebral Venous and Sinus Thrombosis

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77: Hemispheric Disconnection Procedures

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311: Classification of Spinal Deformity

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155: Chordomas and Chondrosarcomas

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220: Moyamoya Disease

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383: Surgical Approaches to Intracranial Aneurysms

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Overview and Controversies (General)

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231: Split Spinal Cord

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294: Assessment and Treatment of Benign Intradural Extramedullary Tumors

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19: Surgical Simulation and Robotic Surgery
362: Intraoperative Cerebral Protection

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69: Motor, Sensory, and Language Mapping and Monitoring for Cortical Resections

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267: Radiosurgery for Malignant Intracranial Tumors

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238: Thoracolumbar Spinal Disorders in Pediatric Patients
Overview and Controversies (Spine)
317: Evaluation and Treatment of Adult Scoliosis and Sagittal Plane Deformity
319: Treatment of High-Grade Spondylolisthesis

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305: Evaluation and Treatment of C2 (Axis) Fractures

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274: Assessment of Spinal Imaging

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299: Adult Congenital Malformations of the Thoracic and Lumbar Spine

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346: Clinical Pathophysiology of Traumatic Brain Injury

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244: Pathophysiology of Surgical Nerve Disorders

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122: Endovascular Techniques for Tumor Embolization

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396: Infectious Aneurysms

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173: Stereotactic Radiosurgery for Trigeminal Neuralgia
264: Radiosurgery Technique

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158: Esthesioneuroblastomas

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219: Skull Lesions in Children: Dermoids, Langerhans Cell Histiocytosis, Fibrous Dysplasia, and Lipomas

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396: Infectious Aneurysms

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93: Neurophysiologic Monitoring for Movement Disorders Surgery
106: Motor Cortex Stimulation for Pain and Movement Disorders

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256: Secondary Procedures for Brachial Plexus Injuries

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343: Therapeutic Strategies for Repair and Regeneration following Traumatic Brain Injury

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367: Carotid Artery Angioplasty and Stenting

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84: Clinical Overview of Movement Disorders

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349: Critical Care Management of Traumatic Brain Injury

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103: Lesioning Surgery for Spasticity
182: Dorsal Root Entry Zone Lesions for Pain

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16: Principles of Neurocritical Care

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303: Medical Management of Spinal Cord Injury

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32: The Role of Third Ventriculostomy in Adults and Children: A Critical Review

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Overview and Controversies (Spine)
317: Evaluation and Treatment of Adult Scoliosis and Sagittal Plane Deformity
319: Treatment of High-Grade Spondylolisthesis

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150: Pituitary Tumors: Functioning and Nonfunctioning

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81: Anatomy and Synaptic Connectivity of the Basal Ganglia

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403: Adjuvant Endovascular Management of Brain Arteriovenous Malformations

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141: Pineal Tumors

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325: Anterior Cervical Instrumentation

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184: Neuroanesthesia in Children

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304: Classification and Treatment of O-C1 Craniocervical Injuries
325: Anterior Cervical Instrumentation

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218: Pediatric Intraventricular and Periventricular Tumors

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276: Disk Degeneration and Regeneration

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268: Radiosurgery for Benign Intracranial Tumors

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380: Perioperative Management of Subarachnoid Hemorrhage

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Overview and Controversies (Epilepsy)
75: Standard Temporal Lobectomy

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222: Pediatric Cerebral Aneurysms
Overview and Controversies (Vascular)
411: Microsurgery for Cerebral Cavernous Malformations

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256: Secondary Procedures for Brachial Plexus Injuries

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162: Skull Tumors

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374: Cerebral Venous and Sinus Thrombosis

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89: Deep Brain Stimulation for Parkinson's Disease

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161: Tumors of the Orbit

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30: Clinical Evaluation of Adult Hydrocephalus

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406: Surgical and Radiosurgical Management of Grade IV and V Arteriovenous Malformations

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299: Adult Congenital Malformations of the Thoracic and Lumbar Spine

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352: Traumatic and Penetrating Head Injuries

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88: Ablative Procedures for Parkinson's Disease

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356: Prognosis after Traumatic Brain Injury

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366: Carotid Endarterectomy

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90: Deep Brain Stimulation for Dystonia

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20: Positioning for Cranial Surgery

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124: Genetic Syndromes of Brain Tumors

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133: Endoscopic Approaches to Brain Tumors

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262: Radiobiology of Radiotherapy and Radiosurgery

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146: Metastatic Brain Tumors

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254: Management of Acute Peripheral Nerve Injuries

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102: Surgery for Anorexia Nervosa

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85: Patient Selection Criteria for Deep Brain Stimulation in Movement Disorders

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Overview and Controversies (Functional)
97: Thalamotomy for Focal Hand Dystonia

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373: Adult Moyamoya Disease

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386: Microsurgery of Anterior Communicating Artery Aneurysms

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267: Radiosurgery for Malignant Intracranial Tumors

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Overview and Controversies (Epilepsy)

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122: Endovascular Techniques for Tumor Embolization

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Winston-Salem, North Carolina
84: Clinical Overview of Movement Disorders

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134: Awake Craniotomy and Intraoperative Mapping

Claudio E. Tatsui, MD
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294: Assessment and Treatment of Benign Intradural Extramedullary Tumors

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404: Endovascular Management of Arteriovenous Malformations for Cure

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205: Genetics of Pediatric Brain Tumors

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105: Treatment of Intractable Vertigo

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332: Sacropelvic Fixation: Anterior and Posterior Options

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133: Endoscopic Approaches to Brain Tumors

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35: Basic Science of Central Nervous System Infections

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288: Evaluation and Treatment of Degenerative Lumbar Spondylolisthesis

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336: Epidemiology of Traumatic Brain Injury

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304: Classification and Treatment of O-C1 Craniocervical Injuries
325: Anterior Cervical Instrumentation

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415: Pregnancy and the Vascular Lesion

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241: Clinical Features and Management of Cerebral Palsy

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354: Indications and Techniques for Cranial Decompression after Traumatic Brain Injury

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107: Deep Brain Stimulation for Obesity

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75: Standard Temporal Lobectomy

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393: Endovascular Flow Diversion for Intracranial Aneurysms

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249: Distal Entrapment Syndromes: Carpal Tunnel, Cubital Tunnel, Peroneal, and Tarsal Tunnel

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358: Rehabilitation of Patients with Traumatic Brain Injury

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48: Neurons and Neuroglia

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190: Chiari Malformations
232: Tethered Spinal Cord: Fatty Filum Terminale, Meningocele Manqué, and Dermal Sinus Tracts

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39: Brain Abscess

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Overview and Controversies (General)

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384: Microsurgery of Paraclinoid Aneurysms

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278: Electrophysiologic Studies and Monitoring
328: Anterior and Lateral Lumbar Instrumentation

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86: Functional Imaging in Movement Disorders

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306: Evaluation, Classification, and Treatment of Cervical (C3-C7) Injuries

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138: Radiologic and Clinical Criteria of Treatment Response

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67: Single-Photon Emission Computed Tomography in Epilepsy Surgery Evaluation

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135: Intraoperative Magnetic Resonance Imaging

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135: Intraoperative Magnetic Resonance Imaging

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38: The Use and Misuse of Antibiotics in Neurosurgery

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296: Assessment and Treatment of Malignant Primary Spinal Tumors

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143: Intracranial Ependymomas in Adults

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156: Glomus Tumors

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322: Lumbar Arthroplasty

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115: Malignant Glioma Microenvironment

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311: Classification of Spinal Deformity

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335: Minimally Invasive Techniques for Degenerative Disease

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99: Surgery for Tourette's Syndrome

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91: Deep Brain Stimulation: Mechanisms of Action

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276: Disk Degeneration and Regeneration

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117: Delivery of Therapy to Brain Tumors: Problems and Potentials

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101: Surgery for Major Depressive Disorder

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321: Cervical Arthroplasty

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185: Neurocritical Care in Children

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69: Motor, Sensory, and Language Mapping and Monitoring for Cortical Resections

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191: Craniopagus Twins

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385: Intracranial Internal Carotid Artery Aneurysms

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352: Traumatic and Penetrating Head Injuries

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118: Epidemiology of Brain Tumors

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256: Secondary Procedures for Brachial Plexus Injuries

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316: Minimally Invasive Treatment of Adult Scoliosis
333: Spinal Osteotomies

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303: Medical Management of Spinal Cord Injury

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95: Transcranial Magnetic Resonance Imaging–Guided Focused Ultrasound Thalamotomy for Tremor

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15: Intracranial Pressure Monitoring

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205: Genetics of Pediatric Brain Tumors

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131: Risks of Intrinsic Brain Tumor Surgery and Avoidance of Complications

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53: Cerebral Edema

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217: Neurocutaneous Tumor Syndromes

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128: Frame and Frameless Stereotactic Brain Biopsy
129: Basic Principles of Cranial Surgery for Brain Tumors

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18: Surgical Planning: An Overview

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6: Complication Avoidance in Neurosurgery

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111: Brain Tumor Immunology and Immunotherapy

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232: Tethered Spinal Cord: Fatty Filum Terminale, Meningocele Manqué, and Dermal Sinus Tracts

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125: Principles of Chemotherapy

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383: Surgical Approaches to Intracranial Aneurysms
399: Traumatic Cerebral Aneurysms Secondary to Penetrating Intracranial Injuries

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390: Microsurgery of Basilar Apex Aneurysms

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107: Deep Brain Stimulation for Obesity

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82: Rationale for Surgical Interventions in Movement Disorders

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110: Brain Tumors: An Overview of Current Histopathologic and Genetic Classifications
146: Metastatic Brain Tumors

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223: Pediatric Arteriovenous Malformations

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198: Infantile Posthemorrhagic Hydrocephalus

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181: Diagnosis and Management of Painful Neuromas

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340: Genetics of Traumatic Brain Injury

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Overview and Controversies (General)
39: Brain Abscess
377: The Natural History of Cerebral Aneurysms
379: Surgical Decision Making for the Treatment of Intracranial Aneurysms
396: Infectious Aneurysms

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151: Craniopharyngiomas in Adults
210: Pediatric Craniopharyngiomas

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63: Continuous Electroencephalography in Neurological-Neurosurgical Intensive Care: Applications and Value

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240: Pediatric Epilepsy Surgery

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326: Posterior Subaxial and Cervicothoracic Instrumentation

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292: Assessment and Treatment of Benign Tumors of the Axial Skeleton

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275: Spinal Biomechanics and Basics of Spinal Instrumentation

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116: Angiogenesis and Brain Tumors: Scientific Principles, Current Therapy, and Future Directions

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224: Management of Head Injury: Special Considerations in Children

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173: Stereotactic Radiosurgery for Trigeminal Neuralgia

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357: Traumatic Cerebrospinal Fluid Fistulas

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148: Meningeal Sarcomas and Hemangiopericytomas

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257: Nerve Injuries of the Lower Extremity

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376: Genetics of Intracranial Aneurysms

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281: Nonsurgical and Postsurgical Management of Low Back Pain

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159: Trigeminal Schwannomas

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177: Peripheral Nerve Stimulation for Neuropathic Pain

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341: Neurochemical Pathomechanisms in Traumatic Brain Injury

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155: Chordomas and Chondrosarcomas

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358: Rehabilitation of Patients with Traumatic Brain Injury

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249: Distal Entrapment Syndromes: Carpal Tunnel, Cubital Tunnel, Peroneal, and Tarsal Tunnel

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156: Glomus Tumors

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23: Incisions and Closures

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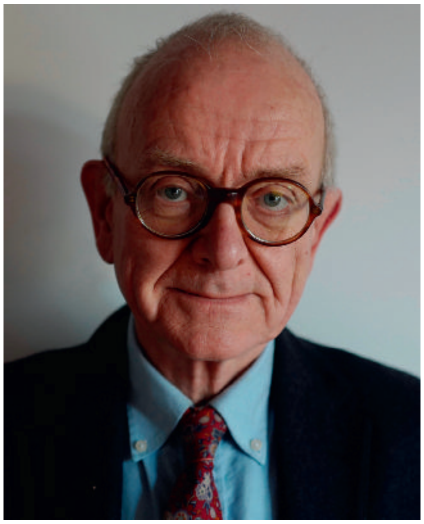
346: Clinical Pathophysiology of Traumatic Brain Injury

Foreword

The human brain, it has often been observed, is the most complicated object in the known universe. The sheer size and scale of *Youmans and Winn Neurological Surgery*, now in its seventh edition and surely the Bible of our craft, is testament to that. It is, however, a salutary thought that despite immense strides in neuroscience in the last few decades, we still understand remarkably little about how our brains really work. We are like Newton, who described himself as a boy, standing on the seashore, playing with pebbles, while "the great ocean of truth lay all undiscovered" before him.

Despite all the science, technology, and clinical knowledge with which, as neurosurgeons, we must remain conversant at all stages of our careers, and which this great textbook embodies so well, the fundamental purpose of everything we do is to help our patients. Neurosurgery has the justifiable reputation of being difficult, and many people (especially neurosurgeons!) consider it to be the acme of surgery. Yet once we have mastered all the intricacies of operating and acquired an understanding of the brain, both in health and disease, most neurosurgeons come to understand that the greatest difficulty of their work is not so much in the technicalities of operating (which for most of us is a joy, albeit at times a painful one) but instead in the decision-making—when to operate and especially when not to operate. Neurosurgical procedures, despite all the recent technological advances, are still very dangerous because the brain is so complex, delicate, and vital to all that makes life worth living. Our patients are very vulnerable. To make the right decisions and to give our patients the best advice, we depend not just on our own experience but on the experience and accumulated knowledge of the thousands of surgeons and scientists who have gone before us or who are continually carrying the specialty forward with new research. It can be a daunting experience to open a textbook as massive as *Youmans and Winn*, edited so expertly for many years by H. Richard Winn. It can fill you with both amazement and alarm that there is so much you do not know but feel that you should. No neurosurgeon can hope—or should try—to assimilate all of it. Besides, in this age of increasing specialization, it is unlikely to be necessary. Nevertheless, here in one place, we can find all that we need to know to remain fully grounded and up-to-date in the science and craft of neurological surgery, the practice of which for most of us is more than just a career and instead something that fills us with the deepest awe and love.



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Henry T. Marsh was the senior neurosurgeon at Atkinson Morley Hospital/St. George's, University of London until he retired in 2015. He was made Commander of the British Empire (CBE) by Queen Elizabeth II for his contributions to British and international neurosurgery in 2010. Dr. Marsh has worked as a neurosurgeon in many countries as noted in the documentary film, *The English Surgeon* (2009). He is the author of two widely acclaimed books about neurosurgery and neurosurgeons: *Do No Harm* (2014) and *Admission* (2016).

Preface

The seventh edition of *Youmans and Winn Neurological Surgery* reflects the dynamic and expansive nature of neurosurgery in the second decade of the 21st century and endeavors to provide an encyclopedic overview of neurological surgery for both the experienced and nascent clinician. Time alone will not convert the latter to the former; the acquisition of knowledge and judgment are essential for this transformation.

This edition is larger than its predecessor, introduces more than 50 new topics and chapters, has both printed and Web-based content, and utilizes hundreds of videos. To a significant extent, we have redesigned the entire book with every illustration, photograph, chart, and table now in color. Some of the changes are described as follows.

- A totally new feature is the addition of introductory chapters for each of the 12 sections. These introductory chapters, written by the subspecialty section editors, are composed of two components: a review of the contents of the section and a thoughtful evaluation of ongoing controversies related to the subspecialty. Thus, each introduction discusses multiple unresolved questions that neurosurgeons, irrespective of their level of training and years of experience, may need to address in dealing with patients.
- The vast majority of chapters now contain videos to supplement the written text. In addition, we have upgraded the quality and added audio commentary. These electronic features are designed to facilitate understanding of the complexities of neurological procedures. The seventh edition also includes videos on perioperative techniques such as patient positioning. For example, Chapter 22 contains 18 different videos on positioning for peripheral nerve surgery. These videos, however, are not restricted to the operating room but are critical components of chapters focused on basic sciences and clinical topics. For example, the 36 videos in Chapter 2, "Surgical Anatomy of the Brain," by Rhoton and his colleagues, provide a broad yet in-depth educational supplement.
- An example of electronic enhancement in the clinical realm is Chapter 8, which deals with ophthalmology and contains many videos demonstrating multiple eye movement disorders associated with cranial nerve dysfunction. Written descriptions of such disorders can be confusing, whereas these videos quickly and more clearly convey the neurological abnormalities.
- We extensively revised and totally rewrote all retained chapters. References were likewise rigorously updated. Retention of previous topics and chapters required a clear indication of relevance and importance to neurosurgical education and practice.
- Because of the dynamic nature of fundamental research, all the basic science chapters have been extensively revised to provide cutting-edge information. In addition, several new topics have been added: examples include "Optogenetics and Clarity" (Chapter 45) and "Extracellular Fluid Movement and Clearance in the Brain" (Chapter 54). The latter has been termed the "glymphatic pathway" and may have a significant impact on patient disorders.
- We have extensively expanded our focus on anatomy by adding a new chapter, "Surgical Anatomy of the Skull Base" (Chapter 3), which complements Rhoton's chapter, "Surgical Anatomy of the Brain" (Chapter 2). In addition, each subspecialty section contains a chapter focused on the relevant anatomy pertinent to the subspecialty topics.
- Radiology, especially magnetic resonance imaging, is the technique by which neurosurgeons study anatomy in the 21st century. Accordingly and reflecting our approach to anatomy, we have expanded the radiology components in the seventh edition. There are initial introductory overviews of brain and spine radiology, including physiologic techniques, and then more highly focused radiology chapters contained within each subspecialty section.
- Patient safety must be of paramount concern for neurosurgeons, and consequently we added new chapters on this topic: "Improving Patient Safety" (Chapter 4) and "Coagulation for the Neurosurgeon" (Chapter 7). In addition, we upgraded several chapters that deal with complication avoidance, which is covered broadly in the initial section and more narrowly in each subspecialty section.
- Cutting-edge practice of neurosurgery demands the knowledge of new technologies, many of which have been added in the seventh edition (e.g., see Chapter 25, "Visualization and Optics in Neurosurgery"). Even new twists on older methods are contained in new chapters such as Chapter 24 ("Brain Retraction").
- Because advances in the neurosciences and neurological surgery are not limited by national boundaries, we have significantly broadened our international authorship to reflect this global basis of knowledge.

The first edition of *Neurological Surgery* by Julian Youmans appeared in 1973 and contained 112 chapters and 2024 pages. Now, almost five decades later, the seventh edition, with much larger pages and resultant 30% increase in the number of words per page, has expanded to 415 chapters and almost 5000 pages. By comparing each section of the first and seventh editions, one can easily see how much has changed in the knowledge base of neuroscience and neurosurgery and the breadth and practice of neurosurgery. Consequently, the neurosurgery trainee of today (and tomorrow) must master considerably more information and techniques while simultaneously assimilating the existing knowledge base. Not to be forgotten are the historical precedents responsible for present-day neurosurgery practice, which are reviewed in detail in the first chapter of the seventh edition.

It should be self-evident that the provision of this knowledge in the seventh edition represents the diligent work of many individual experts. I enthusiastically express my appreciation to the stellar and thoughtful authors of the 415 chapters. Their work represents the essential building blocks for the practice of neurological surgery.

The creation of this multi-authored textbook required hard work and discipline by the section editors, to whom I offer much gratitude. If the individual authors are the building blocks, then the following section editors represent the mortar:

Introduction and General Neurosurgery Section

- William T. Couldwell, MD, PhD
- Basant K. Misra, MBBS, MS, MCh, Diplomate National Board
- Volker Seifert, MD, PhD
- Ugur Türe, MD

Basic and Clinical Sciences Section
- Michel Kliot, MD, MA
- Pierre J. Magistretti, MD, PhD
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Epilepsy Section
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- Osmar José Santos de Moraes, MD
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- Gavin W. Britz, MD, MBBCh, MPH, MBA, FAANS
- Kazuhiro Hongo, MD, PhD
- Michael T. Lawton, MD
- Fredric B. Meyer, MD

I thank my long-time associates, Mitchel S. Berger, MD, MA; Kim J. Burchiel, MD, FACS; Ralph G. Dacey, Jr., MD; M. Sean Grady, MD; Matthew A. Howard III, MD; and Marc R. Mayberg, MD, for their creative input. These deputy editors-in-chief were critical architects in helping with the intellectual design of the seventh edition. And I thank my former laboratory postdoc and neurosurgical colleague, Kathryn Ko, MD, MFA, for allowing her insightful paintings to grace the cover of the seventh edition.

To bring to fruition a work of this magnitude requires a highly professional editorial effort, and for this, I thank the members of the Elsevier global team. Firstly, I thank Senior Content Development Specialist Jennifer Shreiner in Philadelphia, Pennsylvania, who was indispensable on a daily basis in the hard work of organizing chapters and prodding the authors, section editors, and me; Book Production Specialist Kristine Feeherty in St. Louis, Missouri, who masterfully oversaw copyediting, proofreading, and conversion of manuscripts into printed proofs; and lastly, Senior Content Strategist Charlotta Kryhl in London, England, for her long-term advice, input, and patience. The seventh edition would not have been brought to fruition without the assistance of Mss. Shreiner, Feeherty, and Kryhl.

A personal note of gratitude goes to my wife, Debbie, for her sustaining support and editorial assistance; our son, Randy, and his wife, Tamara; our daughter, Allison, and her husband, Adam; and Campbell, Mia, Amelia, Lexi, and Charlie for being here.

H. Richard Winn

†Deceased.

SECTION I

Introduction and General Neurosurgery

Overview and Controversies

William T. Couldwell, Basant K. Misra, Volker Seifert, Ugur Türe, and H. Richard Winn

The "Introduction and General Neurosurgery" section is composed of 43 chapters that are divided into seven subparts: "History and Background"; "Related Systems"; "Overview of Radiology"; "Intensive Care"; "The Operating Room"; "Geriatric Neurosurgery"; and "Infections." We designed the "Introduction and General Neurosurgery" section with the goal of providing neurosurgeons in practice and those still in training with comprehensive, up-to-date information on a broad scope of topics central for the mastery of neurosurgery. In this introduction, the section editors initially review the topics contained in the "Introduction and General Neurosurgery" section and then present a series of essays about controversies and unresolved questions related to these topics.

OVERVIEW

The first part of this section opens with a superb chapter on an important topic: the history of neurosurgery. Neurosurgeons have shown an increasing interest in the history of their discipline, as demonstrated by the expanding history section of the American Association of Neurological Surgeons. Neurosurgeons should remember George Santayana's[1] warning that "those who cannot remember the past are condemned to repeat it." The next two chapters comprehensively review the anatomy of the brain and skull base. Chapter 2, by Rhoton and colleagues, contains 35 videos, and Chapter 3 is a totally new entity in which bony cranial and brain landmarks are correlated. Each of the subsequent chapters in the "History and Background" part discusses a subject that is critical for patient care: improving patient safety (Chapter 4), preoperative evaluation for neuroanesthesia (Chapter 5), and complication avoidance (Chapter 6). The final chapter in this part, "Coagulation for the Neurosurgeon," is another new topic and succinctly contains vital insights.

The second part of this section, "Related Systems," focuses on the related topics and systems of neuro-ophthalmology (Chapter 8), neurotology (Chapter 9), and neurourology (Chapter 10). Neurosurgeons have many patients whose problems involve these systems; consequently, they work closely and consult frequently with colleagues in these fields. These chapters are highly focused on the essential information that allows neurosurgeons to knowledgeably provide care and seek appropriate and timely consultation.

The third part of this section, "Overview of Radiology," comprehensively covers basic neuroradiology with separate chapters on computed tomography (CT) and magnetic resonance imaging (MRI) of the brain (Chapter 11) and spine (Chapter 12) and then intensive chapters on physiologic analysis involving the use of MRI (Chapter 13) and positron emission tomography (PET; Chapter 14). This entire part on neuroradiology and imaging serves as a cornerstone for multiple individual neuroradiologic chapters that appear in the specialty sections (e.g., "Oncology" [Section V], "Pediatrics" [Section VII], and "Vascular" [Section XII]) later in the book.

The fourth part of this section, "Intensive Care," begins with Chapter 15, in which the scientific basis of intracranial pressure is reviewed and the various approaches to monitoring intracranial pressure are described. Separate chapters then deal with principles of intensive care unit (ICU) treatment (Chapter 16) and the unique role of neurosurgeons in providing care in the neurosurgical ICU (Chapter 17).

The fifth part of this section, "The Operating Room," opens with Chapter 18, an overview of surgical planning. Surgical simulation and surgical robotics, a new and emerging field with the potential for a major influence on neurosurgery, is then explored in Chapter 19. Positioning is a critical component of neurosurgery and is covered in separate chapters related to cranial, spinal, and peripheral nerve surgery. All these positioning chapters contain illustrative and extensive videos. For example, Chapter 22 ("Positioning for Peripheral Nerve Surgery") contains 18 separate videos. Although incisions and closings are seemingly routine, many difficulties can arise when they are performed. We thus included Chapter 23, which deals with these two topics. Chapter 24, a new topic, provides insights on a technique "routinely" used but not frequently discussed in neurosurgery: retraction. Continuing the "insights" theme, Chapter 25 covers visualization and optics. Chapter 26 explores the advantages and disadvantages of endoscopic surgery. With this background, the reader is then presented with Chapter 27, which focuses on thoracic endoscopic surgery. "The Operating Room" part of this section then concludes with Chapter 28, about another "routine" procedure that necessitates attention to detail to achieve success: cranioplasty.

Because of the aging population throughout the world, the sixth part of this section, "Geriatric Neurosurgery," concentrates on two topics: normal-pressure hydrocephalus (NPH) and chronic subdural hematomas. For each of these entities, we provide chapters describing the relevant basic science and pathophysiologic features, patient evaluation, and treatment options, including a critical review of third ventricular ventriculostomy (Chapter 32).

The seventh part of this section, "Infections," covers this important topic broadly, starting with Chapter 35, a very comprehensive discussion of the basic science of central nervous system (CNS) infections. Separate chapters (36 and 37) deal with postoperative infections of the brain (and head) and the spine. Next, the important topic of antibiotic usage is explored in Chapter 38. Specific types of infections affecting the CNS are then discussed in separate chapters: brain abscess (Chapter 39), meningitis and encephalitis (Chapter 40), acquired immunodeficiency syndrome (Chapter 41), and parasitic infections (Chapter 42). This section closes with an increasingly important topic for surgeons: surgical risk of transmittable diseases (Chapter 43).

CONTROVERSIES AND UNRESOLVED QUESTIONS

In this part of the introduction, we discuss a number of important and controversial topics in modern neurosurgery: treatment of hydrocephalus; coagulation for the neurosurgeon; the proper treatment of chronic subdural hematomas; the use of endoscopy with transfacial surgery; technical advances involving robotic surgery, visualization and optics, and brain retraction; the glymphatic system; the role of the neurosurgeon in neurointensive care; and education and training of neurosurgeons. Although perhaps we do not offer definitive answers, our goal is to focus attention, raise awareness, provide context, and perhaps point the way to answering unresolved questions.

Question 1: Adult and Pediatric Hydrocephalus: The Role of Third Ventriculostomy and Choroid Plexus Cauterization

Endoscopic third ventriculostomy (ETV) has been increasingly used for treating both adult and pediatric hydrocephalus since the early 2000s (see Chapter 32). This procedure has much inherent appeal, in that avoiding or removing an indwelling ventricular shunt—which condemns the patient to probable lifelong dependency on a device with a high failure rate over time—is a laudable goal. Rates of success with ETV vary from 50% to 90%. The indications for this procedure are in evolution. It is clear that the success of the procedure is highly dependent on the cause of the hydrocephalus. Patient selection is the key to achieving clinical success.

In the adult population, late-onset idiopathic aqueductal stenosis is the indication for which the implantation of a shunt has the highest success rate. In addition, lesional obstructive hydrocephalus (secondary obstructive hydrocephalus) remains an intuitively appealing indication for which shunt implantation has a high success rate. Perhaps more surprisingly, NPH, long believed to be a disorder of cerebrospinal fluid (CSF) dynamics and absorption, is an emerging indication. The published rates of success with ETVs in patients with NPH have been variable, ranging from 21% in a study of 14 patients[1a] to 87% in a study of 15 patients with 27 months of follow-up.[2] Gangemi and colleagues[3] had a success rate of 69% in their series of 110 patients with NPH treated with ETVs at four centers and monitored for a minimum of 2 years. Potential predictors of success included a shorter duration of symptoms and milder symptoms; patient age was not predictive of response. In adult patients with shunts, conversion to ETV and removal of the shunt has been successful in 70% at a median follow-up of 36 months. This population represents a considerable opportunity.

The success rate of ETV in children with hydrocephalus secondary to tectal gliomas is high (close to 90%), whereas ETVs performed in the context of intraventricular hemorrhage associated with prematurity succeed in only a third or fewer of cases. Young age (<6 months) is associated with a lower success rate, independent of cause; however, this age effect either plateaus or diminishes after the age of 2 years, perhaps because of cranial maturation.[4,5] The literature indicates that the rate of success with ETV is high in patients older than 2 years in whom noncommunicating hydrocephalus is caused by aqueductal stenosis, tectal glioma, and posterior fossa tumors.

With regard to the question of whether a choroid plexus coagulation should be added to the ETV procedure, data suggest that in the infant population (<2 years old) with noninfectious hydrocephalus, adding choroid plexus coagulation may further bolster the success rates of this procedure. ETV with choroid plexus coagulation is now routinely performed at children's hospitals around the world and has resulted in an approximately 30% decrease in the placement of new ventricular shunts in the pediatric age group in selected institutions (W.T. Couldwell, personal communication, University of Utah Department of Neurosurgery).

Question 2: Clotting and the Neurosurgeon

The imperative in neurosurgery, as in other fields of surgery, is to critically balance the risks of bleeding against thrombosis in patients. The assessment of the coagulation system is vital in preoperative management, as well as in the determination of any deleterious effects of medications used by the patient. In this regard, there is a paucity of high-level evidence concerning the effects of antiplatelet agents and anticoagulants on patients with neurosurgical conditions.

Currently, more than 1% of the general population is receiving some form of oral anticoagulation for various cardiovascular conditions. These problems are further confounded by the increasingly common use of dual antiplatelet agents in patients with cardiac, peripheral vascular, and intracranial stents. The management of such patients after neurotrauma represents a controversial area in neurosurgery (see Chapter 7). Although some investigators have focused on the management and outcome of patients with trauma who receive anticoagulants or antiplatelet therapy, there are no strict guidelines (and a lack of class I evidence). Several questions have been raised about testing of antiplatelet and anticoagulation effects on patients at hospital admission, reversal of the pharmacologic effects of these agents to mitigate against neurological deterioration, and the timing of reinstitution of therapy. Patients taking oral anticoagulation medication are considered to be at high risk for neurological deterioration, and more prospective and comparative effectiveness research is necessary to answer these important questions.

Another related dilemma is posed by the use of contemporary anticoagulants for the management of cardiovascular conditions. Several small compounds that specifically block activated coagulation factor X (FXa) or thrombin (FIIa) have become popular alternatives to vitamin K antagonist compounds. As opposed to vitamin K antagonists, direct oral anticoagulants (DOACs) target a specific coagulation factor. Such direct oral anticoagulants include dabigatran etexilate (thrombin inhibitor) and edoxaban and rivaroxaban (inhibitors of FXa). These agents have become popular for venous prophylaxis or treatment of thromboembolism and for prevention of neurological events associated with atrial fibrillation. With regard to intracranial hemorrhage, the safety profile of the DOACs has been shown to be poorer than that of vitamin K antagonists. The difficulty arises with the use of these agents when intracranial hemorrhage occurs, either spontaneously or in relation to trauma.[6-8] The development of reversal agents has lagged behind the introduction of these agents for therapeutic benefit for common cardiovascular problems; as a result, difficulty arises when bleeding events occur, especially in relation to the CNS. Because most DOACs have a short half-life, time is an efficient way to eliminate the anticoagulant effect if waiting is possible; however, devastating neurological outcomes have been reported with the use of these agents.[9] New agents are currently being developed that should reduce this problem over time.[10,11]

Question 3: Correct Surgical Management of Chronic Subdural Hematomas: Do Surgeons Now Have the Definitive Answer?

Chronic subdural hematoma, for which the mean age at occurrence is in the eighth decade, represents a growing problem in much of the developed world as the population ages. This demographic shift, together with the increasing use of anticoagulants and antiplatelet agents in older patients, complicates the management of these patients.

Treatment for chronic subdural hematoma remains surgical; observation is recommended for affected patients with minimal or no symptoms. The three options for surgical drainage are burhole drainage (which can be performed with the patient under local or general anesthesia, usually in the operating room), twist-drill craniostomy (which is usually performed with the patient under local anesthesia, at the patient's bedside), or open craniotomy (in the operating room). The results of these options, compared in a contemporary meta-analysis, were that craniotomy was associated with a lower rate of recurrence (usually less than 10%), but rates of morbidity and mortality may be higher with this procedure. Twist-drill craniostomy produces the least morbidity, but it is associated with a higher recurrence rate (exceeding 30% in some studies). Thus the compromise option, bur-hole drainage, remains the most commonly used because its morbidity and recurrence rates are balanced.[12,13] There is high-quality evidence that drains reduce the incidence of recurrence and should be used.[14]

The technical controversies in the use of bur-hole drainage are related to the number of bur holes and the type of drain to be used (external drain, subperiosteal, or subgaleal). There appears to be little consensus in the literature on these points.

Furthermore, the recurrence rates between studies are remarkably variable. In studies since the 1990s, the reoperation rate has been reduced to a range of 10% to 20%.[12] This probably indicates that although chronic subdural hematoma is treated as a single entity, it is not advisable to perform procedures without tailoring treatment according to individual hematoma characteristics. Experienced surgeons define treatment on the basis of the patient's age, comorbid conditions present, and imaging characteristics of the hematoma. In studies, researchers have not stratified data for such factors to provide strong evidence-based conclusions for treatment in this nuanced manner.

In addition, the role of adjuvant therapies such as steroids needs to be better defined. Because the burden of chronic subdural hematoma is likely to rise, outcomes for this common neurosurgical condition must be improved.

Question 4: Endoscopy: When Should Transfacial Endoscopy or Traditional Open Microsurgery Be Used in Skull Base Surgery?

Since the 1990s, neurosurgeons have been increasingly interested in approaching various tumors of the base of the skull by using a transfacial (transnasal or transmaxillary) corridor. This has been the result of enhanced endoscopic techniques primarily developed and used by and with otolaryngologists to address sinus disease and is an extension of the transsphenoidal approach to approach other lesions besides traditional pituitary tumors (see Chapter 26).

The use of an endoscopic approach to a pituitary tumor was first documented by Guiot and associates[15] in Paris in 1962. Although Bushe and Halves[16] reported the first use of the endoscope for pituitary tumors in the literature in 1978, the endoscope was not used widely until the mid-1990s, when endoscopic sinus surgery was universally adopted by otolaryngologists. Neurosurgeons were attracted to its use by the increased visualization of the surgical site and began to explore the possibilities in transsphenoidal surgery. Jho and Carrau[17] reported on a series of 50 patients who underwent endoscopic endonasal transsphenoidal surgery, with encouraging results. Thereafter, the endoscopic approach to transsphenoidal surgery for resection of pituitary macroadenomas was adopted rapidly by neurosurgeons.

With the expansion of the transsphenoidal approach to other tumors of the skull base,[18] the endoscope was an ideal tool to apply to these approaches because it offers wide-angle and side-angle visualization, a capability that is not possible with the microscope from below. In addition, there are several advantages to approaching anterior skull base lesions from below. For example, an anterior endoscopic endonasal transcribriform or transplanum approach may confer advantages to anterior skull base management for certain meningiomas, depending on size and location. Complete resection of hyperostotic bone of the olfactory groove, planum sphenoidale, and tuberculum sellae is more easily accomplished, and manipulation of neurovascular structures and brain retraction on the frontal lobes to increase exposure is avoided. In an endoscopic approach, the craniotomy through the anterior skull base is made directly over the basal dural attachment at the anterior skull base. The meningioma can be devascularized early in the operation to decrease blood loss and facilitate tumor removal. Complete removal of all bone that has become hyperostotic from tumor infiltration facilitates a Simpson grade I resection. The endoscopic approach may be suitable for an anterior skull base meningioma that has recurred or extends into the paranasal sinuses.

Disadvantages of the endonasal endoscopic approach stem from the inherent limitations of its midline exposure. Tumors that have extended beyond the medial orbital wall or over the superior orbital roof and those with dural attachments extending lateral to the optic canal or into the sphenoid wing are difficult to access from a midline endonasal approach and may be better approached via an open transcranial technique. Cranial nerves and vascular structures are identified later in the dissection during an endonasal endoscopic technique and may be prone to injury if manipulated. Tumors encasing the internal carotid arteries or anterior cerebral arteries should be approached by an open technique for more complete visualization and to avoid vascular injury. High-quality studies of the extent of resection, recurrence rates, and complications of each approach are lacking.

CSF leaks that necessitate endonasal exploration to repair may be more common with endoscopic surgery. The osteodural defect is larger when created by an approach from below than when created by a Simpson grade I resection with a transcranial approach from above. Approaching a meningioma in the olfactory groove may necessitate resection of bone and dura extending from the posterior wall of the frontal sinus to the planum sphenoidale. Resection of the hyperostotic endonasal bones and entering the paranasal sinuses further increase the risk of a CSF leak.

Modern surgical techniques, such as the use of vascularized nasoseptal mucosal flaps or allogenic acellular dermal allograft (AlloDerm; LifeCell Corporation, Bridgewater, NJ), may decrease the rate of CSF leaks without the need for lumbar drainage and may grant surgeons the confidence to perform a more complete surgical resection; however, prospective trials in which the effectiveness of these newer techniques are evaluated have not yet been published.

Question 5: Technical Advances: Revolutionary or Evolutionary?

Several new chapters deal with innovation and technical advances in operative neurosurgery: simulation and robotics (Chapter 19), brain retraction (Chapter 24), and visualization and optics (Chapter 25). In those chapters, the authors endeavor to place these advances in context, evaluate whether they truly deserve to be termed "revolutionary," and attempt to address what effect these advances will have on the future of neurosurgery (Fig. I-1).

With regard to the terms *revolutionary* and *evolutionary*, many investigators make claims for the former but rarely for the latter. *Revolutionary* means a complete or fundamental change. It therefore follows that the majority of innovations contributing to advances in neurosurgery are evolutionary. Gordon[19] reviewed examples of revolutionary changes that transformed the 20th century: the internal combustion engine, distribution of electricity, and public health advances. The internal combustion engine evolved into the automobile and the airplane; distribution of electricity enabled the development of household and business devices such as the refrigerator and, later, the computer; and public health advances led to the delivery of potable drinking water and sanitary collection of sewage. According to Gordon's line of reasoning, a major revolutionary change in neurosurgery was Wilhelm Röntgen's discovery of x-rays, and all subsequent events and discoveries were evolutionary, including Walter Dandy's description of ventriculography and

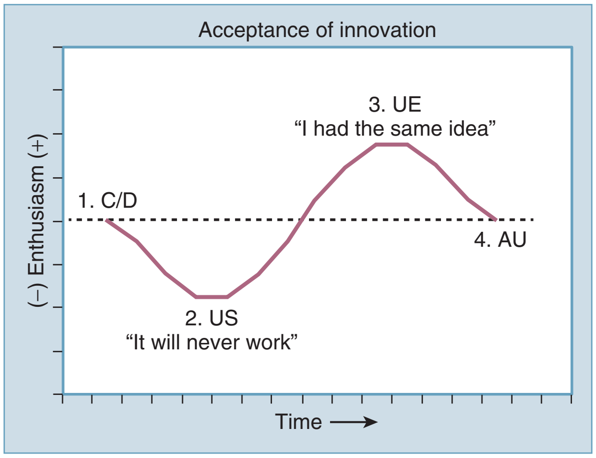

Figure I-1. Four phases of acceptance of innovation. Phase 1: Creation/Development, (C/D). Phase 2: Unrestricted Skepticism (US). Phase 3: Unrestricted Enthusiasm (UE). Phase 4: Appropriate Utilization (AU). The duration of each phase is highly variable. With medical innovation, the transition from phase 3 to phase 4 may be prolonged, or phase 4 potentially may never be achieved.

pneumoencephalography (1918/1919), António Egas Moniz's achieving opacification of the carotid artery (1927), and Sir Godfrey Hounsfield's development of the CT scanner (1973).

Before physicians attempt to predict the future, it would be wise to remember that "rational prediction of future developments is, to some degree, an oxymoron. Predictive accuracy would probably be higher with Isaac Asimov* and other science-fiction writers than with academics limited by conditioned skepticism."[21] It would also be prudent to remember Bergland's 1973 article "Neurosurgery May Die," published in the *New England Journal of Medicine*.[22] Unlike Bergland, modern neurosurgeons can use the "retrospectoscope" to see that almost simultaneously with the publication of Bergland's article predicting the demise of this specialty, Hounsfield and James Ambrose were in the midst of perfecting the CT scanner. The CT scanner and MRI, while evolutionary only from a technology perspective, nevertheless had a revolutionary effect on neurosurgical practice. These devices profoundly expanded the scope of neurosurgery and prevented its demise. However, Bergland based his prediction on the failure of neurosurgical education and, as will be discussed later, he may be correct about future difficulties ahead for neurosurgery.

Simulation and Robotic Surgery

In 1921, Karel Capek, a Czech playwright, introduced the term *robots*, using it to mean forced labor; today this term applies to tools that can perform a variety of tasks under the direction of a human or computer. The first robotic application in the realm of surgery was in 1988 in neurosurgery—for needle biopsy.[23] Since then, robotics have been applied widely in radiosurgery and, to a lesser extent, in spinal and cranial surgery. However, few studies have demonstrated a clear advantage to robot-assisted surgery across the breadth of surgery.

Instead of surgery itself, perhaps the major application for robotics in the near term will be in simulation and training, as noted in Chapter 19; however, neurosurgeons and engineers need to make significant progress before virtual operations simulate actual conditions in the operating theater. Advances in virtual reality technology are transforming the gaming and other industries and will soon be applied to simulation of neurosurgical procedures. Such advances will not only affect patient safety (see Chapter 4) but will probably also have a major positive effect on neurosurgery training, at a time when education is being eroded (see later discussion).

Should neurosurgeons be concerned about the steady march toward the mechanized and robotic future, or do such concerns represent the reflex protestations against progress by a generation of Luddites who are unfamiliar with emerging technology? Without question, potential losses and negative consequence lie ahead. In the absence of robotics, surgery is at the end of a spectrum that begins with the individual surgeon's knowledge, mental visualization of the neuroanatomy in three dimensions, correlation of the anatomy and imaging, and then activation of personal executive function to create a surgical plan. Robotic surgery in the future may allow bypass of these important intellectual tasks; therefore, when technology fails, surgeons will be left poorly equipped to handle certain situations.

We are mindful, however, of how the introduction of the CT scanner and MRI, while changing the practice of neurosurgery, has had a secondary effect on neurosurgical education and neuroanatomy. Before the development of CT and MRI, the popularity of neuroanatomy was in decline, considered a nice bit of knowledge to acquire (comparable to knowing the distinction between Doric, Ionic, and Corinthian columns), but not thought to be essential to the practice of neurosurgery. The "imaging studies" before CT were pneumoencephalography and ventriculography. These techniques required some knowledge of the cerebral ventricles and, in general terms, what could displace them, but knowledge about the brain outside of the ventricles was still sparse. With the introduction of CT and MRI, knowledge of neuroanatomy became a necessity, not a luxury, and led to a vastly increased emphasis on neuroanatomy teaching and research. This is reflected in the expansion of chapters devoted to anatomy in the 7th edition of *Youmans and Winn Neurological Surgery*.

Visualization and Optics

Most neurosurgical procedures on the brain, spine, or peripheral nerves as of the second decade of the 21st century remain "open" surgeries involving direct vision and similar to those performed by Harvey Cushing in the second decade of the 20th century. Ted Kurze's introduction of the microscope into the neurosurgery operating room, as well as subsequent refinements by Raymond M.P. Donaghy, Gazi Yaşargil, Albert L. Rhoton, and other innovative pioneers, fundamentally expanded the neurosurgical operative universe. Less well recognized and documented is the role that illumination has played in advancing microneurosurgery.

In their insightful Chapter 25, on visualization and optics, Sorenson and colleagues correct this deficit in recognition by reviewing the development and current status of lighting for microsurgery; they also review the past and current status of optics. Obviously, without adequate light, microscopic neurosurgery would be impossible. Similarly, lack of light initially impaired the widespread use of endoscopes (see the earlier section "Question 4: Endoscopy").

According to the analysis of Sorenson and colleagues, lighting, rather than optics, is rate limiting for the development of magnification more powerful than what is used today, which is based primarily on human vision. Increasing the power of illumination has limitations related to effects on tissue and the inability to discriminate difference in contrasts. Sorenson and colleagues believe that the use of digital technology and high dynamic range (HDR) imaging will replace the current optical systems. Such tools could ensure superb illumination and focus that will exceed today's optic systems, which are dependent on human vision

*A famous science fiction writer who popularized the term *robotics* in 1941.[20]

alone. In addition, they envision the development of systems that will allow the neurosurgeon to "see through the brain," truly "image"-guided surgery, and they even foresee the introduction of detached remote visual techniques. Such developments, like the effect of digital cameras on photography, are destined to expand the current microsurgical world.

Brain Retraction

Is old technology with staying power no longer critical in today's "micro"/"endo" world of neurosurgery? Improvements in visualization may have a secondary effect by altering the degree of and even the need for brain retraction (see Chapter 24). As with the case of illumination, the development of retractors specialized for neurosurgery contributed to the expansion of microsurgery. As outlined in Chapter 24, replacing handheld retraction with self-retaining systems increased the surgeon's manual options. One- or three-handed surgery was expanded to two- or four-handed procedures and undoubtedly increased patient safety. The neurosurgery literature has largely ignored the contribution of self-retaining retractors to patient safety.

Although retractors are universally used in neurosurgery, the science of brain retraction and the causes of retraction injury are not as well studied. Few laboratory-based studies have documented the pressure/duration limits of neural tissue or biologic strategies designed to decrease retraction injuries. Mechanical and engineering advances have been made in retractor design, but on-line pressure-sensing retractors remain primitive. The increasing advocacy for minimal retracting techniques may reflect the acknowledgment and underreporting of the frequency of retraction injuries. Minimal retraction methods may also be related to more radical skull base dissection and advances in anesthesia methods to maximize brain relaxation.

The correct, rational, step-by-step application of retractors is based on achieving appropriate exposure with minimal risk to neural tissue while simultaneously enabling operating surgeons' access. Success or failure may depend on initial placement of the head holder and subsequent stabilization of the flexible arms. These seemingly minor steps can optimize surgical access or, if retraction is incorrectly applied, result in significant neural injury. An infrequently recognized truth is that brain retraction does indeed involve an art, as well as a science.

In summary, historic and more recent technical advances in neurosurgery have been impressive, but in the current and future environment, there remains the risk of overreliance on technology. As with humans, technology can fail and, at some point, the individual neurosurgeon must recognize this failure. For example, as reported in the *Daily Mail*,[24] a woman, planning to drive to a railroad station 38 miles from home, instead drove 900 miles over 2 days because she slavishly followed the incorrect directions provided by her global positioning system (GPS) device (Fig. I-2). The ability to recognize technology-related errors is dependent on previous training and education, as well as common sense. As indicated previously and discussed in detail subsequently, training and educational exposure are being constrained. The combination of increased dependency on technology and constriction in clinical training may be a lethal mixture.

Figure I-2. Drive of 38 miles to a local train station became a 900-mile, 2-day journey *(red arrows)* because of the driver's adherence to erroneous directions by a global positioning system (GPS).

Question 6: Advances in Basic Sciences: New Information and Possible Clinical Implications

As noted previously in the preceding discussion, revolutionary changes occur infrequently in neurosciences and neurosurgery; evolutionary changes are more common. We would describe Chapter 45 ("Optogenetics and Clarity," by Fenno, Hsueh, Purger, and Kalanithi) and Chapter 54 ("Extracellular Fluid Movement and Clearance in the Brain: The Glymphatic Pathway," by Iliff and Penn) as having revolutionary content that has potential clinical application. Optogenetics is a laboratory tool that involves the expression of light with cellular activation and allows real-time insights into the basic physiologic mechanisms of neural networks in the brain.

The glymphatic system is a network of perivascular pathways throughout the brain along which CSF recirculates through the brain parenchyma and interstitial fluid (ISF) solutes are cleared to CSF. This novel concept may help explain physiologic activities such as memory acquisition and has profound implications about several clinical entities such as Alzheimer's disease, brain edema, and hydrocephalus.[25,26] Accordingly, we think it is important to draw neurosurgeons' attention to the glymphatic system.

Because the brain and spinal cord lack a conventional lymphatic vasculature, classical lymphatic functions such as interstitial protein homeostasis and immune surveillance are thought to occur through the interactions between the CNS extracellular fluid compartment and the CSF compartments. According to the "CSF sink hypothesis," articulated by Oldendorf and Davson[27] in the middle of the 20th century, interstitial wastes from CNS were eliminated through the exchange of ISF with CSF and the subsequent reabsorption of CSF into the bloodstream. However, more recent data by Iliff (who began his investigatory career in a neurosurgery laboratory right after high school[28]) and his collaborators have mandated revision of the basic elements of this classical model of CSF-ISF exchange.[29,30] The characterization of classical lymphatic vessels associated with dural sinuses and vasculature on the margins of the CNS suggests that waste clearance and immune surveillance may be taking place in a much more complex manner than previously believed. These data have demonstrated that the process of CSF-ISF exchange is both more organized and more functionally consequential than previously realized.

Using dynamic imaging approaches in rodents, researchers have demonstrated that, contrary to the conventional view of CSF circulation and reabsorption, a substantial proportion of CSF from the subarachnoid compartment recirculates back into and through the brain parenchyma along perivascular spaces surrounding penetrating cerebral arteries, rapidly exchanging with surrounding ISF. Interstitial solutes, in turn, are cleared from the brain along a distinct set of perivascular pathways surrounding large-caliber draining veins, including the internal cerebral vein. The exchange of CSF and ISF along these perivascular pathways, driven in part by arterial pulsation, supports the clearance of interstitial solutes, including metabolic wastes and pathologic substrates such as amyloid β peptide and tau protein.

Perivascular spaces therefore function as a crossroads in the CNS, in which, in proximity to the blood-brain barrier, the extracellular compartment of the CNS interacts with the peripherally communicating CSF. Fluid exchange along these perivascular pathways is supported by astrocytic water transport. Astrocytes express large amounts of the water channel aquaporin-4 in perivascular end-feet that ensheathe the cerebral vasculature, which helps organize water movement within the CNS along the axis of the cerebral vasculature, in a manner similar to the way that water diffusion organizes along axons in white matter tracks. Disruption of aquaporin-4, or its perivascular localization, slows perivascular CSF-ISF exchange and impairs the clearance of interstitial solutes from brain tissue.

Researchers have also shown that glymphatic function is a feature primarily of the sleeping brain, inasmuch as perivascular CSF-ISF exchange and the clearance of interstitial solutes, including amyloid β peptide, are dramatically slower in the awake brain than in the sleeping brain. In an intriguing finding, electrophysiologic measurements suggested that during slow-wave sleep, the brain extracellular space increases in volume, facilitating more rapid solute diffusion and perivascular exchange. These findings suggest that the clearance of extracellular wastes may be one of the physiologic bases of the restorative functions of sleep.

From a physiologic perspective, the clearance of extracellular wastes and the reabsorption of interstitial proteins are basic and essential elements of organ function. Within the CNS, with its high rate of metabolic activity and neural cells' sensitivity to changes in extracellular environment, the glymphatic pathway is probably a key contributor to basic brain function. In addition to facilitating the efflux of solutes that cannot be locally degraded or cross the blood-brain barrier, the glymphatic system probably provides a route along which signaling molecules, such as trophic factors, neuropeptides, and neuromodulators, are distributed through different brain regions. The association of the choroid plexus and dural vasculature—known nodes of peripheral immune cell trafficking—with the CSF and perivascular spaces of the glymphatic system suggests that these anatomic features constitute an integrated system that facilitates peripheral immune surveillance of the brain without breaching the relative "immune privilege" of the CNS.

Because glymphatic function underlies basic elements of brain function, it is likely that its dysfunction contributes to the development or progression of many different pathologic states. Glymphatic function, including the clearance of interstitial amyloid β peptide, slows in the aging brain, which suggests that age-related decline in its function may underlie the vulnerability of the aging brain to neurodegenerative disease characterized by misaggregation of different protein species, including amyloid β peptide and tau protein in Alzheimer's disease or α-synuclein in Parkinson's disease and Lewy body dementia. Similarly, glymphatic function is impaired in the young brain after traumatic brain injury, which may promote the development of neurodegeneration, including Alzheimer's disease or chronic traumatic encephalopathy, in the decades after traumatic injury.

In addition to its impairment after traumatic brain injury, glymphatic function is compromised after cerebral ischemia and subarachnoid hemorrhage, according to the results of several experimental studies. The failure of interstitial solute and fluid efflux in the setting of blood-brain barrier disruption may support the formation and persistence of cerebral edema after neurovascular injury. Conversely, the creation of an oncotic sink within edematous brain tissue may disrupt wider glymphatic pathway function, exacerbating the local effects of brain injury.

The emerging understanding of the glymphatic system and interactions between the CSF and ISF compartments along perivascular pathways has important implications in neurosurgery. Many different kinds of brain disease can interfere with fluid movement. For example, cerebral edema probably affects the dimensions of extracellular pathways, whereby the dimensions of the extracellular compartment are increased by vasogenic extracellular edema and decreased by neurotoxic edema with cellular swelling. In hydrocephalus, tissue edema around the ventricles and tissue compression of the cortex also change these flow patterns. Likewise, brain tumors change the pattern of flow because of tissue compression and breakdown of the blood-brain barrier. Successful therapeutic interventions, such as delivering medicines to gliomas, are highly dependent on flow patterns.

Convection within the extracellular compartment must be considered for effective delivery of therapeutic molecules to CNS targets through the CSF via intracerebroventricular or intrathecal infusion, directly within CNS tissue by convection-enhanced delivery, or across the blood-brain barrier. Perivascular solute flux is a key determinant of therapeutic distribution through CSF compartments. Thus a greater understanding of the mechanics and determinants of perivascular fluid movement will help surgeons optimize therapeutic delivery. A better understanding of the effects that aging, brain injury, or other pathologic processes have on these dynamics will enable more accurate drug delivery. In principle, drug delivery methods could be adapted to the individual patients once the dynamics of CSF and ISF flow are known.

Question 7: What Should Be the Neurosurgical Involvement in the Critical Care Management of Neurosurgical Patients?

Critical care medicine has developed as a specialty to diagnose, treat, and prevent life-threatening illnesses that necessitate invasive monitoring, as well as pharmacologic and mechanical organ support. Since the era of Harvey Cushing, neurosurgeons have been integrally involved in the delivery of critical care to their patients. Since 2000, interest in the management of neurosurgical patients in the ICU has intensified in several specialties. These units are now referred to as "neurocritical care units" but were previously referred to as "neurosurgical ICUs," which represented the predominance of the patients that occupied the beds. In North America, several professional associations in neurology established a certification council as a mechanism to codify subspecialties, accredit training programs, and certify physicians—all laudable goals. They defined neurocritical care as such a subspecialty.

This career path represents a significant opportunity for neurosurgical trainees. With the accreditation from the Committee on Advanced Subspecialty Training (CAST) of the Society of Neurological Surgeons, neurosurgery has a comparable mechanism for accreditation of programs and certification of trainees. About one critical care position is created by the business generated by four practicing neurosurgeons: a considerable opportunity for neurosurgery as a specialty.

Within neurosurgical residency in the United States, critical care training is now formally included within the curriculum, and competency is monitored by the residency program director and tested in certification examinations (both written and oral) by the American Board of Neurological Surgery. This has been a concerted effort on behalf of neurosurgery organizations to emphasize the importance of critical care management in the training of a contemporary neurosurgeon. With the parallel effort of other specialties, such as neurology and anesthesia, it is yet unclear whether these units will be staffed by multidisciplinary groups or primarily by neurosurgeons. What is also unresolved is whether such an interest in critical care training for neurosurgery residents will be embraced in other countries. The neurosurgeon has a unique responsibility and necessary role in managing and coordinating care for patients in the neurocritical care unit, which should not be abrogated.

Question 8: Neurosurgical Education and Training: Have Duty Hour Restrictions Accomplished the Goals Envisioned by Those Who Advocated for Changes in Neurosurgery Training?

One of the most important goals of the 7th edition of *Youmans and Winn Neurological Surgery* and of this section is educational: to provide comprehensive, up-to-date, neurosurgically relevant information to neurosurgeons in practice and in training. Time alone will not convert those in training to those in practice. This transformation requires what constitutes "training": the acquisition of knowledge, judgment, and technical skill.

Historically, training in neurosurgery grew out of general surgery, as did the discipline as a whole. In the Cushing and post-Cushing era, full training in general surgery preceded a 1- to 2-year experience in neurosurgery with the educational mode akin to an apprenticeship. Before and after World War II, specialty-specific residency training evolved into a more organized educational experience with a specified number of years in duration. Daily work hours were not constrained except by the duration of a day.

As residencies evolved, so did organizations designed to provide oversight and regulation of postgraduate training. As a result of a tragic case in the mid-1980s, the state of New York investigated working conditions and supervision of house officers and, through subsequent legislation, limited work hours of house officers to 80 hours per week. Adding to the general public concern was a study issued in 2000 by the U.S. Institute of Medicine titled *To Err Is Human: Building a Safer Health System.*[31] This study suggested that 50,000 to 100,000 hospital-based deaths occurred in the United States each year in relation to errors. In 2003, the Accreditation Council for Graduate Medical Education (ACGME) enacted (and, in 2011, modified) duty hour restrictions (DHRs) that affected all medical residencies in the United States. These DHRs were not unique to the United States, inasmuch as similar but more constraining regulations were instituted in Europe and the United Kingdom. The changes mandated by the ACGME were envisioned as decreasing patient-related errors and improving resident well-being without compromising resident education and training; however, as outlined as follows, those advocating for change in duty hours appear to be incorrect in their underlying assumptions:

- The ACGME assumed that mastering different disciplines was identical to training required for postresidency work. Common sense would dictate otherwise, and yet DHRs were identical for disparate specialties such as dermatology and neurosurgery. In the nonmedical world, no one questions that training differs according to the task; whether for the Bolshoi Ballet or a baseball team.
- As in specialties, differences exist among individuals in their ability to tolerate sleep deprivation, a trait that may be related to adenosine receptor sensitivity.[32] Individuals choosing to enter specialties known to require long hours and conditions in which sleep deprivation is common may self-select a career in neurosurgery. Moreover, substantial human and animal data demonstrate that individuals can expand their ability to tolerate sleep deprivation. Training in neurosurgery should focus on development of coping skills related to sleep deprivation. After all, neurosurgery training is not an abstract concept; in essence, the goal is to prepare the individual for the practice of neurosurgery, an environment in which hour restrictions currently do not apply.
- Furthermore, many advocates predicated the need for DHRs on the assumption that fatigue, caused by sleep deprivation, compromised patient care; they assumed that DHRs would improve patient safety. These advocates ignored the existing data derived from two decades of DHRs in the state of New York and the lack of improvement in hospital errors. Furthermore, a study from 1995 on surgical residents failed to demonstrate that fatigue affected patient errors or outcome,[33] and these results were further supported by a later study of neurosurgery residents and manual skills.[34] After 2003, when the ACGME instituted DHRs, the preponderance of studies across many disciplines have failed to demonstrate the hoped-for improvement in patient care,[35] even with modification of the DHRs.[36] In contrast, in several neurosurgical studies, DHRs have had a negative effect on patient care.[37-42] For example, in a novel study, Dumont and associates[41] evaluated meningioma resection before and after implementation of DHRs and demonstrated an increase in complication rates in academic units, but not in nonteaching institutions in which DHRs were not in effect.
- Another promised benefit of DHRs was that residents would have more time for education and research. The opposite has occurred because limitation on hours applies to time spent both in teaching and in patient care.[42] In neurosurgery, surveys of faculty members yielded uniformly negative responses about the influence of DHRs on teaching both inside and outside the operating room.[42] An objective measurement of the effect of DHRs is the decrease in residents' performance on in-service examinations for self-assessment, administered by the American Board of Neurological Surgery.[42,43] In addition, many neurosurgery residencies restricted their research exposure for residents, with the resultant decrease in the number of resident-presentations at national neurosurgery meetings.[42]
- House officers have high rates of depression, suicides, and job burnout. Consequently, another motivation for the introduction of DHRs was the concern for the well-being of residents. However, studies have uniformly failed to demonstrate an improvement in psychological difficulties or job burnout in house staff after institution of DHRs.[44,45]

In summary, DHRs have failed to achieve the intended goals of improving patient care or the well-being of house staff. Over the long term, in neurosurgery and perhaps other specialties, compromised inpatient care will potentially continue, and society will come late to recognize that organized medicine failed to anticipate the unintended adverse effect of DHRs. Specifically for neurosurgery education, the implementation of DHRs has had three negative effects: diminution in the overall educational emphasis, constraint on flexibility of individual training, and a deemphasis on research. These three negative effects echo the concerns that Bergland[22] raised in his 1973 article.

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1 Historical Overview of Neurosurgery

James Tait Goodrich and Eugene S. Flamm

Neurosurgery, as a subspecialty in general surgery, is a very recent development, having occurred only in the latter half of the 19th century. Three critical developments and concepts had to occur for neurosurgery to become a specialized subspecialty: anesthesia, antisepsis, and cerebral localization. All three of these developments occurred over less than 40 years (the 1840s to the 1870s). In this chapter, the underlying theme is that neurosurgery advanced as surgeons obtained a better understanding of the anatomy and pathophysiology of the nervous system, a goal that continues to be followed today.

This concept was clearly provided in 1602 by **William Clowes,**[1] a leading surgeon of the Elizabethan age. Clowes invoked a challenge that neurosurgeons must still overcome, even in the age of computerized imaging, microsurgery, and functional neurosurgery:

> Those which are Masters and Professors chosen to performe the like operation, ought indeede to have a Lyons heart, a Ladies hand, and a Haukes eye, for that it is a worke of no small importance.

Hippocrates, the father of medicine, had even further detailed this concept when he stated, "Nullum capitis vulnus contemnendum est": no head injury should be considered trivial.[2]

NEUROSURGERY IN THE PREHISTORIC PERIOD

Neurosurgery is, in many ways, one of the most ancient of professions. Early humans clearly recognized that to bring down an enemy, a blow to the head was the quickest means. To accomplish this goal, a number of weapons and, in particular, clubs were fashioned to inflict these injuries. Numerous anthropologic collections around the world include examples of skulls with head injuries; more remarkable are a number of skulls with successful trephinations: that is, the patient clearly survived the surgical opening of the skull.[3-5] From some cultures, such as early Peruvian communities, there exist many skulls that show evidence of trephinations, in most cases for reasons that remain unknown. Paul Broca (1824-1880) in the mid-19th century was one of the first to speculate that this procedure was performed for religious or medical reasons, but there is no documentation for why these procedures were done. It has become apparent that the surgical skill for performing a trephination was worldwide; there are examples from virtually every major civilization, some dating back approximately 12,000 years. There are three common methods for performing a trephination: (1) scraping away the bone, (2) drilling a series of small holes and connecting them, and (3) making cross-hatch cuts in the bone and connecting them to remove a rectangular piece of bone. A trephine skull on which the scraping technique was used, from the early Chimu culture in Peru, and two examples of the typical tool used to perform the scraping (called a *tumi*) are illustrated in Figure 1-1.

ANCIENT EGYPTIAN NEUROSURGERY

The earliest known written documents that relate to early neurosurgery date from the ancient Egyptian period. During this period, which covered approximately 30 successive dynasties, the earliest known practicing physician and Egyptian polymath lived: **Imhotep,** or **Ii-em-Hotep** (c. 2650-2600 BC). So powerful was Imhotep's influence that he was given divine status after his death. This period of history has provided the earliest known existing medical and surgical writings. Three Egyptian papyri that have relevance to medicine still exist: the Ebers, Hearst, and Edwin Smith papyri.[6-8]

According to these Egyptian papyri, the practice of medicine was based largely on magic and superstition. Medical and surgical treatment relied on simple principles, whereby nature provided restoration of health with little intervention and mostly observation with simple mendicants. Of interest to modern neurosurgeons is the concept that the Egyptians realized that immobilization in a neck or back injury was important in reducing further injury. These early physicians commonly prescribed and applied splints for treatments.

The oldest medical text dates from this early civilization and was written in the 16th century BC, approximately 300 years after Hammurabi. This text, now called the *Ebers papyrus*, includes more than 100 pages of hieratic writing and is of interest for its extensive discussions of contemporary surgical practice. Included are discussions of the removal of tumors, along with recommendations for the surgical drainage of abscesses.[6]

The oldest work that deals extensively with medical and surgical techniques to deal with traumatic injuries is the *Edwin Smith papyrus*. Edwin Smith was from New York but had moved to Luxor, Egypt, to become an antiquities dealer; he acquired this papyrus in 1862. Smith spent considerable time translating the document into English. This didactic work appears to have been intended to be a surgical textbook. It was originally written during the time of the New Kingdom. This papyrus scroll is 15 feet in length and 1 foot in width and is written in a cursive hieratic script. The surviving text consists solely of a list of 48 cases, including 22 cases of injuries to the spine and cranium. There is even a case of a cranioplasty (Case 9), discussed along with what might be the earliest reported case of neurofibromatosis (Case 45). Each case is discussed with a diagnosis, followed by a formulated prognosis. As a result of scholarly research by Professor James Henry Breasted, this papyrus was translated again in 1930 from the original hieratic script. More recently (2012), a neurosurgeon (Gonzalo M. Sanchez) and a hieratic script expert (Edmund S. Meltzer) collaborated on reinterpreting the document and provided a more detailed medical/surgical explanation of the various cases. The papyrus is now in possession of the New York Academy of Medicine.[8-10] The following two cases show the insight and some of the techniques illustrated in this early historical papyrus[9]:

> Case Two
>
> **Title:** Instructions concerning a gaping wound in his head, penetrating to the bone.
>
> **Examination:** If thou examinest a man having a gaping wound in his head, penetrating to the bone, thou shouldst lay thy hand upon it and thou shouldst palpate his wound. If thou findest his skull uninjured, not having a perforation in it….
>
> **Diagnosis:** Thou shouldst say regarding him: "One having a gaping wound in his head. An ailment which I will treat."
>
> **Treatment:** Thou shouldst bind fresh meat upon it the first day; thou shouldst apply for him two strips of linen, and treat

ABSTRACT

The field of neurosurgery is a very recent one, having developed only as a subspecialty at the end of the 19th century. The profession dates back to origin of *Homo sapiens.* Conflicts, falls, battles, and other events all have led to various forms of head injuries and trauma; people quickly realized that a blow to the head was the quickest way to bring down an enemy or an animal for food. Trephinations of the skull have been found in human skulls more than 10,000 years of age. This chapter is a review of neurosurgery dating to antiquity. In accordance with various schools of surgery and medicine, the development of neurosurgery is detailed from the writings of surgical experts and various schools of teaching around the world. Formal medical education begins with the Greek schools of the Asclepiads and Hippocrates. Greco-Roman surgeons such as Galen of Pergamon used the spoils of war and gladiators to learn human and animal anatomy and then the surgical skills to treat the surgical injuries. During the Byzantine era, the Islamic schools and Arab teachers codified much of the medical and surgical knowledge of antiquity. Although the medieval period in Europe led to the development of some strong and interesting surgical theories, few advances were made in dealing with head injuries. With the Renaissance came a better and more accurate understanding of human anatomy and, in particular, a better understanding of the brain and its underlying function. Modern experimental medicine and science began with the learned societies of Europe and some leading scientists and physicians. However, advancements in a field of surgery depended on three critical developments and concepts: anesthesia, antisepsis, and cerebral localization. No surgeon could operate on the brain without sufficient knowledge of the anatomic location of the lesion. The operation could be safely performed only with an anesthetized patient and good antisepsis. Before antiseptic techniques were developed, more than 85% of treated patients died of some type of sepsis. The 20th century led to the development of modern neurosurgery. With better instrumentation, diagnostic equipment, and superbly trained surgeons such as Harvey Cushing, the specialty of neurosurgery came into being. This chapter details the schools of teaching that led to the development of neurosurgery as a profession and the prominent individuals involved.

Figure 1-1. A skull from Peru with a left frontal trephination accomplished by the "scraping" technique. The surgeon would use the two hand-held Peruvian tumis, positioned in front of the skull. These tumis, made of a copper/bronze mix, date from the period 800-1100 AD. The patient survived the procedure, as indicated by evidence of healed bone regeneration at the site. *(Courtesy James Tait Goodrich, MD, PhD.)*

afterward with grease, honey, and lint every day until he recovers.

Gloss: As for: "Two strips of linen," it means two bands of linen which one applies upon the two lips of the gaping wound in order to cause that one join to the other.

Case Five

Title: Instructions concerning a gaping wound in his head, smashing his skull.

Examination: If thou examinest a man having a gaping wound in his head, penetrating to the bone, and smashing his skull; thou shouldst palpate his wound. Shouldst thou find that smash which is in his skull deep and sunken under thy fingers, while the swelling which is over it protrudes, he discharges blood from both his nostrils and both his ears, and he suffers with stiffness in his neck, so that he is unable to look at his two shoulders and his breast…

Diagnosis: Thou shouldst say regarding him: "One having a gaping wound in his head, penetrating to the bone, and smashing his skull, while he suffers with stiffness in his neck. An ailment not to be treated."

Treatment: Thou shalt not bind him but moor him at his mooring stakes, until the period of his injury passes by….

Other than the isolated cases, these remaining papyri provide little information about the actual practice of neurosurgery.[9,10] It is evident from these writings that Egyptian physicians recognized head injury and would elevate a skull fracture if necessary. At the same time, if the injury appeared to be too severe, then no treatment was advocated. Both the management and the codification of head injury were not formalized until the development of the Greek schools of medicine (c. 460 BC), by individuals such as Hippocrates.

CLASSICAL PERIOD: GREEK AND BYZANTINE NEUROSURGERY

Hippocratic School

The intellectual evolution of neurological surgery originated in the golden age of Greece with the founding of the Alexandrian School in 300 BC. For the first time, open anatomic dissection was incorporated into formal lectures.[11] The concept of a surgeon performing surgery on the head and spine also became formalized for the first time. Because of sporting injuries, particularly gladiator injuries, and wars, head injuries were clearly plentiful and provided ample opportunities to develop the early skills of neurosurgery.

The earliest medical writings from this period are those of **Hippocrates** (c. 460-370 BC), the most celebrated of the Asclepiadae.[12-14] Classical philologists consider that many of the writings attributed to Hippocrates were in reality composed by members of the Hippocratic School. The Hippocratic collection includes clinical cases based mainly on observation, and in most cases, only the simplest of theories are offered. The many neurological cases within the Hippocratic corpus reveal that the understanding of head injury was rather sophisticated. Hippocrates was the first to describe a number of neurological injuries, most resulting from battlefield injuries. The vulnerability of the brain to injury was categorized by location in the brain, from lesser to greater, with injury to the bregma being represented as a higher risk than one to the temporal region, which, in turn, was more dangerous than an injury to the occipital region.[14-16] Hippocrates devoted a full chapter to injuries of the head, *De capitis vulneribus*, which deals with the diagnosis and management of head injuries and is the first systematic work devoted to head injuries. He divided head injuries into five categories that were based on the details of the skull fracture. Five types of fractures are described: linear fracture, contusion, depressed fracture, hedra (or dent) occurring with and without fracture, and contrecoup fracture.[14] The neurological condition of the patient was not thought to have any bearing on the surgical indications. Surgery was advised according to the type of fracture. The greater the injury to the skull, the less was the need for trephination. The technical aspects of the process of trephination are presented in a curious mixture of sound advice and incomprehensible admonitions (Fig. 1-2).

The Hippocratic writings contain numerous anatomic descriptions, even though human dissection appears not to have been routinely practiced. The Greeks also were without an anatomic vocabulary, not to be introduced until Galen standardized the use of the Latin language in medicine. These deficiencies combined to limit any standardized anatomic procedures or the practice of surgery. Despite these drawbacks, the Hippocratic writings contain a number of interesting neurological case studies that reflect a view of the early practice of neurosurgery (Fig. 1-3).

One of the earliest descriptions of subarachnoid hemorrhage appears in the *Aphorisms*[17,18]:

> When persons in good health are suddenly seized with pains in the head, and straightway are laid down speechless, and breathe with stertor, they die in seven days, unless fever comes on.

Hippocrates and his followers also warned against incising the brain, as convulsions can occur on the opposite side and render the prognosis especially serious. Hippocrates advised against making an incision over the temporal artery, because this could also lead to contralateral convulsions. The writings of Hippocratic schools demonstrate the simple concepts of cerebral localization. Also well understood was the concept of a potential critical prognosis in head injury and that sometimes it was best not to operate. In this early era of medicine, the risk of infection, lack of antiseptic technique, and minimal anesthesia all precluded any serious or aggressive surgical intervention in head injury.

Herophilus of Chalcedon

From the region of the Bosporus, among the crowded schools of Alexandria, came **Herophilus (Herophilos)** (335-280 BC), a student of Praxagoras and Chrysippus and a member of the educated dynasty of Ptolemies. According to his writing, Herophilus performed dissection on humans and not on animals as was the common practice then.[19-21] The work of Herophilus, along with that of Galen later, was key in the task of developing an anatomic nomenclature and in forming a much-needed language of anatomy. In examinations of the nervous system, Herophilus's neurological contributions included following the origin of nerves to the spinal cord anatomically. He was the first to recognize the difference in the motor and sensory tracts. Furthermore, he differentiated between nerves and tendons, thereby correcting a common earlier error. Herophilus was first to detail the anatomy of the brain ventricles and venous sinuses. The description of the "confluence of the sinuses," or *torcular herophili* (Λανοζ = wine press), comes from his early investigations. Herophilus provided the first description and naming of the choroid plexus *(plexus choroides)*, so named because of its resemblance to the vascular membrane (chorion) of the fetus. Herophilus also provided the first detailed account of the fourth ventricle and that peculiar arrangement at its base that he called the *calamus scriptorius* (Αναγλυφη τχ χαλαμχ), which he described as "resembles a pen in writing." Among his many other contributions was his recognition of the brain as the central organ of the nervous system and the seat of intelligence.[20]

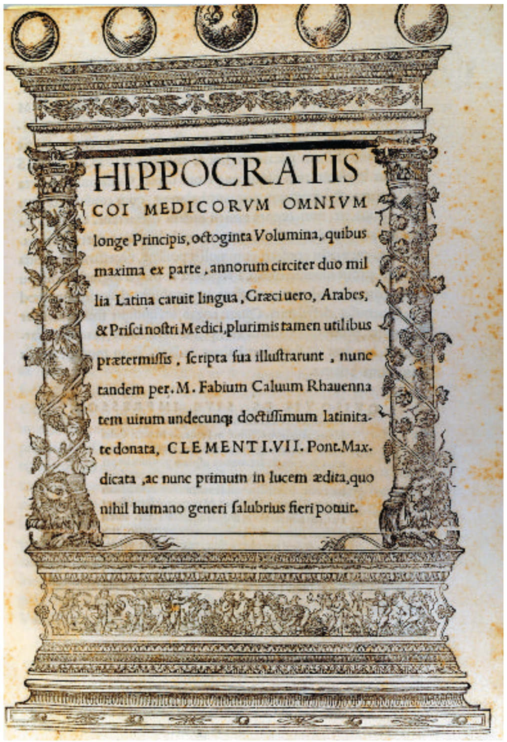

HIPPOCRATIS
COI MEDICORVM OMNIVM
longe Principis, octoginta Volumina, quibus maxima ex parte, annorum circiter duo millia Latina caruit lingua, Græci uero, Arabes, & Prisci nostri Medici, plurimis tamen utilibus prætermissis, scripta sua illustrarunt, nunc tandem per M. Fabium Caluum Rhauennatem uirum undecunque doctissimum latinitate donata, CLEMENTI. VII. Pont. Max. dicata, ac nunc primum in lucem ædita, quo nihil humano generi salubrius fieri potuit.

Figure 1-2. Title page from the first printed edition of the writings of Hippocrates, in 1525. *(From Hippocrates.* Coi Medicorum Omnium Longe Principis, Octoginta Volumina, Quibus Maxima ex Parte, Annorum Circiter Duo Millia Latina Catruit Lingua, Gaecivero, Arabes & Prisci Nostri, Scripta sua Illustrarunt….Latuita te Donata, Clementi. LVII. Pont. Max. Dictata…. *Rome: Franciscus Minutius Calvus; 1525. Courtesy James Tait Goodrich, MD, PhD.)*

Herophilus's writings were not free of errors. An anatomic error that remained in vogue for nearly 1800 years was his introduction into the anatomic literature of the *rete mirabile*, a structure present in ungulates but notably lacking in higher primates. In ungulates this structure acts as an anastomotic network at the base of the brain, a structure that the Greeks incorporated into the early physiologic theories of brain function.[22] In the 2nd century AD, the *rete mirabile* was later further detailed and elaborated on by Galen of Pergamon. The concept of this structure became entrenched in the anatomic literature, having been codified by the Byzantine Islamic and later European medieval writers, until the 16th century, when it was finally challenged in the anatomic accounts of Andreas Vesalius (1514-1564) and Jacopo Berengario da Carpi (1460-1530).[23-25] Both of these anatomists, who performed their own human dissections, clearly recognized that the *rete mirabile* did not exist in humans. It is possible that the human cavernous sinus confused the early writers and they in turn thought that this represented the *rete mirable*.

Aulus Aurelius Cornelius Celsus

Celsus (25 BC-50 AD) was neither a physician nor a surgeon, nor was he a bedside practitioner; rather, he was an intellectual patrician and a medical encyclopedist who attempted to compile all of the important writings of his time. His writings had an important early influence on medicine and surgery. His medical writings were mostly a compilation of the writings from the schools

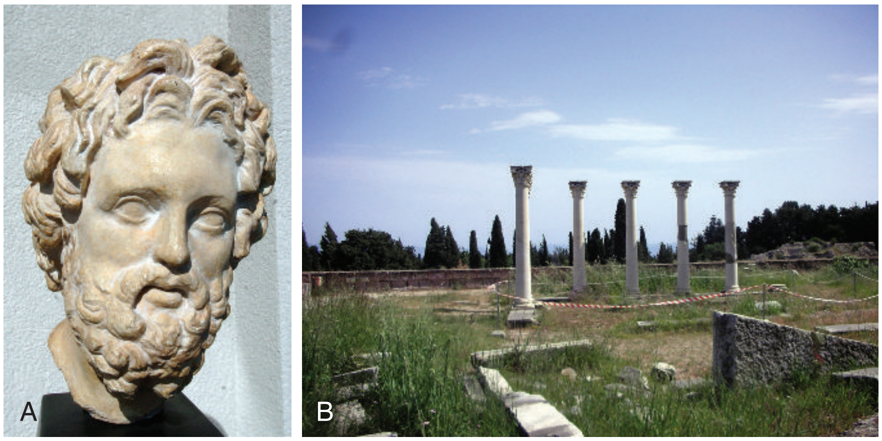


Figure 1-3. A, Bust of Asclepius (Aesculapius). **B,** Temple of Asclepius on the island of Kos, Greece. Kos is the birthplace of Hippocrates and the Hippocratic schools of medicine. *(Courtesy James Tait Goodrich, MD, PhD.)*

of Hippocrates and the Asclepiadae and from the Alexandrian schools. Celsus lived during the height of the Roman Empire. As counselor to the emperors Tiberius Caesar and Caligula, Celsus was held in great esteem. His book on medicine, titled *De Re Medicina*,[26,27] is now considered one of the most important early medical documents after the Hippocratic writings. Because this work was originally lost, Celsus was one of the few major authors whose works were not transcribed by the Islamic/Arabic writers. In 1443, an early Celsus manuscript was uncovered by Thomas of Sarzanne (later Pope Nicolas V) and reintroduced to the medical community. With the introduction of printing and moveable type, Celsus's manuscript became the first medical writing to be printed (1478), before even the writings of Hippocrates and Galen. In the *De Re Medicina*, Book IV, Chapter 10, his classic description of inflammation appears: "Notae vero inflammationes sunt quattuor, rubor, et tumor, cum calore et dolore [There are four signs of an inflammation: redness, swelling, heat, and pain]."

Celsus made a number of interesting early observations in the field of neurosurgery. Celsus believed that all surgeons should be ambidextrous. Book VIII, Chapter 4, contains one of the earliest descriptions of an epidural hematoma resulting from a ruptured middle meningeal artery.[27] For head-injured patients, Celsus recommended that the surgeon always operate on the side of greater pain. Celsus was a strong advocate for use of the trephine in head injuries. He noted that the trephine should always be placed at the point where the pain is best localized. Celsus described a technique for a craniectomy that involved drilling a number of holes and then connecting them with a hammer and chisel. The chisel had a protective blade, which separated the dura from the bone and prevented injury to it during the surgical dissection. However, he regarded the operation of trephination as the *ultimum refugium*, to be used only when all conservative measures had been exhausted (Fig. 1-4).

Several interesting neurological conditions are described in the *De Re Medicina*, including accurate descriptions of hydrocephalus and facial neuralgia. In accordance with earlier writings, Celsus clearly recognized that a high cervical spine fracture could lead to vomiting and difficulty in breathing. Injury to the lower lumbar spine could cause weakness or paralysis of the legs, as well as urinary retention or incontinence.

Galen of Pergamon

Galen of Pergamon (129-200 AD), whose name comes from *galenos*, meaning "calm" or "serene," is remembered as a powerful personality and an original investigator, as well as a leading proponent of the doctrines of Hippocrates and the Alexandrian school. Galen began his writing career at the age of 13 and continued to add to the literature of medicine, philosophy, mathematics, and grammar until his death at the age of 70. His writings remained the most extensive in early antiquity in size, scope, and influence. Galen's prodigious output still accounts for more than 80% of all the surviving medical writings of antiquity.[28] Many of his writings and manuscripts, however, were lost in a fire at the Temple of Peace in Rome (Figs. 1-5 and 1-6).

Galen's life and activity occurred during the reigns of two of the greatest Roman emperors: Antoninus Pius (86-161 AD; reigned 138-161 AD) and Marcus Aurelius (121-180 AD; reigned 161-180 AD). Galen became the physician to the gladiators of Pergamon and, as a result, saw and treated many traumatic injuries. Drawing from both his surgical experiences and anatomic studies, he made a number of contributions to the fields of neurology, neurosurgery, and neuroanatomy. In his writings, Galen differentiated between the pia mater and the dura mater and gave one of the earliest accurate descriptions of the corpus callosum, the ventricular system, the pineal and pituitary glands, the infundibulum, and what is now called the *aqueduct of Sylvius.* Nearly 1600 years before the Scottish anatomist Alexander Monro *secundus* (1733-1817), Galen also described the structure now called the *foramen of Monro.* He performed a number of anatomic experiments, including early studies on the effects of transection of the spinal cord.[29,30] From these studies, Galen was able to describe the specific loss of function below the level of the transection. In a now classic experiment, he sectioned the recurrent laryngeal nerve in dogs and described the hoarseness

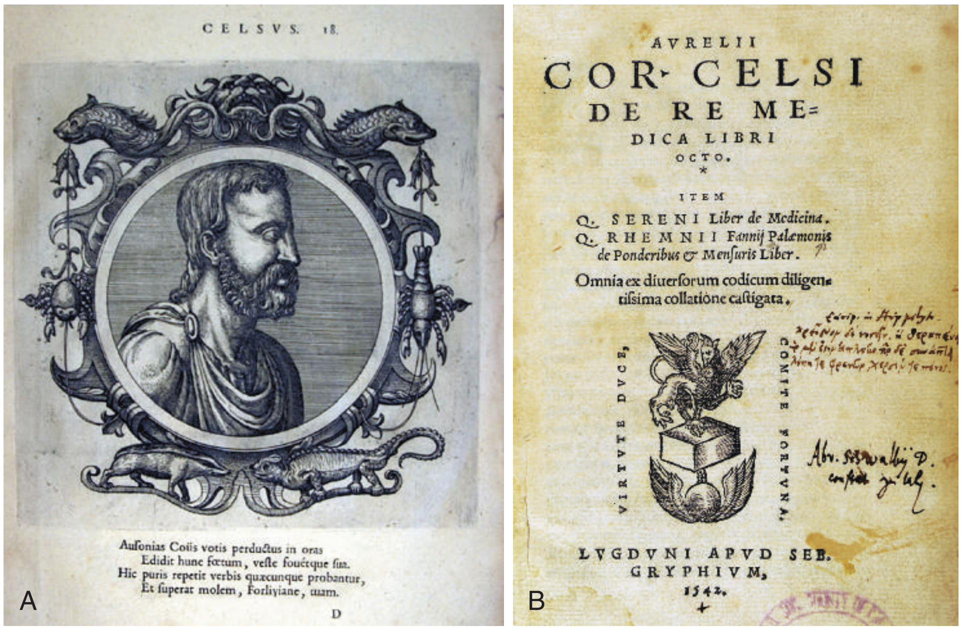


Figure 1-4. A, Portrait of Celsus. **B,** Title page from a 1542 edition of Celsus's writings. *(Courtesy James Tait Goodrich, MD, PhD.)*

Figure 1-5. Portrait of Galen of Pergamon. *(Courtesy James Tait Goodrich, MD, PhD.)*


GL. GAL.
DE VSV PARTIVM CORPORIS HVMANI,
LIBRI XVII.
Nicolao Regio Calabro interprete, ex plurium Græcorum exemplarium collatione caſtigatiores quàm vnquam aliâs.
Acceſsit diuiſio ſingulorum librorum in capita, præfixis argumentis capitum ſummam complectentibus, cum indice copioſiſsimo.
IN VIRTVTE ET FORTVNA.
LVGDVNI,
Apud Gulielmum Rouillium,
ſub ſcuto Veneto.
1550.

Figure 1-6. Title page of one of Galen's important writings on the anatomy and physiology of human anatomy. *(From Galen of Pergamon.* De Usu Partium Corporis Humani, Libri XVII. Nicolao Regio Calabra Interprete…. *Lugduni [Lyons]: Apud Gulielmum Roullium; 1550. Courtesy James Tait Goodrich, MD, PhD.)*

that occurred (discussed further in Chapter 7; see also *De usu partium corporis humani*, Book VII, Chapters 11-18).[29]

Galen was the first to provide an early classification of the cranial nerves. In his original classification, he described 11 of the 12 cranial nerves, but because he combined several, he thought the total was only 7. In his descriptions, Galen regarded the olfactory nerve as merely a prolongation of the brain and hence did not consider it as a cranial nerve.[29] Galen published a number of interesting views on higher cortical functions, embracing views that the brain was responsible for intelligence, fantasy, memory, and judgment. In studying muscle contractions, Galen made the observation that the stimulus originated in the brain and the impulse was carried to the muscle by nerves. These views were original and represented an important departure from the cardiocentric teachings of the earlier medical and philosophical schools such as Aristotle's. Galen challenged the Hippocratic view that that the brain was only a gland and instead attributed to the brain the powers of voluntary action and sensation (encephalocentric), this last being a remarkable advance in thinking for the period.

From a series of anatomic studies, Galen provided some of the earliest observations on cervical spine injury and the resulting disturbance in arm function. Further study of spinal cord injury led to his elegant description of what is now called the *Brown-Séquard syndrome*, a hemiplegia with contralateral sensory loss that results from a hemisection of the cord.[30] Galen provided one of the earliest clinical descriptions of hydrocephalus and clearly recognized the poor prognosis in affected individuals. Using his extensive experience in head injuries, he provided some innovative arguments for elevation of depressed skull fractures, fractures with hematomas, and comminuted fractures. Galen was more aggressive in his treatment by recommending the removal of bone fragments, particularly those pressing into the brain. In describing surgical techniques, Galen detailed a safer and more reliable use of the trephine and argued particularly for continuous irrigation to a trephine to avoid delivering excessive heat and causing injury to the underlying brain. Galen, following or adapting earlier Hippocratic views, reiterated the concept that the dura should never be violated by the trephine.

Galen was clearly a brilliant physician, surgeon, and early innovator in medicine. Unfortunately, Galen's writings contained a number of errors, but the historical world, particularly the Byzantine world, later accepted Galen's writings as the only true authority. As a result, Galen's writings obtained the status of unchallengeable medical dogma. Galen's work on neurology and neuroanatomy also remained essentially unchallenged for the next 1500 years. For all practical purposes, any relevant new investigations ceased altogether from Galen's death until the Renaissance. Some writers have pointed out that Galen was literally idolized by Arabic/Islamic writers and, later, the physicians of the Middle Ages. As a result, Galen's errors (e.g., writings about the *rete mirabile*) also remained part of the anatomic literature. Each of these errors or incorrect beliefs were carefully repeated and scribed by subsequent Arabic/Islamic and medieval physicians and surgeons. Because of the strength of Galen's views and those of subsequent writers, no one was willing to challenge what were clearly anatomic and scientific errors, which had a stultifying effect on science and medicine for approximately 1500 years.

Paulus Aegineta (Paul of Aegina)

Paulus Aegineta (625-c. 6) was a brilliant Byzantine Greek physician and surgeon who also trained in the Alexandrian school. He was an influential compiler of works in both the Latin and Greek schools; his writings, especially *The Seven Books of Paul of Aegineta*, were being consulted until well into the 17th century; the *Compendium* was translated into English in the 19th century.[31,32] His skill as a surgeon, described in the sixth book of the *Compendium*, clearly reflected an unusual understanding of surgical principles. His skills became legendary, causing patients from far away to consult him. Although Paulus venerated the teachings of the ancients as tradition required, he also introduced his own techniques with good results. His classic work, *The Seven Books of Paul of Aegineta*, contains an excellent section on head injury and the use of the trephine.[31,32] Paulus classified skull fractures in several categories: fissure, incision, expression, depression, arched fracture, and, in infants, dent (what is now called a *ping pong fracture*). In dealing with fractures, he used an interesting skin incision: two incisions intersecting one another at right angles, forming the Greek letter X, one leg of the X incorporating the scalp wound. For the comfort of the patient undergoing a trephination, he would stuff the patient's ear with wool so that the noise of the trephine would not cause undue distress (see *The Seven Books of Paul of Aegineta*, Book VI, Section XC[32]) (Fig. 1-7).

In a contemporary discussion on hydrocephalus, Paul of Aegina introduced the intriguing concept that traumatic birth delivery and intraventricular hemorrhage were related; he appears to have been the first to suggest the possibility that an intraventricular hemorrhage and its "inert fluid" might actually cause hydrocephalus:

> The hydrocephalic affection…occurs in infants, owing to their heads being improperly squeezed by midwives during parturition, or from some other obscure cause; or from the rupture of a vessel or vessels, and the extravasated blood being converted into an inert fluid….
>
> **(Book VI, Section 3, page 250[32])**

One of the reasons for Paulus's longstanding influence was that several of his manuscripts survived and were continuously recopied by amanuenses over the centuries. These manuscripts depict a number of surgical instruments that he designed specifically for neurosurgical procedures; these include elevators, raspatories, and bone biters. He also introduced trephine bits with conical styles to reduce the risk of plunging, along with different biting edges. Because of his sophisticated wound management, he probably had better-than-average surgical outcomes. He made use of wine-soaked dressings (helpful in antisepsis, although a concept then unknown), and he stressed that dressings should be applied with no compression to the brain itself.

The Greek and Byzantine periods were eras of intense scholarship and original investigation in medicine and surgery and produced physicians and surgeons who were intensely interested in the better management of their patients. As discussed, individuals such as Galen of Pergamon, Paulus Aegineta, Herophilus of Chalcedon, and members of the Hippocratic school all attempted to improve management in head injuries and at the same time uncover some of the principles of brain function. Unfortunately, as discussed in the next section, further neurological investigation and the development of new surgical techniques were seriously impaired because of scholarly reverence of these earlier writers. Although there were some exceptions to this trend, they were distinctly uncommon.

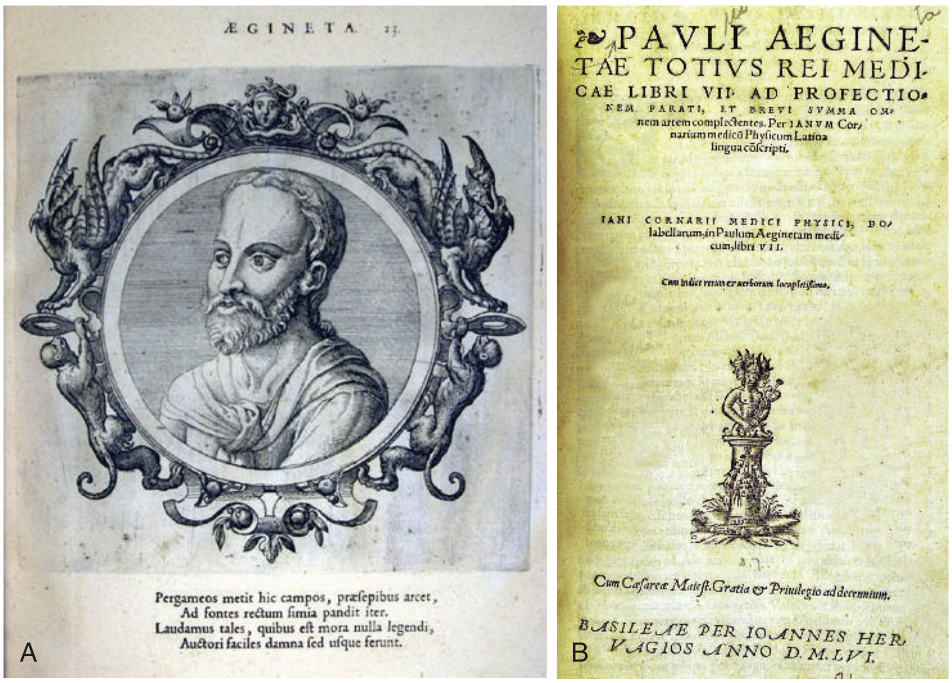


Figure 1-7. A, Portrait of Paulus Aegineta. **B,** Title page of the collected works of Paulus Aegineta. *(Courtesy James Tait Goodrich, MD, PhD.)*

ISLAMIC/ARABIC MEDICINE: PRESCHOLASTIC PERIOD

After the great Greek and Roman periods of medicine, the intellectual centers of this discipline shifted to the Islamic/Arabic and Byzantine cultures. This era, "The Golden Age of Islamic Medicine," had an influence that lasted from approximately AD 750 until 1200, when the medievalist era began and the influential schools of medicine shifted to Europe. Interestingly, this period in Europe was intellectually quiescent and unimaginative because this area of the world had been overrun and ruled by barbarians (Huns, Goths, and Norsemen), individuals not concerned with high scholarship. Unfortunately for neurosurgery, this was a dormant period; the dormancy prevailed in all facets of surgery. The Islamic/Arabic schools were satisfied to codify the surviving manuscripts from the Greek and Roman period. Remarkable insights were offered, but this was a rather rare phenomenon. However, thanks to the zeal of the Arabic amanuenses, the best of Greek medicine was made available to Arabic readers by the end of the ninth century and remained available into the Middle Ages.

Unfortunately, a rigid scholastic dogmatism became characteristic of these learning centers. Rather than offering innovation, the "writers" became copyists of the great works of antiquities. As a result of their efforts, an amazing number of manuscripts were translated from Latin, Greek, and Hebrew into Arabic, and knowledge that could have been easily lost into antiquity was systemized. Unfortunately, as copyists, these writers frequently added their own "favorite" or contemporary view of the manuscript, and some of the originality was consequently lost in translation. In fairness to these early copyists, they rendered the service of preserving knowledge; in Europe at this time, having been overrun by barbarians, scholarly pursuit remained at a standstill.

A number of modern writers have offered the view that it was the religious influence of the Koran that caused the absence of originality and progress in Islamic/Arabic medicine. It has often been commented on that the Koran forbade dissection; this is only partially correct. Some dissection was allowed and reported on by writers of this time. However, as a practical consideration, the climate in this part of the world was hot, which caused rapid putrefaction of cadavers and made anatomic dissection undesirable. The opinion of these schools was that the Greeks had already accomplished most of the anatomic studies of interest, and so Islamic students of medicine felt no need to duplicate these earlier and more superior efforts. There were some rare exceptions that are discussed as follows.

In Islamic/Arabic medicine, the concept of a physician doubling as a surgeon was rarely acceptable. The more typical practice for a physician was to confine himself to writing learnedly and assign the "menial" tasks of surgery to an individual of a lower class, most typically an apprentice surgeon. As a result of this "demotion" of the surgeon to a mere plebian, the advances in surgery and anatomy developed by the great Alexandrians, among others, were essentially ignored or lost. Fortunately, the writings of physicians such as Galen of Pergamon and Paulus Aegineta were saved and translated into Arabic, but few new techniques or concepts were added.

The dominant period for Islamic scholarship in medicine was the 10th through 12th centuries. Several medical scholars rose to prominence during this period; among the most illustrious were Avicenna (980-1037), Rhazes (865-925), Avenzoar (d. 1162), Albucasis (1013-1106), and Averroës (1126-1198). The writings of these great physicians reveal an extraordinary effort to canonize the writings of their Greek and Roman predecessors. Rather than innovation, these Islamic/Arab scholars and physicians became the guardians and academics of Hippocratic, Greek, and Galenic writings, which now became dogma.

Figure 1-8. Image from a later copy of a manuscript by Avicenna. A physician is depicted applying "red-hot" cautery to a patient's leg. *(Courtesy James Tait Goodrich, MD, PhD.)*

One of the most beneficial teaching methods, and quite modern, did arise during the Islamic/Arabic period: the concept of bedside medical care and teaching. The relative paucity or lack of regular anatomic dissection, along with the prevalent view that surgery was performed only by individuals of inferior status, inevitably reduced any preoccupation with surgical art. Another unfortunate surgical practice that occurred during this period was the reintroduction of the Egyptian technique of using the hot cautery for control of bleeding. In addition, hot cautery was also employed in lieu of the scalpel to create a surgical incision, the results of which often proved unfortunate for surgical patients (Fig. 1-8).

One of the significant scholars of this period was **Rhazes (Abu Bakr Muhammad Ibn Zakariya)** (865-925). Rhazes was a scholarly physician, learned in diagnosis, and a review of his writings reveals him to be loyal exclusively to Hippocratic teachings. Rhazes developed a considerable reputation that led him to become a court physician. Rhazes was not a surgeon, although he did write on surgical topics.[33] Rhazes introduced the use of animal gut as a suture material. Rhazes was an early believer in the concept of "concussion" and would advocate surgery for penetrating injuries of the skull—this in a period when these types of surgical outcomes were almost always fatal. Rhazes believed that head injuries were among the most devastating of all injuries. Because skull fractures could be permanently damaging to the patient as a result of the compression of the brain, his surgical advice would be to elevate these depressed areas of the fractured skull.

Among the most influential physicians of this period was **Avicenna** (980-1037), physician and philosopher of Baghdad, also known as the chief or "second doctor," the first being Aristotle. Avicenna's writings and translations clearly extended the original Greek influence with a force so persuasive and durable that it remained the dominant scholarship until well into the 18th century. His greatest contribution must be judged to have been the detailed translation of Galen's collected works, the *Opera Omnia*. Avicenna's major work, *Canon Medicinae*, was an encyclopedic effort clearly based on the writings of Galen and Hippocrates.[34] The Greek word *canon* refers to a straight rod, a carpenter rule, or standard of measurement. Accordingly, Avicenna's *Canon* became the "rule," the codification of Galen's and Greek medicine. The *Canon* contains a number of interesting neurological discussions. Avicenna provided an early and accurate clinical understanding of epilepsy, for which his treatment consisted of administering various medicants and herbals with described good results. Avicenna apparently conducted anatomic studies, although he did not discuss this directly. He gave a correct anatomic commentary on the vermis of the cerebellum

Figure 1-9. Unpublished manuscript leaf from a later collection of works of Avicenna. Avicenna is depicted participating in an anatomic dissection. *(Courtesy James Tait Goodrich, MD, PhD.)*

Figure 1-10. An illustration from Avicenna's *Libor Canonis.* Pictured is a "rack" device for dealing with fractures and injuries to the spine. *(From Avicenna.* Liber Canonis, de Medicinis Cordialibus, et Cantica. *Basel: Joannes Heruagios; 1556. Courtesy James Tait Goodrich, MD, PhD.)*

and the "tailed nucleus," now known as the *caudate nucleus.* Avicenna's writings on the treatment of spine injuries and stabilization reveal remarkably modern views for this area[35-37] (Figs. 1-9 and 1-10; see also Fig. 1-8).

Whereas Avicenna was clearly the "second doctor," **Albucasis (Abu Al-Qasim or Al-Zahrawi)** (936-1013), a learned Islamic Moorish Spaniard, was clearly the best surgeon of the times. In the Islamic tradition, Albucasis was both a great compiler and a serious scholar whose writings (≈30 volumes) were focused mainly on surgery, dietetics, and materia medica. Albucasis's insights into the importance of surgery are clearly revealed in his introduction to the collected works.[38,39] In his introduction, Albucasis provides an interesting discussion about why Arabs had made so little progress in surgery. Albucasis attributed this lack of progress to a lack of anatomic study and inadequate knowledge of the classics. Albucasis clearly believed that anatomic studies were the key to learning and certainly key in performing any surgical interventions. Although his thoughts on anatomic studies were excellent, Albucasis unfortunately popularized the frequent use of emetics as prophylaxis against disease, a form of medical treatment that survived in the form of "purging" and a medical practice that continued until well into the 19th century. So influential were Albucasis's surgical writings that they remained in use in the schools of Salerno and Montpellier for approximately 500 years and had an enormous influence on medicine in the Middle Ages (Fig. 1-11).

Figure 1-11. An allegorical scene of Albucasis operating in the field on an injured soldier. Albucasis is shown removing an arrow from a patient's chest. Described in the 17th-century Scultetus monograph on surgery. *(From Scultetus J.* Χειροπλοθηκη [Cheiroplothiki]. Armamentarium Chirurgicum XLIII. *Ulm, Germany: Balthasar Kühnen; 1655. Courtesy James Tait Goodrich, MD, PhD.)*

The final section of the *Compendium* contains a lengthy summary of contemporary surgical practice.[38-40] Also included in this part of Albucasis's work is a unique collection of illustrations of surgical instruments. These illustrations became a long-lasting influence, inasmuch as his style of instrument was used extensively in the schools of Salerno and Montpellier and later became an important influence in the medieval period. Many of the instruments illustrated were probably designed by Albucasis. In the text, he clearly described their design, along with technical aspects of their use. Following up on the earlier writings of the Greeks, he provided a novel design for a "nonsinking" trephine. The design for this instrument and others became classic and formed the template for many later such instruments. An early and apparently unique technical innovation involved placing a collar on the trephine in a circular manner, a further and rather ingenious design to prevent the trephine from plunging into the brain. Some of the instruments were clearly copied from those described earlier by Paulus Aegineta, but their practical use was further enhanced by their inclusion in the *Compendium.*

Albucasis's treatise on surgery is an extraordinary work in so many ways. The text is rational, comprehensive, well illustrated, and designed with the intent to educate the surgeon on details of each treatment, neglecting not even the types of wound dressings to be used. Albucasis's techniques of brain surgery, however, were extremely crude. In fact, modern readers can only wonder how patients would allow themselves to undergo some of his surgical practices. For chronic headache, he applied a hot cautery to the occiput, burning through the skin but not the bone. Another headache treatment he described required hooking the temporal artery, twisting it, placing ligatures, and then, in essence, ripping it out.

For neurosurgeons, Albucasis identified and described various types of spinal injury. Albucasis recognized the seriousness of spinal injury, particularly dislocation of the vertebrae. In cases of total subluxation, he appreciated that the prognosis was essentially terminal because affected patients demonstrated involuntary activity (passing urine and stool), along with flaccid limbs. He was quite innovative in dealing with the lesser spinal injuries. In his surgical writings, Albucasis described and illustrated some of the methods and splints he used for reduction of such injuries. To modern readers, some of these techniques might seem to be dangerous in design, especially stabilizations that required an aggressive combination of spars and winches, as well as a "stretching" of the spinal column. Following earlier Greek and Byzantine views, Albucasis believed that bone fragments in the spinal canal should be removed. In reviewing skull fractures, Albucasis has an elegant discussion of the pediatric "ping-pong" fracture of the skull[38]:

> This is a fracture due to a fall or a blow from a stone and the like, making a dent in the surface of the bone and a hollow at the site as occurs in a bronze bowl when a blow falls on it and a portion of it is pushed in. This mostly occurs in heads whose bones are soft, as those of children.

The treatment of hydrocephalus was a vexing problem for surgeons and physicians because its outcome was almost always fatal. Albucasis recommended drainage of cerebrospinal fluid in hydrocephalus via a series of drains and wicks. He designed a lenticular shaped surgical tool to make the puncture, which was performed over the anterior fontanelle. Having detailed the technique well, he then noted the outcome is almost always fatal. Of interest is that the surgery was not the issue; rather, he attributed the poor outcomes to "paralysis" of the brain from relaxation. Albucasis cleverly pointed out that the physician must pick the site for drainage carefully and must never cut over an artery because the potential hemorrhage can rapidly lead to death. Some 20th century authors have advocated the treatment of hydrocephalus by binding the head with tight wraps. Albucasis was advocating this form of treatment more than 1000 years ago. For a child with hydrocephalus, he would bind the head with a wrap and then put the child on a "dry diet" with limited fluid intake to help dehydrate the child. In retrospect, this was a rather progressive and reasonable treatment plan for this disorder.[38,39]

MIDDLE AGES: THE AGE OF MEDIEVAL MEDICAL SCHOLASTICISM

In the early Middle Ages, the influence of the Islamic/Arabic schools on medicine was beginning to lessen, along with a geographic switch in which intellectual centers for medicine were forming in Europe. With the advent of medieval scholasticism, a new school of thought developed in which philosophical and metaphysical explanations and dialectic interpretations became prominent in medical schools. One of the preeminent schools proposing this view was the School of Salerno in what is now Italy.[41,42] In much of Europe, the barbarians were still in control, but despite that, physicians were being trained, and libraries were being built and expanded. Throughout Europe, new medical schools were being established at a steady rate.

At the School of Salerno, an early leader in developing medical scholasticism was **Constantinus Africanus** (1020-1087), *magister orientis et occidentis*.[42] Constantine provided an important bridge in medicine by introducing the scholarship of Islamic/Arabic medicine at Salerno and eventually to all of Europe. Constantine received his medical education in Baghdad, learning the prevalent views of Islamic medicine. He moved to a monastery at Monte Cassino, where, in the tradition of this period, he translated Arabic manuscripts into Latin. Modern scholars believe that his translations were somewhat inaccurate and, as a result, introduced errors in the subsequent medical literature. In reviewing some studies, modern historians considered Constantine to be mostly a plagiarist and an unreliable translator. However, his translation of texts from Arabic to Latin were the earliest transfer of Arabic/Islamic medical literature into Europe, which was valuable. Nonetheless, because the original Greek texts had been translated into Arabic, and Constantinus translated the Arabic works into Latin, the legacy of Galen and other early writers remained firmly entrenched as dogma. Rather than providing or developing new ideas, the classical texts in medicine merely propounded medical dogma. How much medical and surgical knowledge was lost or distorted by inaccuracies in these successive translations is unimaginable.

Constantine did make a key contribution to medieval medicine when he reintroduced anatomic dissection with an annual dissection of a pig. Of interest is that as the dissection progressed, the findings were compared with those recorded in the Greek classics. If the dissector's findings did not match those of the ancient texts, they were simply ignored! Constantine was clearly a learned scholar, but his style of teaching became typical of the Medical Ages. Extensive compilations and translations were undertaken, but original thought or advance in knowledge was notably lacking. In the Middle Ages, the School of Salerno did lead the way and was subsequently followed by the great medical schools at Naples, Bologna, Paris, and Montpellier, the early pillars of medieval medicine (Figs. 1-12 and 1-13).

An unusual and remarkable book was produced during this period: *Regimen Sanitatis Salernitum* [*Salernitan Rule of Health*], a work that first appeared in the 12th century and was later republished in approximately 140 different editions extending well into the 19th century.[41,42] This book summaries the Salernitan school directions for medical maintenance and care of patients. In Europe, a strong educational system was being developed, but the treatment of health care remained cloaked in the literature of classical Greeks and Islamic writing; for the most part, surgical

Figure 1-12. An illustration of Constantine the African lecturing at the School of Salerno. *(Courtesy James Tait Goodrich, MD, PhD.)*


CONSTANTINI
AFRICANI POST HIPPOCRATEM ET GALENVM, QVOrum, Græcę linguæ doctus, sedulus fuit lector, medicorũ nulli prorsus, multis doctissimis testibus, posthabendi opera, cõquisita undiq; magno studio, iam primum typis euulgata, præter paucula quędam quæ impressa fuerũt, sed & ipsa à nobis ad uetustissimorum exemplarium manuscriptorum ueritatem tanta cura castigata, ut huius autoris antehac nihil æditum censeri possit. Librorum ægrotis & medicis utilissimorum maximeq; necessariorum catalogum hæc pagina uersa & prima epistola demonstrabunt.

BASILEÆ APVD HENRICVM PETRVM.

Figure 1-13. Title page from a collection of works of Constantine the African, 1536. *(From Constantinus Africanus.* Constantini Africani Post Hippocratem et Galenum. *Basel: Henricus Petrus; 1536. Courtesy James Tait Goodrich, MD, PhD.)*

Figure 1-14. Illustrations of Roger of Salerno demonstrating brain and skull surgery. *(From the Sloane manuscript 1977. Courtesy British Library Board.)*

education and surgical practice continued to be an avocation limited to uneducated barber-surgeons and apprentices. Nonetheless, there were a few exceptionally talented surgeons who developed some original surgical works and practices.

Roger of Salerno (Ruggiero Frugardi) (fl. 1170) is considered the first learned medieval European writer on surgery (Figs. 1-14 and 1-15). Roger was educated in the Salerno tradition and followed many of its teachings. His book on surgical practice, *Practica Chirurgiae*,[43] offers several interesting surgical techniques of interest to neurosurgeons. An example was his technique for checking for a tear of the dura and leakage of cerebrospinal fluid in a patient with a skull fracture. To detect a leak, Roger would have the patient hold his or her breath and strain (i.e., the Valsalva maneuver) and then look for air bubbles around the fracture site, this being a clear sign of a leak. Roger was a pioneer in the techniques of managing peripheral nerve injury. For a severed nerve, he argued for reanastomosis of the nerve ends with close attention paid to their alignment. In dealing with the large bleeding veins of the neck, he urged direct ligation with a suture rather than cautery. For neurosurgeons, several chapters of his text are devoted to the treatment of skull fractures. Much of the described technique mirrors views of earlier classical writers, but the style is clearer and more succinct. This style is exemplified in this short description of management of various skull fractures[43,44]:

> When a fracture occurs it is accompanied by various wounds and contusions. If the contusion of the flesh is small but that of the bone great, the flesh should be divided by a cruciate incision down to the bone and everywhere elevated from the bone. Then a piece of light, old cloth is inserted for a day, and if there are fragments of the bone present, they are to be thoroughly removed. If the bone is unbroken on one side, it is left in place, and if necessary elevated with a flat sound (spatumile) and the bone is perforated by chipping with the spatumile so that clotted blood may be

Figure 1-15. Medieval manuscript on the writings of Roger of Salerno. The lower left image is a gilt-scribed image of Roger lecturing. *(From the Sloane manuscript 1977. Courtesy British Library Board.)*

> soaked up with a wad of wool and feathers. When it has consolidated, we apply lint and then, if it is necessary (but not until after the whole wound has become level with the skin), the patient may be bathed. After he leaves the bath, we apply a thin cooling plaster made of wormwood with rose water and egg.

A 12th-century manuscript owned by Harvey Cushing and attributed to Roger of Salerno contains an early description of a soporific for pain relief, for use in surgery. The soporific consisted of bark of mandragora (mandrake), hyoscyamus (henbane), and levisticum (lovage) seed, all of which were mixed together and ground and then applied wet to the forehead of the patient.[44] In view of the ingredients, it was unlikely that this soporific was able to achieve any real pain relief. In Roger's writings on surgical anatomy, many of the old errors persisted because of his recapitulating earlier anatomic treatises. Roger was particularly fond of citing the writings of Albucasis and Paulus Aegineta. He strongly favored therapeutic plasters and salves but was not a strong advocate of the popular treatment of application of grease to injuries of the dura. Interestingly, Roger advocated the use of trephination in the surgical treatment of epilepsy, although he did not indicate why this technique would work. Chapters (capita) 1 to 13 are of particular interest to neurosurgeons because they detail contemporary surgical treatment of scalp wounds and fractures of the skull. One of Roger's most significant errors in surgical practice was the concept that provoking pus suppuration in a wound encouraged healing. The concept of "laudable pus" in wound healing was introduced here and seriously hampered wound care until the time of Sir Joseph Lister and 19th-century antisepsis.

An unusually talented and inventive medieval surgeon from Bologna was **Theodoric of Cervia (Borgognoni)** (1205-1298). In comparison with Roger of Salerno, Theodoric was a pioneer in the use of aseptic technique: not the "clean" aseptic technique of today, but rather a method based on avoidance of "laudable pus." Theodoric believed that he had found the ideal conditions for good wound healing, which included control of bleeding, removal of contaminated or necrotic material, avoidance of dead space, and careful application of a wound dressing bathed in wine, the last providing a degree of antisepsis. He also argued for primary closure of all wounds when possible and avoiding "laudable pus"[45,46]:

> For it is not necessary, as Roger and Roland have written, as many of their disciples teach, and as all modern surgeons profess, that pus should be generated in wounds. No error can be greater than this. Such a practice is indeed to hinder nature, to prolong the disease, and to prevent the conglutination and consolidation of the wound.

Theodoric's surgical work was first written in 1267, and it is one of the best reviews of contemporary medieval surgery.[45] He is also remembered as one of the earliest writers to include illustrations of his techniques in his book. Theodoric surgical technique called for meticulous (almost Halstedian) techniques, with gentle handling of surgical tissues being key. Theodoric believed that aspiring surgeons should train only under competent masters. In the field of head injury, Theodoric argued that parts of the brain could be removed through a wound with little effect on the patient. In the treatment of skull fractures, he strongly argued for elevating depressed fractures. Theodoric advocated avoiding any punctures of the dura because these could lead to abscess and convulsions, thereby resulting in adverse outcomes. For pain relief during surgery, he developed his own "soporific sponge," containing opium, mandragora, hemlock, and other less important ingredients, which he applied to the patient's nostrils; once the patient fell asleep, Theodoric began surgery. Opium was probably the key ingredient in this recipe.

William of Saliceto (Guglielo da Saliceto) (1210-1277) was a uniquely skilled Italian surgeon and a professor at the University of Bologna. William's book on surgery, *Chirurgia* (or *Cyrurgia*), completed in 1275, contained some highly original concepts that were not totally based on previous classical writings but in which the influence of Galen and Avicenna is clear.[47] This book was written by William for his son Bernardino. The text is mostly original and based on his own observations. Rarely did William quote other writers. Book IV contains the earliest known treatise on surgical and regional anatomy. His most significant contribution during this era was his decision to discard the surgical technique of burning with cautery and use instead the surgical knife[47]:

> De anathomia in communi et de formis membrorum et figures que sunt considerande in incision et cauterizatione.
>
> [The anatomy of the members and the figures concerning the forms of which are to be considered in general and in the incision and cauterization.]

William's writings contain some interesting and unique techniques for a primary peripheral nerve suture repair. In this pre-Harveian era, he was able to distinguish arterial bleeding from venous bleeding by the "spurting" of blood. William's views on the brain were also unique by contemporary standards, inasmuch as he put forth some interesting neurological concepts that the cerebrum governs voluntary motion and the cerebellum involuntary function.

Leonardo of Bertapaglia (ca. 1380-1460) was a prominent 15th-century Italian surgeon and writer. Leonardo established an extensive and lucrative practice in the area of Padua and in neighboring Venice. At a time when anatomic dissection was rarely practiced in Europe, Leonardo became one of the earliest proponents of the study of anatomy. In 1429 he offered a course of surgery that included the dissection of an executed criminal. Leonardo devoted one third of his book to surgery of the nervous system and head injuries.[48,49] He considered the brain the most precious of organs, regarding it as the source of voluntary and involuntary functions. In his treatment of skull fractures, he always avoided materials that might generate pus. Leonardo argued for never placing a compressive dressing that might drive bone into the brain; if a piece of bone pierced the brain, the surgeon was to remove it.

Leonardo put together a set of rules to guide the practice of a 15th-century surgeon that are still applicable five centuries later[49]:

> To…be the perfect surgeon, you must always bear in mind these eight notations, and remembering them you will be preferred to others.
>
> The first task…to become a good surgeon should be to use his eyes….
>
> Second, you must accompany and observe the qualified physician, seeing him work before you yourself practice….
>
> Third, you must command the most gentle touch in operating and treating lest you cause pain to the patient….
>
> Fourth, you must insure that your instruments be sharp and unrusted whenever you cut anywhere….
>
> Fifth, you must be courageous in operating and cutting but timid to cut in the vicinity of nerves, sinews and arteries, and, so as not to commit error, you should study anatomy, which is the mother of this art…perform your surgery cleverly and never operate on human flesh as if you were working on wood or leather….
>
> Sixth, you must be kind and sympathetic to the poor, for piety and humility greatly augment your reputation and the sick will more freely commit themselves to your care.
>
> Seventh, you must never refuse anything brought you as a fee, for the sick will respect you more.
>
> Eighth, you must never argue about fees with the sick, or indeed demand anything unless it be previously agreed upon, for avarice is the most ignoble of vices and should you be so inflicted, you will never achieve the reputation of a good doctor.

Lanfranchi (Lanfranc) of Milan (c. 1250-1306) was a pupil of William of Saliceto and was often referred to as the father of French surgery. Lanfranchi also advocated his teacher's use of the knife in place of the burning cautery. Although born and educated in Italy, he had to leave Italy for France to avoid political strife. His *Cyrugia Parva* details a number of interesting surgical techniques. Lanfranchi perfected the use of the suture for primary wound repairs.[50] He was among the first to associate the direct effect of head injury on brain function. Hippocrates had been the first to articulate the concept of *commotio cerebri*, but Lanfranchi provided the first modern characterization of what is now known as a cerebral concussion. For surgeons, he developed a series of guidelines for trephination in skull fractures and "release of irritation" of dura. Because of the dangers of skull surgery, Lanfranchi argued for employing the trephine only when absolutely necessary; for other cases, he invoked the skills of the "Holy Ghost" to provide the cure. Among his innovative surgical techniques was the development of esophageal intubation during surgery, a technique not commonly practiced until the 19th century. As an educated surgeon and a "surgeon of the long robe" (i.e., academic), he attempted to elevate the art and science of surgery above the mediocre level of the menial barber-surgeon ("surgeons of the short robe"). Lanfranchi also argued against the separation of surgery and medicine, advocated since the time of Avicenna, believing that a good surgeon should also be a good physician (Fig. 1-16).

Another important person in the history of French medicine and surgery was **Henri de Mondeville** (c. 1260-1317). Educated in Paris and Montpellier, Henri later went on to become a professor at Montpellier. Henri was strongly motivated to elevate the profession of surgeon, and he clearly detested the barber-surgeons, stating, "Most of them were illiterates, debauchees, cheats, forgers, alchemists, courtesans, procuresses, etc."[51]


Tracta. Tertij Lanfran.ma. 203

Figure 1-16. Surgical instruments designed by Lanfranchi of Milan. This illustration appeared in this early 1519 book. *(From Lanfranchi of Milan. Chirurgia. In:* Cyrurgia Guidonis de Cauliaco et Cyrurgia Bruni, Teodorici, Rolandi, Lanfranci, Rogerii, Bertapalie. *Venice: Bernardinus Venetus de Vitalibus; 1519. Courtesy James Tait Goodrich, MD, PhD.)*

In 1306 Henri undertook the task of developing a new treatise on surgery for the education of his students at Montpellier. Unfortunately, because of tuberculosis and general ill health, he never completed the manuscript; the edited portions were not published until 1892, when Professor Julius Pagel of Berlin completed the task.[52] Henri adopted and followed a number of the views of Lanfranchi. He was a believer in clean wounds and avoiding "laudable pus." Unfortunately, Henri would be the last surgeon in this era to argue for avoiding "laudable pus." Subsequent surgeons returned to the older belief that the development of pus in a wound was a good sign of healing. Henri offered some originality in wound management by advocating for healing by primary intention: *modus novus noster*. In surgical treatment of wounds, he encouraged the removal of foreign bodies and the use of wine dressings in wound care, the wine acting as an antiseptic and providing better healing. Henri's designs of a number of surgical instruments were clever. He is remembered for the design of a needle holder and also a forceps-type instrument for extraction of arrowheads. Henri was a bit more conservative than his predecessors in dealing with head injuries. He argued against elevating skull fractures if there was no injury to the overlying soft tissues, believing that nature would do a better job of healing the fracture by natural union. It was his opinion that unnecessary exploration and probing of the wound would only cause more injury than natural healing: in retrospect, such an insight into wound care was brilliant.[51]

No history of surgery can be complete without a discussion of the contributions of **Guy de Chauliac** (1300-1368).[53] He was clearly the most influential European surgeon of the 14th and 15th centuries. He was so highly respected that he became physician to three popes at Avignon (Clement VI, Innocent VI, and Urban V) and leading surgeon and educator at the school of Montpellier. Guy was educated in Toulouse, Paris, Montpellier, and Bologna. He was an early proponent of anatomic dissection of a human cadaver. He stated, "In these two ways we must teach anatomy on the bodies of men, apes, swine, and divers other animals, and not from pictures, as did Henri de Mondeville who had thirteen pictures for demonstration of anatomy."[51] His writings were popular and continued to exert an influence on surgery until well into the 17th century. His principal didactic surgical text, scribed in 1363, was titled the *Collectorium Cyrurgie*.[53,54] There are 34 known manuscripts of this work; the first printed edition appeared in 1478, and more than seventy editions have been published since (Fig. 1-17).

In promoting surgeons as individuals more skilled than "mechanics" (i.e., barber-surgeons), he stated four conditions that must be satisfied for a practitioner to be a good surgeon: (1) the surgeon should be learned; (2) he should be expert; (3) he must be ingenious; and (4) he should be able to adapt himself (from the introduction of *Ars Chirurgica*). Guy devised interesting techniques for the treatment of head injuries. For example, before the beginning of surgery, he recommended shaving the patient's head so as to prevent hair from getting into the wound and interfering with primary healing. For depressed skull fractures, Guy preferred to put wine-soaked cloths into the injured site to assist healing. He categorized head injuries into seven types and discussed the management of each in detail. He believed that scalp wounds required only cleaning and débridement but that a compound depressed skull fracture must be treated by means of trephination and elevation. Skin closure was done by primary repair, for which he claimed good results. To help control excessive bleeding and provide hemostasis, he used egg albumin. For reasons that are not at all clear, Guy set back good surgical healing by readopting the views of "laudable pus" as being good for wound healing. "Laudable pus" remained part of surgical

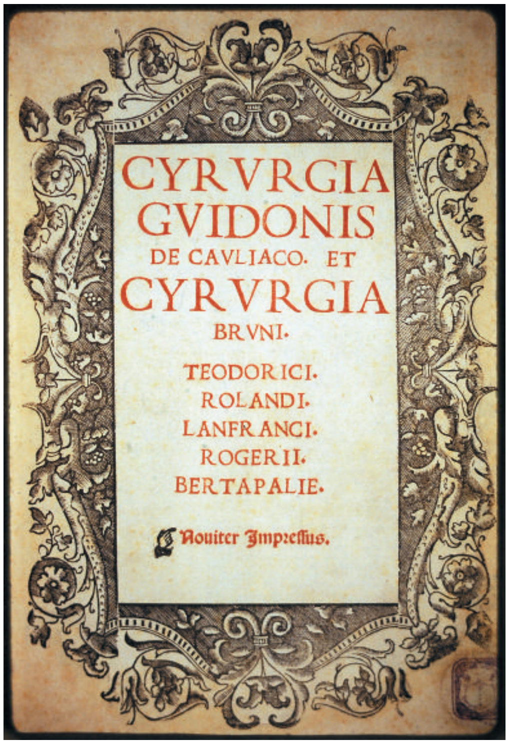


Figure 1-17. Title page from a collected works dealing with the surgical writings of a number of medieval surgeons, including Guy de Chauliac. *(From Guy de Chauliac. Chirurgia magna. In:* Cyrurgia Guidonis de Cauliaco et Cyrurgia Bruni, Teodorici, Rolandi, Lanfranci, Rogerii, Bertapali. *Venice, Bernardinus Venetus de Vitalibus, 1519. See also Leonardo RA:* History of Surgery. *New York: Froben Press; 1943:116. Courtesy James Tait Goodrich, MD, PhD.)*

practice and was not to be corrected until the works of Sir Joseph Lister nearly 500 years later.

As England was moving away from the period of barbarian invasions and into the Middle Ages, university education in England began to become comparable with the European model. The leading surgeon of this period in England was **John Arderne (Arden)** (1307-1380), who trained as a military surgeon and had much war experience. In 1370 he came to London and joined the Guild of Military Surgeons. He characterized himself as *chirurgus inter medicos* (a surgeon among physicians). His manuscript on surgery was written circa 1412. This manuscript, *De Arte Phisicali et de Cirurgia*, translated into English by D'Arcy Power in 1922, was a valuable addition to the English literature on early surgery.[55] John Arderne was evidently a very skilled surgeon with a number of practical insights into what could or could not be done surgically. He believed firmly in clean hands and well-shaped nails for surgery, although some writers have thought that this was more for social reasons than surgery.[56] In addition, he would bathe his open wounds with an irrigation that contained turpentine, a useful surgical antiseptic for keeping wounds clean. Of most importance, John Arderne was a firm believer in education and learning. In addition, he wrote that the surgeon must "always be sober during any surgery as drunkenness destroys all virtue and brings it to naught."[56-58]

The late Byzantine/Islamic and medieval periods were an era of great misguided intellectual activity and of unoriginality of thought. Clearly the educators had more faith in the teachings of antiquity. From the fall of the Roman Empire to the beginning of the 16th century, anatomy and the practice of surgery, with only rare exceptions, remained stagnant, guided by a staunch Galenic and Hippocratic orthodoxy. The translation of medical manuscripts from Latin, Greek, and Hebrew into Arabic and back into Latin resulted in many errors of translation and interpretation. The combination of a lack of anatomic knowledge and poor surgical outcomes naturally led physicians to recommend against operating on the brain, except in simple cases. A review of the work done by the surgical physicians just described reveals that despite a period of intellectual paralysis, a number of prominent physicians did make some advances. It is clear that monastic recluses in often-inaccessible mountain retreats carefully guarded medical knowledge, but despite this state of affairs, some surgeons clearly succeeded in mastering their art in the midst of intellectual darkness[58]:

> The history of medicine consists of a successive series of intellectual movements proceeding from different centers and each engulfing its predecessor.

ORIGINS OF NEUROSURGICAL PRACTICE IN THE RENAISSANCE

With the Renaissance came interesting innovations in surgical concepts and techniques. Beginning in the mid-15th century, physicians and surgeons introduced basic investigative techniques to learn human anatomy and physiology. Of enormous significance was the introduction of routine anatomic dissection in medical schools. Moving away from subservience to the medievalists, great physicians such as Leonardo da Vinci, Jacopo Berengario da Carpi, Nicholas Massa, and Andreas Vesalius explored the human body without being encumbered by the erroneous writings of earlier authors. Codified anatomic errors, many ensconced since the Greco-Roman era, were being corrected. A better understanding of human anatomy led to a change of epistemiologic presuppositions, which led to a great surge of interest in surgery. Putting the teachings of antiquity aside, surgeons began, with great vigor and enthusiasm, to investigate medical mysteries. As a result of this shift from the somber and somnolent medieval period to the enlightened, radically inventive Renaissance, the early foundations of modern neurosurgery were laid.

Any discussion of Renaissance surgery and anatomy has to begin with **Leonardo da Vinci** (1452-1519), the quintessential Renaissance man. Multitalented, recognized as an artist, an anatomist, and a scientist, da Vinci used the dissection table to better understand surface anatomy and its relationship to art and sculpture. From his studies, da Vinci is now recognized as the founder of iconographic and physiologic anatomy.[59-62] He provided the earliest, albeit crude, diagrams of the cranial nerves, the optic chiasm, and the brachial and lumbar plexi. He developed a wax casting technique that allowed him to work out and understand the anatomy of the ventricular system. To do this, he took a fresh brain and poured a liquid wax into the ventricles and placed a hollow tube to allow egress of the air. His experimental studies included sectioning a digital nerve in a living person and noting that the affected finger no longer had sensation, even when placed in a fire. Da Vinci was not a surgeon, but he gave an important impetus to the study of anatomy and the defining of correct anatomic relationships—vital concepts for any surgeon. Unfortunately, he died before he could finish his great opus on anatomy, which was to be published in approximately 120 volumes.[59] His anatomic manuscripts did circulate among the artist community in Italy throughout the 16th century, only to be lost; then they were rediscovered in the 18th century by William Hunter (1718-1783). These anatomic works had a profound influence on artists and physicians and subsequently on the development of modern anatomic studies. Da Vinci, as a founder of modern anatomy, provided a creative spark to reexplore the human body by hands-on dissection (Figs. 1-18 to 1-20).

Figure 1-18. Leonardo da Vinci's drawing of the ventricular system and also the "cell doctrine" theory, a belief that the functions of the brain arose from the ventricular system and not the brain itself. *(Courtesy Royal Collection Trust; copyright Her Majesty Queen Elizabeth II, 2015.)*

Figure 1-19. Leonardo da Vinci's three-dimensional drawing of skull anatomy. *(Courtesy of the Royal Collection Trust; copyright Her Majesty Queen Elizabeth II, 2015.)*

The earliest printed surgical work to contain illustrations was *Dis Ist das Buch der Cirurgia*, authored by **Hieronymus Brunschwig** (ca. 1450-1512) and published in Strasbourg in 1497.[63] Although the images have nothing to do with specific surgical procedures, the book is the first to discuss the management of gunshot wounds; gunpowder had only just recently been introduced in weapons of war. This work was considered to be valuable enough to be plagiarized and published in a pirated edition the same year and appeared in many other editions throughout the 16th century. In the 1513 edition, the first illustration of a patient with a head injury undergoing treatment was added to the work (Fig. 1-21).

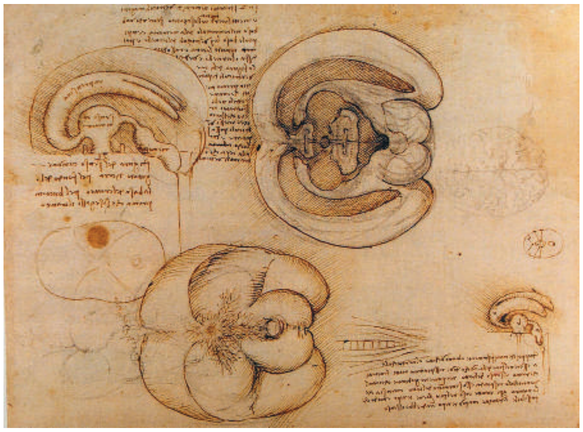


Figure 1-20. Leonardo da Vinci's wax casting modeling of the ventricular system. *(Courtesy of the Royal Collection Trust; copyright Her Majesty Queen Elizabeth II, 2015.)*

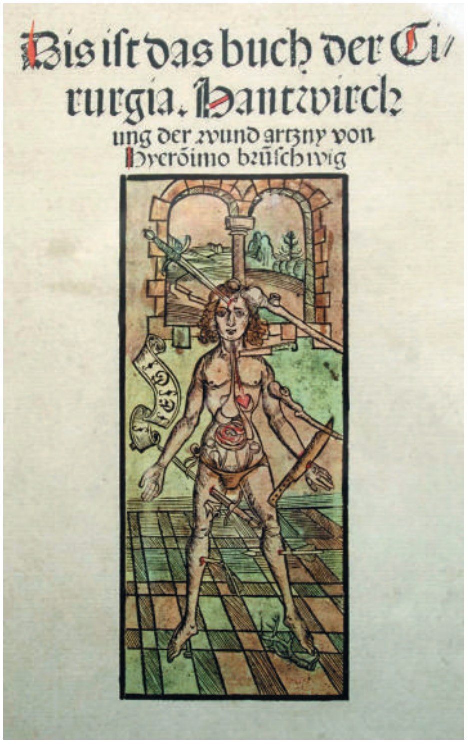


Figure 1-21. Title page from the first edition of an important work in surgery showing a "wound man" figure with the various injuries a surgeon could expect to treat. *(From Brunschwig H.* Dis Ist das Buch der Cirurgia. *Strasbourg, France: J Grüninger; 1497. Courtesy James Tait Goodrich, MD, PhD.)*

One of the early Renaissance surgeons who incorporated some of the recently revealed anatomic concepts was **Hans von Gersdorff** (1455-1529). In his surgical book *Feldtbüch der Wundartzney*, published in 1517, are some of the earliest illustrations on surgical technique.[64] Gersdorff was a military surgeon and,

Figure 1-22. Rare colored trephination plate from Hans von Gersdorff's 1517 manual on surgery. The victim has clear evidence of a third nerve palsy caused by a depressed skull fracture. *(From Gersdorff HF.* Feldtbüch der Wundartzney. *Strasbourg, France: J Schott; 1517. See also Flamm ES: The dilated pupil and head trauma.* Med Hist. *1972;16:194-199. Courtesy Reynolds-Finley Historical Library, the University of Alabama at Birmingham.)*

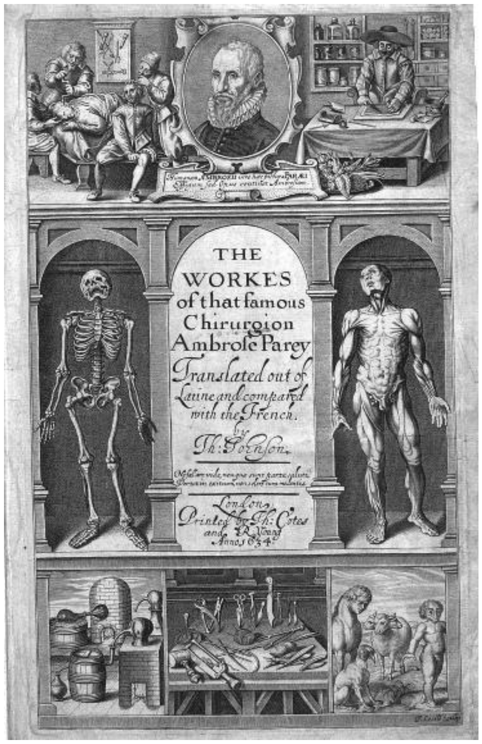


Figure 1-23. Title page of the English publication of Ambroise Paré's collected works on surgery. *(From Johnson T, Trans.* The Workes of That Famous Chirurgion Ambroise Parey. *London: Richard Coates; 1649. Courtesy James Tait Goodrich, MD, PhD.)*

with more than 40 years of war experience, became quite adept at handling battlefield injuries. This handbook for surgeons was divided into four parts: anatomy, surgery, leprosy, and a glossary of anatomic terms, diseases, and medications. The section on anatomy was based on his own extensive experience, and he used the earlier writings of the Islamic physicians and the works of Guy de Chauliac. The surgical portion deals with military surgery, mostly on how to extract foreign objects, tourniquet techniques to control bleeding, and amputation techniques. Several woodcuts dealing with surgical technique and surgical instrumentation are of interest to modern neurosurgeons; one woodcut clearly illustrated a third nerve palsy on the side of the depressed skull fracture and a facial paralysis on the opposite side. Included in this work is also the first plate showing a dissection of the human brain. This surgical work became very popular and was published in several editions; this was because of both its practical presentation of surgery and the illustrations in the text (Fig. 1-22).

One of the greatest physicians in the history of surgery remains **Ambroise Paré** (1510-1590), a poorly educated, humble Huguenot, an individual whom many historians have considered the father of modern surgery. After extensive military surgical experience, Paré was able to organize and publish a great deal of practical knowledge, along with innovative instrument designs. At this time, most physicians and surgeons published their writings in Latin; Paré preferred to publish in French instead.[65-68] Paré's books therefore were more widely disseminated and appreciated. As his reputation grew, Paré became a valued surgeon to the European royal courts. One of Paré's most famous cases was a head injury sustained by Henri II of France. Paré (and also Andreas Vesalius) attended the king and was also present at the autopsy. Henri II had suffered penetrating right orbital injury and a subdural hematoma after a joust during the celebration of the marriage of his daughter, Elizabeth of France, to Philip, King of Spain. When Paré described the clinical findings in Henri II, he noted that the patient complained of a headache and blurred vision. Henri II went on to develop vomiting, lethargy, and ominous signs of decreased respiration, and he died 11 days after the injury. Paré postulated that the injury was caused by a tear in one of the bridging cortical veins, and he was clearly describing signs of increased intracranial pressure. Paré's remarkable clinical observations and clinical history were confirmed at autopsy. Thus, despite humble beginnings, Paré became one of the most celebrated physicians in this formative period of surgery (Figs. 1-23 and 1-24).

Paré commented on the "surgeon's duties":

> Five things are proper to the duty of a Chirurgeon: To take away that which is superfluous; to restore to those places such things as are displaced; to separate those things which are joyned together; to joyn those which are separated and to supply the defects of nature. Thou shalt far more easily and happily attain to the knowledge of these things by long use and much exercise, than by much reading of Books, or daily hearing of Teachers. For speech, how perspicuous and elegant soever it be, cannot so vively express anything, as that which is subjected to the faithfull eyes and hands.

Among Paré's surgical works, his writings on the brain remain the most remarkable.[67,68] Book X is devoted to the diagnosis and management of skull fractures. Although it was not an original idea, Paré popularized the interesting technique of elevating a depressed skull fracture through the use of the Valsalva maneuver[66]:

> …for a breath driven forth of the chest and prohibited passage forth, swells and lifts the substance of the brain and meninges where upon the frothing humidity and sanies sweat forth.

Figure 1-24. Trephination plate **(A)** and neurosurgical tools **(B)** from Ambroise Paré's surgical works. *(From Johnson T, Trans.* The Workes of That Famous Chirurgion Ambroise Parey. *London: Richard Coates; 1649. Courtesy James Tait Goodrich, MD, PhD.)*

Figure 1-25. Title page from Jacopo Berengario da Carpi's treatise on head injury. *(From Berengario da Carpi J.* Tractatus de Fractura Calvae Sive Cranei. *Bologna, Italy: Hieronymus de Benedictus; 1518. Courtesy James Tait Goodrich, MD, PhD.)*

Through this method, both blood and pus can be expelled from the fracture site.

Paré's surgical techniques demonstrated some unusual and unique advances over those of previous writers. Paré provides extensive discussion on the use of trephines, shavers, and scrapers. He was skilled at removal of osteomyelitic bone, incising the dura and evacuating blood clots and pus, procedures that surgeons had previously performed only with a great deal of trepidation. He advocated débridement of wounds for good healing, emphasizing that foreign bodies must be removed from injury sites. Paré's most significant change in contemporary surgical practice was the serendipitous discovery that boiling oil should not be used in gunshot wounds, contrary to common surgical practice; instead, a dressing of egg yolk, rose oil, and turpentine provided for much improved wound healing and in turn led to a dramatic reduction in morbidity and mortality. Paré also discarded the older Islamic technique of hot cautery for control of bleeding, substituting instead the use of ligatures, which enhanced healing and reduced blood loss.[67] The improvement in his results was a source of wonder to Paré and gave rise to his famous aphorism[67]:

> Je le pansay, Dieu le guarit.
> [I took care of him, but God cured him.]

Among the Renaissance "giants" of anatomy and surgery was the great Italian surgeon and anatomist **Jacopo Berengario da Carpi** (1470-1550). In 1518, Berengario wrote the second monograph devoted solely to treating injuries of the head[69] (the first being that of Hippocrates). This book was motivated by Berengario's successful treatment of a serious head injury in Lorenzo dé Medici, Duke of Urbino. Shortly after he had treated the duke, Berengario dreamed that he was visited by a man wearing a cap adorned with a rooster feather and golden-winged sandals (i.e., Hermes Trismegistus, or the Third Mercury), who encouraged Berengario to write a treatise on skull fractures and head injuries. The result was a marvelous *tractatus*, the first printed work devoted solely to injuries of the head. In the text, original surgical techniques are discussed, along with the earliest illustrations of cranial instruments designed for surgical treatment of head injury. As an anatomist, Berengario, like Leonardo da Vinci, provided one of the earliest and most complete discussions of the ventricular system. Berengario presented some of the earliest descriptions of the pineal gland, choroid plexus, and lateral ventricles.[70] His anatomic illustrations are among the first published from actual anatomic dissections. He was a firm believer in anatomic dissection because that was the only way to learn the anatomy; he believed that the written word alone was useless, and he observed that the earlier writings were full of anatomic errors. His anatomic writings were among the first to challenge the medieval dogmatic writings of Galen and others (Figs. 1-25 to 1-27).

A less known writer and anatomist of the Renaissance was a Marburg professor by the name of **Johannes Dryander (Johann Eichmann)** (1500-1560). In 1536, Dryander published an illustrated work (expanded in 1537) on the brain and skull.[71,72] Within this most remarkable work are 16 plates of the brain, showing successive layered dissections of the scalp, dural coverings, and the brain itself. The drawings of the anatomy of the cerebellum and the posterior fossa are particularly striking. There are inaccuracies in the text because of the prevailing influence of Galen and medieval scholasticism; nonetheless, this book can be considered the first textbook of neuroanatomy. Despite Dryander's allegiance to Galen's teaching, he advocated public anatomic

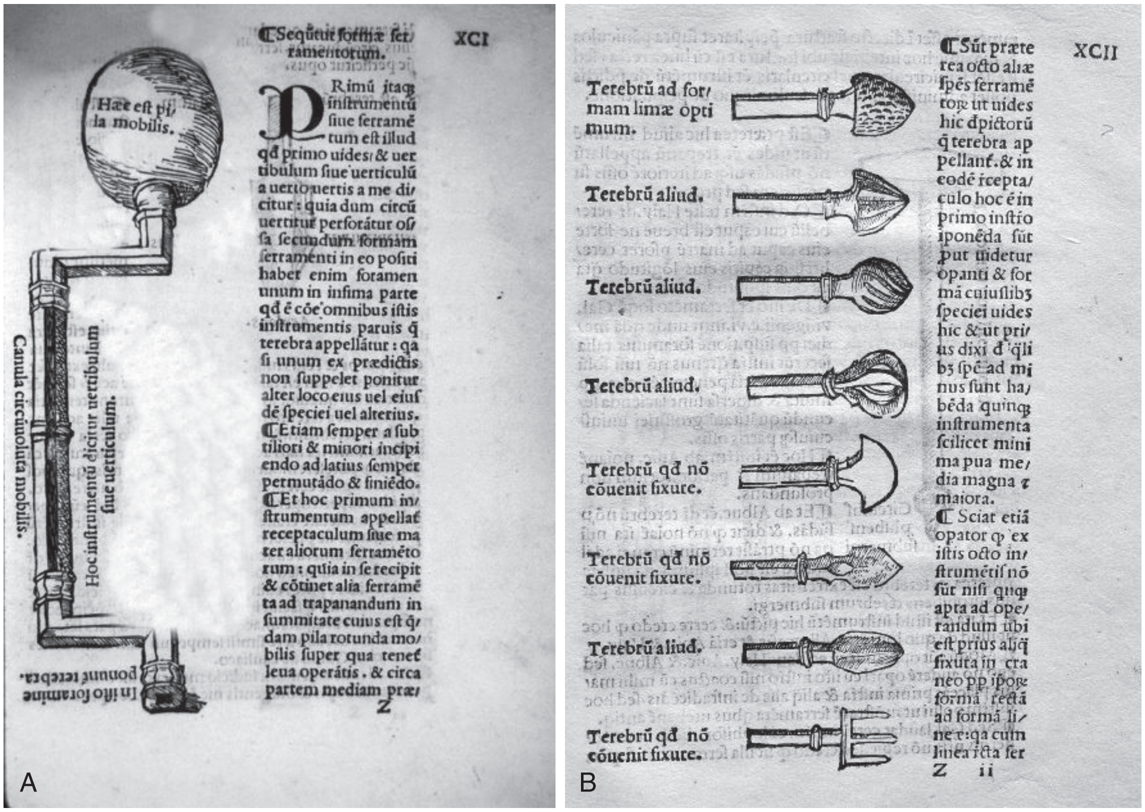


Figure 1-26. A, Neurosurgical trephine (hand brace) designed by Jacopo Berengario da Carpi, very similar to what we call a Hudson brace today. **B,** Berengario designed a series of very imaginative trephine bits for making bur holes and craniectomies. To prevent plunging, the bits are designed with a conical shape. *(From Berengario da Carpi J.* Tractatus de Fractura Calvae Sive Cranei. *Bologna, Italy: Hieronymus de Benedictus; 1518. Courtesy James Tait Goodrich, MD, PhD.)*

dissections, the results of which included these remarkable neuroanatomic drawings (Figs. 1-28 and 1-29).

Military surgery has always been a great educator of surgeons, and one of those particularly influenced by his military service was **Volcher Coiter** (1534-1576). Coiter was an army surgeon and city physician in Nuremberg who had the good fortune to study under several contemporary experts, including Gabriele Fallopius, Bartolomeo Eustachius, and Ulisse Aldrovandi. As a result of their teachings and education, Coiter was able to undertake unique and original anatomic and physiologic investigations.[73] Among his anatomic descriptions are the first anatomically correct details of the anterior and posterior spinal roots. He was the first to distinguish gray from white matter in the spinal cord. Coiter had a particularly strong interest in the spine, which led him to conduct a number of anatomic and pathologic studies of the spinal cord, including an early model of decerebrate posturing. Coiter also provided a number of details on how to trephine skulls of birds, lambs, goats, and dogs.[73] He was the first to associate the pulsation of the brain with the arterial pulse. As an early neurosurgeon and investigator, he reported on opening the brain and removing parts of it with no ill effects noted: an early, surprising precursor attempt at cerebral localization.

One of the most skilled of Renaissance surgeons was a Venetian, **Giovanni Andrea della Croce** (c. 1509-1580). Della Croce was a follower of Paré and adopted many of his techniques and beliefs. A combination of surgical skill and a Renaissance flair for design led della Croce to produce a remarkable book on surgery in 1573.[74] Within this monograph are some of the most beautifully engraved scenes of neurosurgical operations. As was typical for the period, surgical operations were performed in family homes, typically in the bedroom (with the occasional dog lying at the foot of the bed). Della Croce verbally, and in drawings, described the techniques for performing trephinations. Several illustrations show the various types of arrows, spears, and bullets used in warfare, and the techniques for their removal are detailed. An additional series of plates shows his instrument designs for performing neurosurgical procedures. One illustration is of a bloody trephination being performed with minimal anesthesia—a concept considered horrific by modern readers—in a beautifully appointed nobleman's bedroom (Figs. 1-30 and 1-31).

Della Croce illustrated a number of trephination instruments in this monograph, some of which were an improvement on their predecessors. Della Croce's trephination drill was rotated by means of an attached bow, in the manner of a carpenter's drill. Various trephine bits are proposed and illustrated, many surprisingly modern, with conical designs to avoid plunging. The illustrations of surgical instruments include Penfield-style elevators for lifting depressed skull bone.

An expert in surgery and anatomy whose work typifies the great strides of learning in the Renaissance was **Andreas Vesalius** (1514-1564). Vesalius was educated at Louvain, Montpellier, and Paris, all staunch schools of Galenic orthodox teaching. Rejecting the views of his Galen-enthralled professors, Vesalius provided an innovative and dramatic approach to anatomic dissection (Figs. 1-32 and 1-33). Following up on the theme of the earlier 16th century anatomists such as Leonardo da Vinci and Jacopo Berengario da Carpi, Vesalius argued that anatomic dissections had to be performed by the teacher, not by an ignorant prosector being guided by a professor who sat at the lectern reading from a Galenic monograph on anatomy.

Figure 1-27. Title page with an allegorical anatomic dissection scene from Jacopo Berengario da Carpi's 1522 work on anatomy. *(From Berengario da Carpi J.* Isagoge Breves: Perlucide ac Ubertine in Anatomia Humani Corporis: A Co[m]muni Medicorum Academia Usitatam…. *Bononiae, Italy: B. Hectoris; 1522. Courtesy James Tait Goodrich, MD, PhD.)*

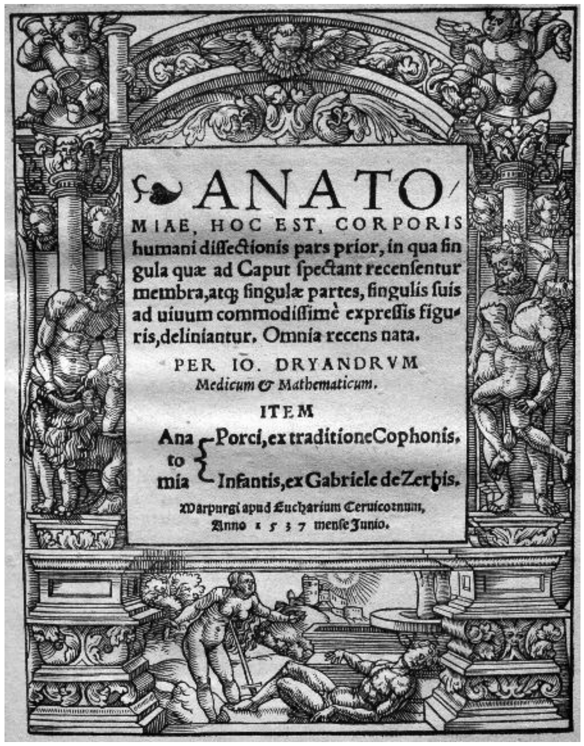


Figure 1-28. Title page from Johannes Dryander's work on the anatomy of the human brain. This work included the earliest realistic illustrations of brain anatomy. *(From Dryander J.* Anatomiae. *Marburg, Germany: Eucharius Cervicornus; 1537. Courtesy James Tait Goodrich, MD, PhD.)*

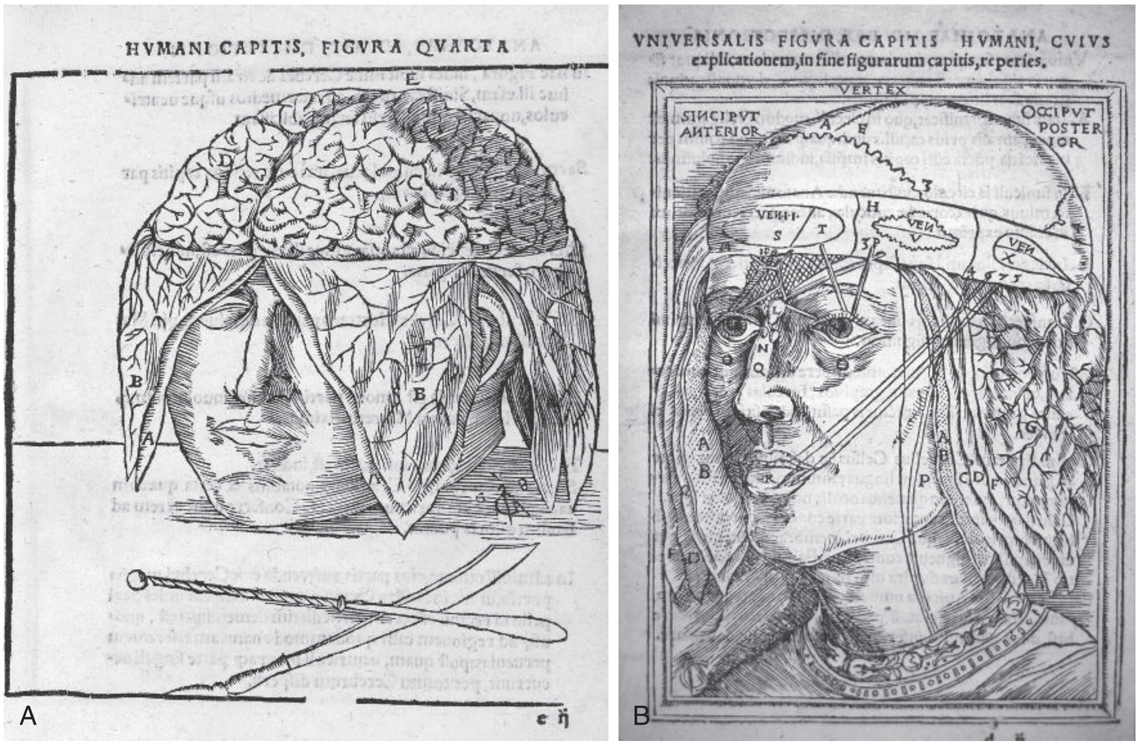


Figure 1-29. A, Johannes Dryander's illustrations of scalp and skull dissection, revealing the dura and brain in layers. **B,** "Cell doctrine" theory within the ventricular system, as illustrated by Dryander. *(From Dryander J.* Anatomiae. *Marburg, Germany: Eucharius Cervicornus; 1537. Courtesy James Tait Goodrich, MD, PhD.)*

Vesalius was appointed professor of anatomy at Padua at the young age of 23. At the age of 28, in 1543, Vesalius produced his great work, *De Humani Corporis Fabrica*.[75] Book VII is an extensive discussion on the anatomy of the brain.[76] Included in the chapter are detailed anatomic discussions with excellent illustrations. Following up on his anatomic caveats, Vesalius noted the "heads of beheaded men are the most suitable [for study] since they can be obtained immediately after execution with the friendly help of judges and prefects."[76]

Vesalius was also trained as a surgeon. The *Fabrica* contains a section of text on the brain and the dural coverings in which Vesalius discussed mechanisms of brain injury and how the various membranes and bone have been designed to protect the brain. In his second edition of *Fabrica* (1555), Vesalius provided an early and interesting case of a child with hydrocephalus and remarked on the condition as originating from cerebrospinal fluid; however, Vesalius was unable to offer any surgical treatment: "…in ipsius cerebri cavitate, adeoque in dextro sinistroque illius ventriculis: quorum cavitas amplitudoque ita increverat, ipsumque cerebrum ita extensum fuerat, ut novem fere aquae libras…continuerint" ["In the same brain cavity, the right and left ventricles' cavity space thus increased, and the brain was so spread out; nearly nine pounds of water…was contained"].[77] Of interest is that several of the initial letters in the text are illustrated with little cherubs performing trephinations!

Figure 1-30. An elegant drawing from Giovanni Andrea della Croce's work of trephination being performed in a nobleman's bedchamber. The patient is in bed, in the prone position; servants are around the room serving and dealing with the instruments. While the surgeon is performing the trephination, a cat is seen in the foreground chewing on a rat on the floor. *(From della Croce GA.* Chirurgiae Libri Septem. *Venice: Jordanus Zilettus; 1573. Courtesy James Tait Goodrich, MD, PhD.)*

A contemporary of Vesalius and another leader in Renaissance anatomic studies was a Parisian anatomist, **Charles Estienne** (1504-1564). His book on anatomy, *De Dissectione Partium Corporis Humani Libri Tres*,[78] was actually completed in 1539, thereby predating Vesalius's work by 4 years, but legal problems delayed its publication until 1546. This book is most notable for a wealth of beautiful anatomic plates dealing with neuroanatomy. It contains representations of a series of anatomic figures with the subjects posed against sumptuous and imaginative Renaissance backgrounds. In the text, the anatomic details are not as original as Vesalius's anatomic treatise. In addition, many of the errors introduced by Galen and his followers are repeated in Estienne's text descriptions. However, the plates on the nervous system are quite graphic and among the most illustrative of this period. An important work, albeit with errors, it does detail the anatomy of the skull and brain more accurately than did previous works (Figs. 1-34 and 1-35).

In view of the contributions of the aforementioned physicians and their works, advances made in the Renaissance were clearly remarkable. Back in vogue was originality in anatomic research, replacing the ex cathedra writings of Galen and the classicists. No surgeon could explore the human body without an accurate understanding of the underlying anatomy. In addition, during the Renaissance, important events included the introduction of the printed book and the production of accurate anatomic illustrations.

The Hippocratic emphasis on the skull fracture continued to dominate the management of head injuries, as it had for the preceding 2000 years. With developments in anatomic knowledge now well under way, the next era was an understanding of

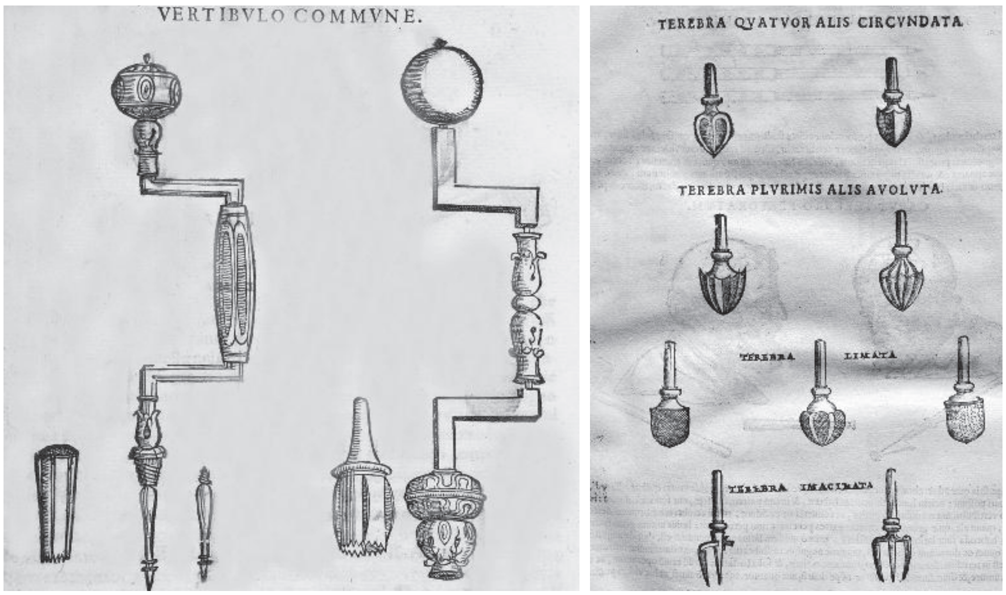


Figure 1-31. Neurosurgical instruments designed and illustrated by Giovanni Andrea della Croce. *(From della Croce GA.* Chirurgiae Libri Septem. *Venice: Jordanus Zilettus; 1573. Courtesy James Tait Goodrich, MD, PhD.)*

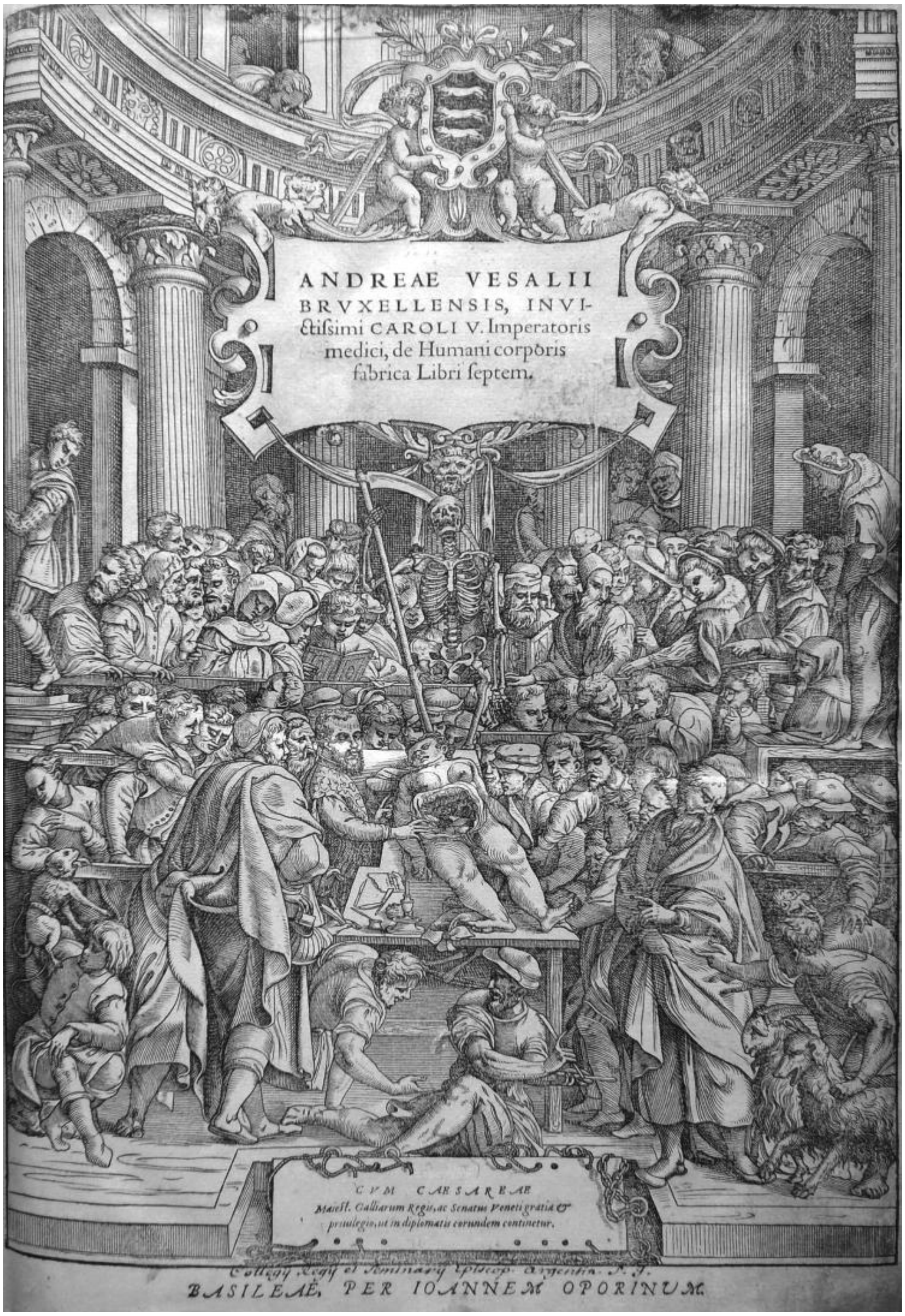


Figure 1-32. Frontispiece from Vesalius's 1555 (second edition) magnum opus on anatomy. Vesalius is depicted in the center, posed over a cadaver and performing a hands-on anatomic dissection. *(From Vesalius A.* De Humani Corporis Fabrica, Libri Septem. *Basel: Johannes Oporinus; 1555. Courtesy James Tait Goodrich, MD, PhD.)*

physiology of the human body: the major theme of the 17th century.

SURGEONS OF THE INSURGENCY: SEVENTEENTH CENTURY

Sixteenth-century medicine and the influence of the Renaissance clearly changed the direction of education and surgical practice for those interested in operating on the brain and spinal cord. The 17th century, the so-called insurgent century, carried these themes even further with significant achievements in science and medicine. Some historical "giants" produced their scientific contributions during this century: Isaac Newton (1642-1727), Francis Bacon (1561-1625), William Harvey (1578-1657), and Robert Boyle (1627-1691) contributed their ideas and innovation in the introduction of physics, experimental design, discovery of the circulation of blood, and physiologic chemistry. Another critical advance was the formation of scientific societies, with the first

Figure 1-33. Two anatomic views of skeletal anatomy in Vesalius's book. The artistic skill and details represent an enormous improvement over previous anatomic texts. *(From Vesalius A.* De Humani Corporis Fabrica, Libri Septem. *Basel: Johannes Oporinus; 1543. Courtesy James Tait Goodrich, MD, PhD.)*

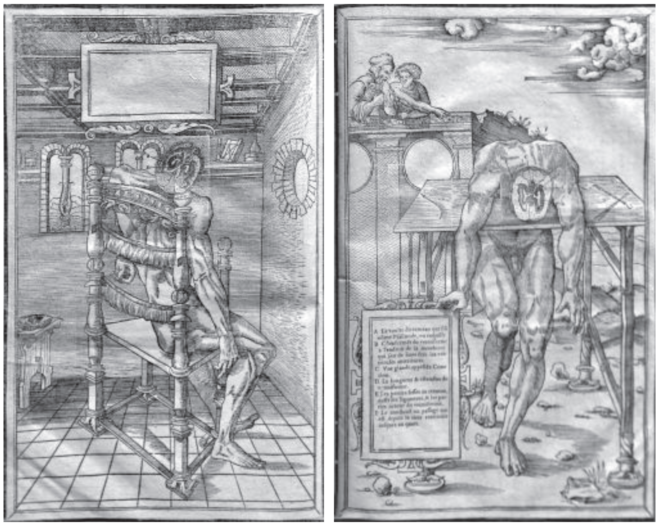


Figure 1-35. Charles Estienne's discussion of the anatomy of the brain, showing a cross section of the head and the ventricular system. *(From Estienne C.* De Dissectione Partium Corporis Humani Libri Tres. *Paris: Simon Colinaeus; 1546. Courtesy James Tait Goodrich, MD, PhD.)*

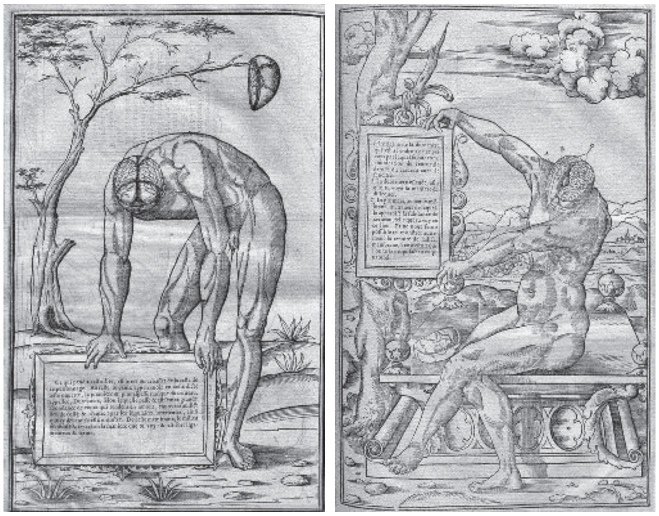


Figure 1-34. Charles Estienne's discussion of the anatomy of the brain and skull. Note the skull hanging from a tree limb on the left and at the knee on the right. *(From Estienne C.* De Dissectione Partium Corporis Humani Libri Tres. *Paris: Simon Colinaeus; 1546. Courtesy James Tait Goodrich, MD, PhD.)*

Figure 1-36. Portrait of Sir Thomas Willis at the age of 45. *(Courtesy James Tait Goodrich, MD, PhD.)*

open public presentations of scientific ideas. Among the most important societies were the Royal Society of London, the Académie Des Sciences in Paris, and the Gesellschaft Naturforschender Aerzte in Germany. Thus scientific education and exchange of information were advanced. For the first time, scientific ideas and information could be distributed publicly, and their merits discussed, in open dialogue.

A distinctive scholar of this period in the early understanding of the brain was **Thomas Willis** (1621-1675), an early describer of the eponymous circle of Willis, familiar to every physician. Willis was educated at Oxford and became a fashionable London physician (Fig. 1-36). Willis published a number of important monographs, but the one that stands out is his *Cerebri Anatomie*, published in London in 1664.[79,80] With methodic attention to detail, this book became the most accurate anatomic study of the brain to date. Willis was assisted in this work by **Richard Lower** (1631-1691) in demonstrating that when parts of the "circle" were tied off, the anastomotic network still provided blood to the brain. The superb and anatomically accurate engravings of the brain (Fig. 1-37) were produced by Sir Christopher Wren (1632-1723).

Willis introduced the concept of *neurology*, or the doctrine of neurons. Willis used the term in a purely anatomic sense, inasmuch as the concept of "neurological" disease had not yet been

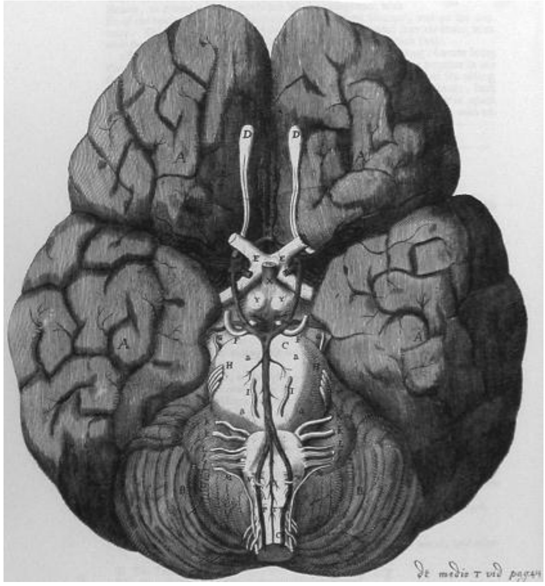
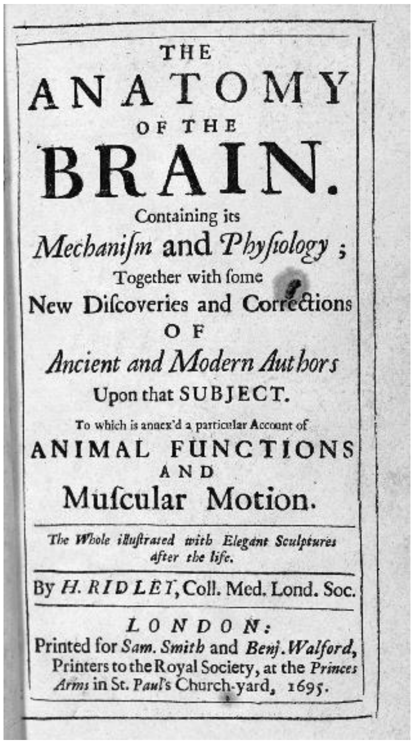


Figure 1-37. The circle of Willis as described by Thomas Willis and drawn by Sir Christopher Wren. *(From Willis T.* Cerebri Anatome: Cui Accessit Nervorum Descriptio et Usus. *London: J Flesher; 1664. Courtesy James Tait Goodrich, MD, PhD.)*



THE
ANATOMY
OF THE
BRAIN.
Containing its
Mechaniſm and *Phyſiology* ;
Together with ſome
New Diſcoveries and Corrections
OF
Ancient and Modern Authors
Upon that SUBJECT.
To which is annex'd a particular Account of
ANIMAL FUNCTIONS
AND
Muſcular Motion.

The Whole illuſtrated with Elegant Sculptures after the life.

By *H. RIDLEY*, Coll. Med. Lond. Soc.

LONDON:
Printed for *Sam. Smith* and *Benj. Walford*, Printers to the Royal Society, at the *Princes Arms* in St. *Paul's* Church-yard, 1695.

Figure 1-38. The title page from Humphrey Ridley's work on brain anatomy. *(From Ridley H.* The Anatomy of the Brain, Containing Its Mechanisms and Physiology: Together With Some New Discoveries and Corrections of Ancient and Modern Authors Upon That Subject. *London: Samuel Smith; 1695. Courtesy James Tait Goodrich, MD, PhD.)*

introduced. *Neurology* as a noun did not enter general use until Samuel Johnson (1709-1784) defined it in his dictionary of 1765.[81] At this point, neurology came to be understood as the entire field encompassing anatomy, function, and physiology. It is also worth noting that the circle of Willis was not described uniquely by Willis; other anatomic descriptions of this circle were provided in several contemporary anatomic publications (the reader is referred to the writings of Vesling,[82] Casserius,[83] Fallopius,[84] and Ridley[85]).

A prominent anatomist at this time and one often overlooked by contemporary writers was **Humphry Ridley** (1653-1708). Ridley was educated at Merton College, Oxford, and at the University of Leyden, where he received his doctorate in medicine in 1679. Ridley produced an important anatomic work on the brain, *The Anatomy of the Brain*, written in English, which became widely circulated and influential (Figs. 1-38 and 1-39).

The Anatomy of the Brain was published in London in 1695.[85] At the time his work on the brain appeared, many of the classic Greek views of the brain were in vogue. Seventeenth-century anatomy and medicine moved away from the earlier "cell doctrine" theory (in which brain function was considered to reside within the ventricles); anatomists had begun to recognize the brain as a distinct anatomic entity. In contrast to the "cell doctrine," cerebral function came to be viewed as a property of the brain.[86,87]

Ridley recorded a number of original observations. Ridley's description of the circle of Willis was even more accurate in details than Willis's and included a more complete anatomic description of both the posterior cerebral artery and the superior cerebellar artery, defined as separate entities. Ridley provided a better demonstration of the principle of anastomotic flow and better elucidated the anastomotic principle of this network with his anatomic studies. To conduct his studies, Ridley had access to recently executed criminals. The method of execution was typically hanging, which caused vascular engorgement of the brain and thus facilitated identification of the vascular anatomy. Ridley's understanding of the deep nuclei of the cerebellum, particularly the anatomy of the posterior fossa, was superior to Willis's. Ridley also provided one of the earliest descriptions of the arachnoid membrane. Of note, Ridley still believed in the *rete mirabile*, a tenacious holdover from Galenic times. To Ridley this was a legitimate anatomic structure, and he provided a strong argument for its existence in this monograph. In addition, Ridley provided the first accurate description of the fornix and its pathways in this monograph. This volume and the work by Willis presented the first scientific anatomic studies of the brain and thereby provided an essential anatomic foundation for future neurosurgeons.

A surgical expert often overlooked in neurosurgical history is **Wilhelm Fabricius von Hilden** (1560-1634). Although Fabricius (also known as Fabry) had received a classical education in his youth, family misfortune did not allow him to go on to a formal medical education. He went on to study in the "lesser field" of surgery, being educated in the apprentice system then prevalent. Fortunately, the teachers who trained him were among the finest wound surgeons of the day. Lacking a formal university education and excelling with a surgical apprentice education, he went on to develop a distinguished career in surgery.

Fabricius produced one of the most important surgical works of the 17th century: *Observationum et Curationum*, a monograph that included more than 600 surgical cases, along with a number of important and original observations on the brain.[88] Fabricius's observations on the brain and surgery included descriptions of a number of congenital malformations, skull fractures, and techniques for bullet extraction, along with original designs for field surgical instruments. He described operations for intracranial hemorrhage (with cure of insanity), vertebral displacement, congenital hydrocephalus, and an occipital tumor in the newborn (probably an encephalocele). Fabricius carried out trephinations for treatment of a brain abscess and cure of a longstanding

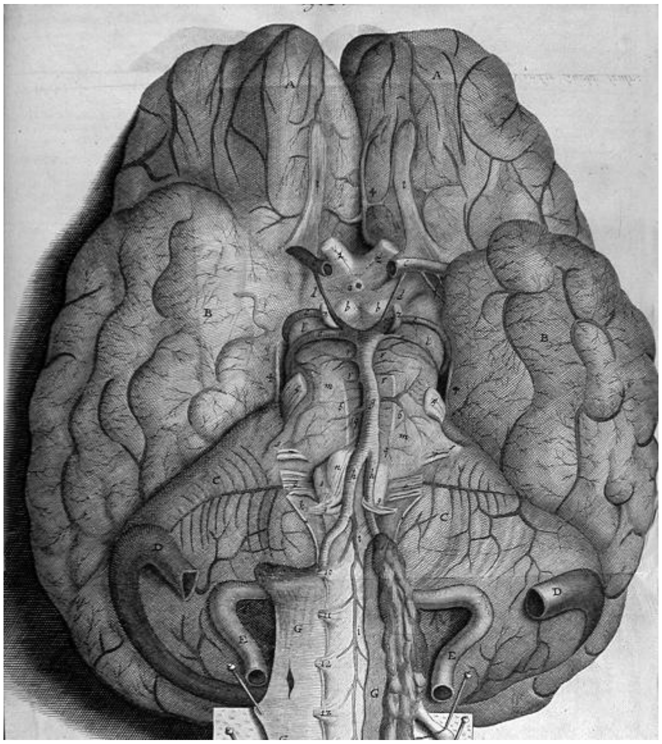


Figure 1-39. Humphrey Ridley's illustration of the anastomotic network at the base of the brain: the circle of Willis. Ridley's anatomic details are better than Willis's and include a more complete anatomic description of both the posterior cerebral artery and the superior cerebellar artery, here described as separate entities. *(From Ridley H.* The Anatomy of the Brain, Containing Its Mechanisms and Physiology: Together With Some New Discoveries and Corrections of Ancient and Modern Authors Upon That Subject. *London: Samuel Smith; 1695. Courtesy James Tait Goodrich, MD, PhD.)*

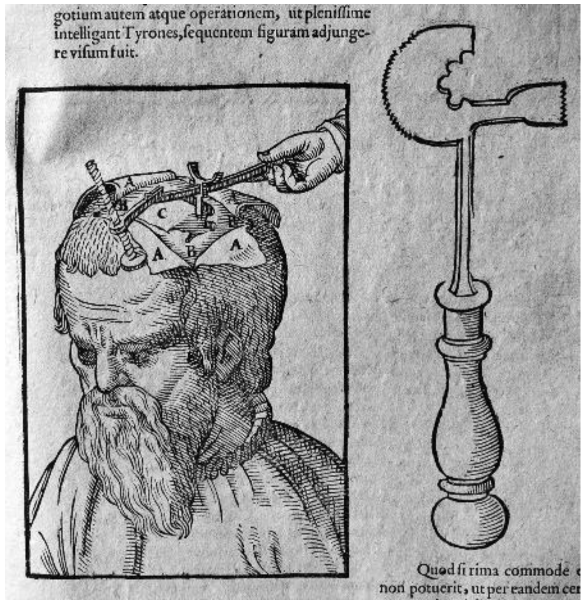


Figure 1-40. A "lever and screw" device, used to elevate a depressed skull fracture. To the right is a saw used to make a series of rectangular cuts for performing a craniectomy. This style of instrument became known later as a Hey saw. *(From Fabricius W.* Observationum et Curationum Chirurgicarum Centuriae. *Lugduni [Lyons]: I. A. Huguetan; 1606-1641. A number of neurosurgical cases are also contained in a later publication of collected works: Fabricius W.* Opera Observationum et Curationum. *Frankfurt: Joannis Beyer; 1646. Courtesy James Tait Goodrich, MD, PhD.)*

aphasia. He even removed a splinter of metal from an eye by using a magnet, a cure that only enhanced his reputation (Figs. 1-40 and 1-41).

Some early and skillfully designed neurosurgical instruments are illustrated in a work by **Johann Scultetus (Schultes)** (1595-1645) of Ulm, titled *Armamentarium Chirurgicum XLIII.*[89] Scultetus provided unique and graphic details of neurosurgical instruments, clearly the finest to appear since those published by Berengario in 1518 and della Croce in 1573. The illustrations graphically reveal surgical techniques for treating fractures and dislocations, along with a variety of bandaging techniques for dealing with wounds. This surgical work was so popular that it was translated into many languages, including English, and it exerted a considerable influence on surgery throughout Europe for more than two centuries. The surgical plates and descriptions of various operations contain exacting details, including concepts from antiquity to the present. Of interest is that many of the instruments illustrated by Scultetus remain in use today. Scultetus's details of surgical operations for injury of the skull and brain are remarkable plebiscite (Figs. 1-42 and 1-43).

Neurosurgical practice continued to evolve in the 17th century. A surgeon who offered some interesting technical advice on developing neurosurgical operating skills was **John Woodall** (c. 1556-1643). Woodall was a military surgeon by training and surgeon-general to the East India Company. For surgeons of the East India Company, he compiled a surgical monograph titled *The Surgeon's Mate* (1617).[90] In his collected works, published in 1639, Woodall provided a list of surgical instruments and sound

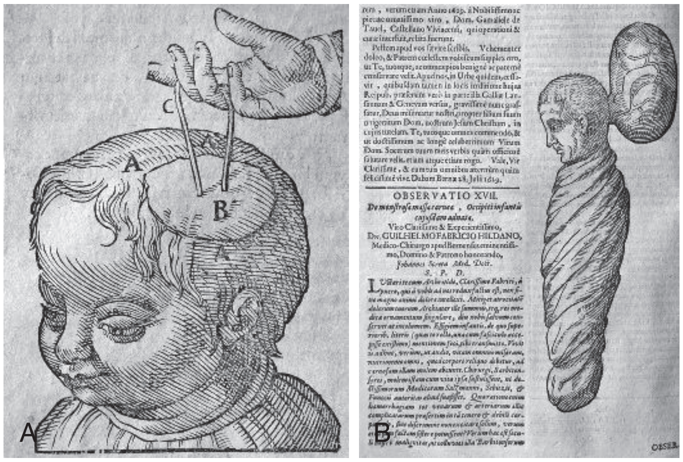


Figure 1-41. A, Wilhelm Fabricius von Hilden's technique for elevating a depressed skull (ping pong) fracture in a child. Two small holes were made, and a leather strap was passed through and pulled up to elevate the depressed fracture. **B,** A very early illustrated example of an occipital encephalocele. Fabricius discussed a case of a child with a large "swelling" in the occipital region that was full of clear fluid. *(From Fabricius W.* Observationum et Curationum Chirurgicarum Centuriae. *Lugduni [Lyons]: I. A. Huguetan; 1606-1641. A number of neurosurgical cases are also contained in a later publication of collected works: Fabricius W.* Opera Observationum et Curationum. *Frankfurt: Joannis Beyer; 1646. Courtesy James Tait Goodrich, MD, PhD.)*

Figure 1-42. Surgical techniques and instruments designed by Johann Scultetus for trephining the skull and dealing with skull fractures. *(From Scultetus J:* Χειροπλοθηκη [Cheiroplothiki]. Armamentarium Chirurgicum XLIII. *Ulm, Germany: Balthasar Kühnen; 1655. Courtesy James Tait Goodrich, MD, PhD.)*

Figure 1-44. Title page from John Woodall's book on military and domestic surgery. *(From Woodall J:* The Surgeon's Mate, or Military and Domestique Surgery Discouering Faithfully & Plainly ye Method and Order of the Surgeon's Chest…. *London: Rob. Young for Nicholas Bourne; 1639. Courtesy James Tait Goodrich, MD, PhD.)*

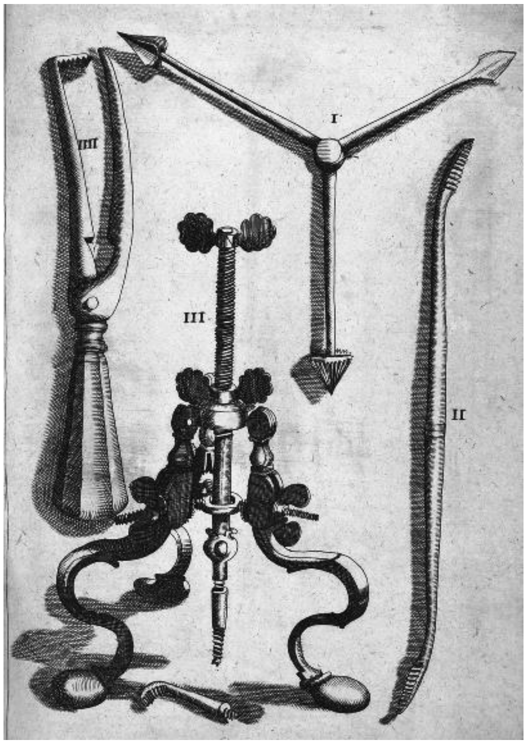


Figure 1-43. Scultetus's tripod-style trephine, with a center pin for elevation. Illustrated also are an elevator (right), a corkscrew type elevator (top), and bone rongeur (left). *(From Scultetus J:* Χειροπλοθηκη [Cheiroplothiki]. Armamentarium Chirurgicum XLIII. *Ulm, Germany: Balthasar Kühnen; 1655. Courtesy James Tait Goodrich, MD, PhD.)*

advice for a surgical practice.[91] Woodall fabricated a trephine with a then-unique design of a crown that included a center pin; this innovation prevented the crown from slipping on a bloody skull. A brace was added to this trephine, which could be placed against the surgeon's chest for additional support and driving force. This innovative design allowed the surgeon to drive the trephine with one hand while the other held the head, all of which could be accomplished on a rolling ship's deck. Woodall, recognizing the ignorance of his contemporary German surgeons, believed that a surgeon should practice trephining on sheep or calf skulls first before performing one on a human head (Figs. 1-44 and 1-45):

> "The Germane Surgeons use no Trapan, that ever I could see my eight years living among them, though they both speak and write of it. But for as much as it is apparent, the work of a Trapan is very good, I therefore would advise a young Artist to make some experience first upon a calves head, or a sheep's head, till he can well and easily take out a piece of the bone; so shall he the more safely do it to a man without error when occasion is."
>
> **(J. Woodall, *The Surgeon's Mate*,[91] p 4)**

An Englishman and Plymouth naval surgeon, **James Yonge** (1646-1721), was among the first to argue emphatically that "wounds of the brain are curable"; Galen had earlier announced, "I have seen the wounded brain heal."[28] Yonge's first surgical text was a small monograph titled *Wounds of the Brain Proved Curable*.[92] Yonge provided a surgical account of a brain operation on a child of 4 with extensive compound fractures of the skull from which brain tissue issued forth. The surgery was successful, with the child surviving, and this inspired Yonge to publish the account. Yonge also reported on more than 60 cases in which brain wounds were cured that he was able to locate in the older literature,